DEVELOPMENT OF AN EXPERT SYSTEM FOR IDENTIFYING EFFECTIVE COUNTERMEASURES AT RURAL UNSIGNALIZED INTERSECTIONS

by

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ABSTRACT

Intersections are among the most dangerous points in a transportation network. Both shortcomings in design and human error contribute to the frequency of crashes at intersections. In this thesis, a knowledge based expert system is created to assist engineers and transportation officials in the process of improving the safety at rural, unsignalized intersections. Currently, the process of identifying countermeasures for rural, unsignalized intersections with a chronic safety problem involves a great deal of experience and subjective assessments. The knowledge based expert system developed attempts to provide a more logical progression of the intersection safety process and incorporate quantitative assessments of potential options. The American Association of State Highway and Transportation Officials' (AASHTO) 2010 publication, the Highway Safety Manual seeks to provide the first quantitative assessment of intersection safety countermeasures. These values are incorporated into the knowledge based expert system (KBES).

The KBES for countermeasure identification is the result of a comprehensive literature search to identify and determine the effectiveness of countermeasures of rural, unsignalized intersections. The countermeasures considered in this project include intersection lane narrowing, advanced warning rumble strips, flashing beacons, advanced warning pavement markings, signage improvements, conversion to roundabout, signalization, conversion to all-way STOP control, left and right turn

lanes, shoulder bypass lanes, sight distance improvements, intersection realignment, intersection illumination, and performing a skid test for pavement quality.

The KBES was created using the software CORVID produced by Exsys® Incorporated. The system is constructed of variables joined together using IF…THEN statements in the logic block and is designed to represent the thinking process of a human expert. The KBES was tested using data from three high crash rural, unsignalized intersections in Delaware which were examined during a previous 2012 Delaware Department of Transportation (DelDOT) study. The results produced by the expert system were comparable to the results achieved by the DelDOT study. Testing the system in this manner begins the process defined by the Federal Highway Association (FHWA) for verification and validation of expert systems.

Chapter 1

INTRODUCTION

It is by design that traffic in conflicting directions meet at intersections. If properly designed, intersections allow traffic to meet and diverge in separate directions with minimal disruption to the traffic flow. However, given the nature of intersections as a center point of conflicting streams of traffic, the interaction between the traffic may not always go as intended and result in crashes. Therefore, it follows that intersections are among the most dangerous locations on the road network for drivers. According to the Federal Highway Administration, 21.5% of fatal crashes, 44.8% of injury crashes, and 37.8% of property damage only crashes in 2007 were related to intersections. Overall in 2007, 39.7% of crashes were intersection related [1]. This trend observed in 2007 as one example is not at all unusual and is indicative of the much greater problem of intersection safety. Although by land area and roadway miles, intersections represent a very small proportion of the overall vehicle transportation network, intersections contribute a large proportion of crashes.

There are many different types of intersections that drivers encounter on a daily basis. One major distinction between types of intersections is those that are controlled by a traffic signal and those that are unisgnalized, or not controlled by a traffic signal. Signalized intersections are typically intersections on major roads with a higher volume of traffic. The crash patterns at signalized intersections are noticeably different from crash patterns at unsignalized intersections. Also, the type of area in which the intersection is located has a great impact on the behavior of vehicles and crash tendencies at the intersection. The two ends of the spectrum for the type of area in which an intersection can exist are rural and urban. Urban intersections are located in a densely populated metropolitan area while rural intersections are found outside a population center. Urban intersections typically have a greater volume and lower approach speeds than rural intersection. The focus of this thesis will be on unsignalized intersections located in rural areas.

There are multiple types of intersections within the category of unsignalized intersections. There must be some type of traffic control at any intersection in order to organize the traffic flow. STOP controlled intersections are the most common type of rural, unsignalized intersections. Intersections can be STOP controlled on the minor road approaches with the major road approaches free to pass through the intersection without stopping. These intersections are referred to as two-way STOP controlled intersections. Another common type of rural, unsignalized intersections control design is an intersection where all traffic approaches must stop before proceeding through the intersection. These types of intersections are referred to as all-way STOP controlled intersections. Two less common types of rural, unsignalized intersections are YIELD controlled intersections and roundabouts. In YIELD controlled intersections, drivers at an approach that is instructed to yield at the intersection must slow down prior to entering the intersection to be sure that no conflicting traffic is present, but are not required to come to a complete stop as is the case at STOP controlled intersections if no conflicting traffic is present. Roundabouts are another type of yield controlled intersection where traffic must circulate in a counterclockwise fashion around a median at the intersection of two conflicting traffic flows. The original condition for the intersections considered in this thesis will be two-way or multi-way STOP controlled intersections because they are the most common types of rural, unsignalized intersections.

While intersections are inherently less safe than other areas on the transportation network, it is not intended for crashes to occur frequently at these sites. Transportation engineers put great care into designing intersections to make them as safe as possible for drivers through designing the geometric conditions of roads to ensure safe turning movements, properly engineering the roadway grade to prevent pooling of water or ice, incorporating measures such as advanced signing to warn drivers of the upcoming intersection, and remove obstructions to vision for drivers at the intersection to the greatest extent possible. There has been a recent shift in the focus of transportation safety from strictly looking at the total number of crashes to also considering the severity of crashes. Transportation engineers now seek to reduce both the overall number of crashes as well as decrease the severity of the crashes that still occur. However, despite the utmost attention to detail when designing intersections, transportation engineers are often faced with the problem of what to do with an intersection that has a chronic problem with crashes. The solutions to these types of problems are often very case sensitive and require investigating a number of potential factors that contribute to the safety problems at a given intersection.

1.1 Problem Statement

In 2010, the American Association of State Highway and Transportation Officials (AASHTO) published the Highway Safety Manual which is the primary national resources for quantitative transportation safety analysis and design. The Highway Safety Manual outlines a process for addressing safety concerns on a roadway or intersection through identifying what types of crashes are occurring, why such crashes are occurring, and selecting countermeasures to correct the problem. The Highway Safety Manual also provides Crash Modification Factors (CMFs) that can be used to predict the reduction in crashes at an intersection when applying a specific countermeasure. However, the process of matching intersection safety problems to countermeasures is a process that is still not fully straightforward as the Highway Safety Manual procedure represents and cannot be approached with the expectation of a generic set of steps that applies to all cases. Since every intersection is different, the effectiveness of a given countermeasure may vary from one intersection to another. Despite the fact that, many research studies have been completed in an effort to better understand safety countermeasures and driver behavior at unsignalized intersections, continuing research is necessary to fully understand these phenomenon. As a result, there is still a need to remove some of the subjectivity and ambiguity in intersection safety studies as well as to streamline the process for selecting countermeasures for rural, unsignalized intersections. The problem addressed in this thesis is that determining effective countermeasures for a rural, unsignalized intersection with a safety problem is an ambiguous and subjective process.

1.2 Purpose and Objectives

The purpose of this thesis is to create an automated system that guides the user through the process of selecting safety countermeasures for rural, unsignalized intersections which have demonstrated a high crash rate. This system will represent the culmination of extensive research in safety countermeasures and the effects of those countermeasures at rural, unsignalized intersections. The system is also a result of a 2012 Delaware Department of Transportation (DelDOT) study of safety at rural, unsignalized intersections.

The system developed in this thesis is intended to be used for planning and initial design ideas for traffic engineering and city or regional planners who are plagued by an intersection in a rural area with recurring safety problems. It is intended that this tool be used to educate beginning engineers or people who are inexperienced in intersection safety to what types of countermeasures would be most appropriate for a particular location. This tool can also be used by more experienced engineers to expedite the process with which they are already familiar to determine a comprehensive list of potential countermeasures as well as their expected effectiveness.

This thesis will accomplish the following objectives:

- Identify the procedure for selecting appropriate countermeasures for rural unsignalized intersections that have a safety concern through reviewing crash records.
- Identify and research through literature review and consultation with safety experts all potential countermeasures for rural unsignalized intersections to be used in this thesis.
- Create a sequence of questioning that will be used to determine what safety problems exist at an intersection and which countermeasure best suit the location.
- Using the Exsys® CORVID software, develop a program that will identify the best countermeasure(s) for a location given the user inputted data from the sequence of questioning previously developed.

- Use two or three of the previously studied intersections as examples of the utility of the program created.

1.3 Scope of the Thesis

Research for this thesis includes reviewing AASHTO's Highway Safety Manual with particular attention to sections regarding the study of intersection safety, selecting countermeasures for unsignalized intersections, and the expected results of implementing the selected countermeasures. Numerous other nationally accepted transportation engineering manuals such as the Manual of Uniform Traffic Control Devices (MUTCD), AASHTO's *A Policy on Geometric Design of Highways and Streets*, the Federal Highway Administration's (FHWA) *Roundabouts: An Informational Guide* as well as other research completed by the FHWA were reviewed as part of this project. Reputable studies from Iowa State University, Minnesota Department of Transportation, Kansas Department of Transportation, and Washington State Department of Transportation have also been included in the sources of this work. The final component of the research for this project includes interviews with professional engineers who have practical experience with safety countermeasures. The professional engineers interviewed for this project are practicing professional engineers from Rummel, Klepper, and Kahl in Baltimore, Maryland and DelDOT.

This thesis seeks to address the safety concerns of as many types of rural unsignalized intersections as possible while acknowledging the most common types of rural, unsignalized intersections and recognizing the limitations of the data and studies currently available. The types of intersections that are the focus of this thesis are STOP controlled intersections with either three or four legs. Two-way STOP controlled intersections are the most common type of rural, unsignalized intersections and the most data currently exists for these types of intersections. All-way STOP controlled intersections are also within the scope of this thesis as they are also a common type of rural, unsignalized intersection, but as these intersections are less common than two-way STOP controlled intersections, less research and certainty regarding the selection and implementation of countermeasures at all-way STOP controlled intersections is available. It is assumed that the base condition for intersections involved in this study have one travel lane in each direction approaching the intersection.

1.4 Organization of the Thesis

The organization of this thesis is described below:

Chapter 2 details background information regarding transportation and intersection safety. The importance and use of the Highway Safety Manual is explained and the CMF values are introduced. The process of performing an intersection safety study and an introduction to knowledge-based expert systems is also included in chapter 2.

Chapter 3 presents an in depth explanation of the intersection safety countermeasures considered in this thesis that will later be used in the programming of the knowledge-based expert system.

Chapter 4 describes the process of creating the variables of the knowledge-based expert system (KBES) using the Exsys® Incorporated program CORVID.

Chapter 5 explains the process of the organization of the variables in the KBES into the logic block that forms the pattern of questioning to be displayed to the user. The design of the command block and user interface is also described in this chapter.

Chapter 6 compares the outputs of the KBES system to the outputs of the 2012 DelDOT study of safety at rural unsignalized intersections. The data from three intersections in Delaware, Delaware 10 & Delaware 15, Delaware 15 & Andrews Lake Road, and Delaware 30 & Zoar Road are used for the comparison.

Chapter 7 provides a summary of the thesis and identifies areas for future research based on the work of this thesis.

1.5 Summary of Chapter 1

Intersections are characteristically some of the most dangerous location on the road network for drivers. However, transportation engineers are working to decrease overall crashes and the severity of crashes through implementing measures to warn drivers of upcoming intersections and designing intersections to enable drivers to navigate the roadway safely. The focus of this thesis will be on improving safety at rural, unsignalized intersections. These intersections are located away from urban areas and are either two-way STOP controlled or all-way STOP controlled. This thesis seeks to remove some of the ambiguity and subjectivity in the process selecting effective countermeasures for a rural, unsignalized intersection through creating a KBES that mimics the process of a human expert in identifying such countermeasures.

Chapter 2

BACKGROUND AND LITERATURE REVIEW

The purpose of this thesis is to create a KBES that takes users through the process of evaluating an intersection and selecting countermeasures that would be effective based on the site specific conditions at the intersection. The Highway Safety Manual is a valuable resource in completing such a safety study because it outlines a process that can be followed to collect the necessary data and direct the user as to how that data should be analyzed. Also, the Highway Safety Manual helps engineers make a quantitative estimate of how a countermeasure would affect the crash rate at an intersection through applying CMFs. The information in the Highway Safety Manual and other intersection safety related literature studies was brought together to be incorporated into the KBES developed in this thesis. Understanding of what a KBES is and how it can be beneficial to transportation engineering is vital to proceeding to the development phase of the KBES.

2.1 The Highway Safety Manual

The Highway Safety Manual is currently the only national, comprehensive guide for safety design and safety improvement available to transportation engineers. The first edition of the Highway Safety Manual was published by AASHTO in 2010 and was designed to provide quantitative information for safety decision making. Prior to the publication of the Highway Safety Manual, no such national resource was available. In January 1999, at the annual meeting of the Transportation Research

Board (TRB), a special conference session was held to discuss the topic of predicting the impact of highway safety design and operation. This conference session spawned a lot of interest in creating a resource that would provide quantitative estimates for safety performance and a meeting sponsored by eight TRB committees and funded by FHWA was held in December 1999. In May 2000, a TRB Joint Subcommittee was formed known as the Task Force for the Development of a Highway Safety Manual (ANB25T) to create what became the Highway Safety Manual. The research and development was primarily funded by the National Cooperative Highway Research Program (NCHRP) along with support from the FHWA. It was decided in 2006 to publish the Highway Safety Manual as an AASHTO document. As a result, a Joint Task Force (JTF) was formed with representatives from the AASHTO Subcommittees on Design, Traffic Engineering, and Safety Management to ensure that the Highway Safety Manual met the needs of the state Department of Transportation and to promote the new manual. In 2009, the subcommittees, the parent committees, the Standing Committee on Highways, the Standing Committee on Highway Traffic Safety, and the AASHTO Board of Directors approved the Highway Safety Manual. When the Highway Safety Manual was published in 2010, it represented ten years of safety research in developing a product that was unlike any other resource available to transportation engineers [2].

While the Highway Safety Manual is groundbreaking in many ways, it is also still in its infancy, and this must be taken into consideration when the information is applied. Professional engineers and state departments of transportation are still in the process of fully adopting the Highway Safety Manual for their work. Other AASHTO publications such as the MUTCD and *A Policy on Geometric Design of Highways and*

Streets, commonly known as the "Green Book," are widely accepted as fact with the standards listed in these publications taken as absolutes. In cases where the Highway Safety Manual differs from these previously established resources, the Highway Safety Manual authors state that the MUTCD or Green Book should take precedence [2]. The Highway Safety Manual is intended to become the set standard for safety analysis in the future, but the current limitations of the publication including limited breadth and depth show the need for further advancements in research until it can become a more comprehensive resource.

There is currently no national regulation requiring the use of the Highway Safety Manual; however, transportation engineers see the benefit of using the Highway Safety Manual in their work to quantify safety improvements, estimate cost to benefit ratios, and communicate with clients the expected benefits of proposed safety improvements. The Highway Safety Manual is intended to be used by practitioners at the state, county, metropolitan planning organization (MPO), or local level to reduce the number and severity of crashes. Users of the Highway Safety Manual should have a base knowledge of transportation safety as well as transportation engineering experience in order to exercise the engineering judgment necessary to apply the information appropriately [2].

The Highway Safety Manual is divided into four parts:

- Part A – Introduction, Human Factors, and Fundamentals
- Part B – Roadway Safety Management Process
- Part C – Predictive Method
- Part D – Crash Modification Factors

Part A of the Highway Safety Manual provides the background information for the rest of the material presented in the manual. This includes an overview of human factor principles for road safety and an introduction to the predictive method, crash modification factor, and evaluation methods. Part B highlights the process involved in selecting locations that would be good locations for safety improvements. From there, Part B continues to outline the entire process for completing a safety analysis including the steps of diagnosis, countermeasure selection, economic appraisal, project prioritization, and effectiveness evaluation. In Part C, the predictive method is introduced for estimating expected average crash frequency of a network, facility, individual site use existing conditions, alternative conditions, or proposed new conditions. These predictions are made using equations that incorporate volume data and site characteristics known as safety performance functions (SPFs). Part D identifies the CMFs which can be used to quantify the safety analysis process described in Part B.

2.2 Crash Modification Factors

CMFs are multiplicative values that are used to predict the expected number of crashes after a countermeasure is implemented. The Highway Safety Manual presents CMFs to be used to quantitatively determine how effective a given safety factor is. CMFs that are effective at reducing crashes will have a value between zero and one. In order to calculate the expected crash reduction after the implementation of a countermeasure, the CMF is multiplied by the number of crashes at occurred at the intersection. For example, if a rural, two-way STOP controlled intersection that experienced twenty crashes over the past three years is converted to a one lane roundabout, it could be estimated that the number of crashes that the intersection would average over a three year period following the roundabout conversion would be twenty multiplied by the CMF for roundabout conversion, 0.29, or approximately six crashes [2].

For some countermeasures, the Highway Safety Manual provides more specific CMFs for different types of crashes or different severities of crashes. In the case of roundabouts, the Highway Safety Manual also provides a CMF value for specifically injury crashes. More specific CMF values are not available for all countermeasures given by the Highway Safety Manual, but when they are available, they can be used to further specify crash tendencies at an intersection. CMFs for injury crashes are applied to injury crashes the same way as CMFs for all crashes. If in the example previously discussed, half of the crashes that occurred prior to the roundabout conversion were injury crashes, it can be expected using the CMF for injury crashes that following the roundabout conversion, that the total number of injury crashes during a three year period at the intersection would be equal to ten multiplied by the injury CMF of 0.13, or about one crash [2].

The CMF values for each countermeasure are considered reliable given that the countermeasure is used properly. For example, the CMF for conversion of a two-way STOP controlled intersection to an all-way STOP controlled intersection is only valid if the requirements in the MUTCD for conversion to multi-way STOP control are met. While this countermeasure has specific guidelines for its use, most other countermeasures do not. However, in line with the purpose of this thesis, it is important to be sure that an appropriate countermeasure is selected for a given location so that it will be most effective. Even if the best countermeasure for a location is chosen, there are still differences between individual sites and drivers at those sights, so there is variability in the effectiveness of a countermeasure in application. For this purpose, the Highway Safety Manual provides standard error values to reflect both the variability in applications as well as the uncertainty or limited sample size of the data studied in creating the countermeasure CMF value. The standard error reflects the expected variability in the effectiveness of a countermeasure over multiple applications and can be used to calculate a confidence interval for expected future crashes.

It is assumed that the mean value is equivalent to the number of crashes expected after the application of the CMF to the data. Given the assumption of a normal distribution, it is expected that 68% of the values will fall within one standard deviation of the mean, 95% of the values will be within two standard deviations of the mean, and 99.7% of the values will be within three standard deviations of the mean. The Highway Safety Manual encourages users to look at the 95% confidence interval of two standard deviations above and below the mean when predicting future crash frequency [2]. Returning to the previous roundabout conversion example, the standard error for all types of crashes and all severities of crashes is 0.04 [2]. The standard error for all types of injury crashes is also 0.04 [2]. To calculate the lower bound of the 95% confidence interval for the CMF and the expected crash rate the results, subtract twice the standard error value from the original CMF. In the roundabout case example, the lower bound CMF would be 0.21 for all severities of crashes and 0.05 for injury crashes. The expected number of crashes during a three year period at the example intersection using the lower bound would be 4.2 total crashes and 0.5 injury crashes. The calculation for the upper bound on the CMF is done in the opposite manner as the lower bound. The standard error is added to the given CMF twice. For the roundabout conversion example, the upper bound for all crashes would be 0.37 and 0.21 for injury crashes. The upper bound CMF is multiplied by the number of observed crashes in order to calculate the upper limit of the 95% confidence interval. For the example case of the conversion of a rural two-way STOP controlled intersection with twenty total crashes, including ten injury crashes, over three years to a one lane roundabout, it is projected that in a three year period following the roundabout conversion, the intersection would experience between 4.2 and 7.4 total crashes with between 0.5 and 2.1 of the crashes resulting in injury. When presenting the results of a CMF computation to a client or the public, it can be helpful to round the values to the nearest integer because it is not possible to have a fraction of a crash occurring at an intersection. Table 1 below summarizes the calculations to estimate how many crashes would occur at the sample intersection over three years following conversion to a roundabout.

Table 2.1: Roundabout CMF application example summary

Before Roundabout Conversion (over a three year period)		CMF Value	Standard Error	After Roundabout Conversion	Lower 95% Bound	Upper 95% Bound
Total Crashes	20	0.29	0.04	5.8	4.2	7.4
Injury Crashes	10	0.13	0.04	1.3	0.5	2.1

The common practice for estimating the effect of two countermeasures is to multiply the CMFs of the respective countermeasures together to find the CMF for the two treatments combined. Unless the two countermeasures are determined to act independently and target two non-overlapping types of crashes, the reduction of the two countermeasures cannot simply be added together. Caution and engineering judgment should be applied when considering the effects of combined countermeasures because research is not sufficient to accurately determine the interrelation of countermeasures [2].

CMFs are developed through compiling the results of many carefully completed studies for each countermeasure. Studies can be experimental, or planned, studies or observational, or unplanned, studies [3]. There are multiple different types of studies that are used to collect the data needed for developing countermeasures. The first types of studies are the before-after with comparison group studies. In these types of studies, a comparison group of similar intersections that receive no treatment are compared to intersections that receive a treatment. Both groups of intersections are monitored before and after the treatment is added to any of the intersections. From the comparison of the before and after performance of the treated intersections and neutralized by the untreated intersections, a CMF can be developed. The second types of studies used are Empirical Bayes before-after studies. These studies use the Empirical Bayes method to estimate how many crashes would have occurred if the countermeasure were not used and this estimation is compared to the observed data at the intersection following the countermeasure treatment installation. The third type of study, case control studies, start with an outcome, such as a crash, and work backwards to determine the prior treatment that led to the increased risk. The fourth type of studies are cross sectional studies. Cross sectional studies compare two locations that are varying in just one feature. By comparing the crash rate of these two locations, it is inferred that the difference between the two sites accounts of the difference in crash rate. The final type of studies, cohort studies, are used to find a change in relative risk over a unit change at a location. The change in relative risk has been found to correlate to crash reduction potential.

The Highway Safety Manual and the FHWA's CMF Clearinghouse are the largest sources of national CMF values available to transportation engineers. The ability to accurately provide a quantitative assessment of crash reduction potential is a relatively new concept, so the availability and precision of all types of countermeasures is limited. In order for a countermeasure to be included in the Highway Safety Manual or CMF Clearinghouse, the quality of the countermeasure must be ensured by examining the study design, sample size, standard error, potential bias, and data source. CMFs are not currently available for all countermeasures, but future editions of the Highway Safety Manual will likely include more information to fill these vacancies when the data becomes available.

2.3 Process of an Intersection Safety Study

The first step in conducting a study to improve the safety of rural unsignalized intersections is to identify what types of crashes are occurring at the intersection. Some common types of crashes at rural, unsignalized intersections include rear end crashes at both the minor and major approach, angle crashes within the intersection, sideswipe collisions, and run off the road crashes. Identifying what types of crashes occur at an intersection can be accomplished through reviewing crash records from the past three to five years and creating a crash diagram. Creating a crash diagram is a beneficial step to determining what types of crashes occur at an intersection through a visual representation of the distribution of crashes at the intersection. The Highway Safety Manual provides guidance on how to create a most useful crash diagram. Each crash that has occurred at the intersection over the past three to five years should be depicted on the diagram at roughly the location with the intersection where the crash occurred. For each crash, it is also helpful to provide some information about the type of crash and include a referencing number to link the symbol of the crash on the diagram to the specific crash in order to locate more details about the specific crash with relative ease.

The next step in improving safety at rural, unsignalized intersections is to determine why the crashes are occurring at the intersection. In order to do this, an in depth review of crash reports to determine trends within the data as well as visiting the site must be completed. From the crash reports, information regarding the type of crash, time of the crash, reason for crash, weather conditions, and severity of crash can be analyzed. Through this information, trends are examined. The time of the day, the week of the month, and the month of the year of the crashes can be searched for patterns. The crash reports also list the birthdate of the drivers involved in the crash, so the ages of the drivers involved can be calculated. The reason for a crash can be determined from the crash report through the crash narrative. If the drivers are unable or unwilling to describe to the police officer who produced the crash report, information about which direction the vehicles in the crash were travelling is still available and can be used to make educated assertions about the cause of the crash. Summarizing this data in charts and tables can be beneficial in performing this analysis [4].

Visiting the site of each intersection is an important early step in the process to observe what conditions drivers experience at the intersection. The Highway Safety Manual can serve as guidance for conducting site visits. As part of collecting data about each intersection, the intersection was traversed from each direction and the experience was compared with crash trends for the intersection. For example, sight distance from each approach to the intersection should be noted and objects that obscure the view of the oncoming traffic should be identified. Another factor to observe when performing a site visit to the intersection is any advanced warning of the intersection and visibility when approaching the intersection. Advanced warning of intersections can consist of signs, pavement markings, rumble strips, or flashing beacons. It is necessary to note the advanced warning measures located on both the main road and the cross road. Gap acceptance can be a challenge at rural, non-signalized intersections if the volume on the main road is large enough. When performing a site visit, the observer can see first-hand what challenges drivers must contend with in order to find an acceptable gap. If acceptable gaps are infrequent, this could cause drivers to become impatient and decide to enter the intersection when conditions are not safe. Observing driver behavior at the intersection can provide valuable insight to driving trends at a particular location. An observer can look at the travel speed of the vehicles in comparison to the posted speed limit, the queue of vehicles that backup at a stop sign, or any other notable driver behavior factors.

2.4 Knowledge-Based Expert Systems

KBES are a technology that is derived as a branch of artificial intelligence. The goals of artificial intelligence are to create mechanisms that mimic human intelligence or can surpass the decision making capability of the human mind [5]. John McCarthy is credited with coining the term artificial intelligence in 1956 at a conference at Dartmouth College [5]. By the 1960's and 1970's, many applications of artificial intelligence were developed in fields such as medicine, chemistry, and linguistics. While many forms of artificial intelligence were developed, much of this work was done using knowledge based systems. It was not until many decades later that artificial intelligence was first applied to transportation engineering. Transportation networks present many complicated problems for engineers. The problems of efficiency, safety, and environmental compatibility of transportation networks could be addressed using artificial intelligence in ways that are faster and beyond the capabilities of humans.

One of the earlier medical applications of KBES was developed in 1979 for the purpose of pulmonary function analysis [6]. This system became known as PUFF and was frequently used in the medical community. In order to use this system, the patient inhales and exhales through tube that is connected to a computerized instrument to measure flow rate and air volume. This information is combined with user inputs of patient information about age, gender, and smoking history to determine a diagnosis for the patient. PUFF was developed by an expert pulmonary physiologist at Pacific Medical Center in San Francisco. This expert was able to create rules that would allow other less experienced physicians to make accurate diagnoses for patients using the expert's proven methodology.

There are also numerous applications of KBES in transportation engineering. In 1987, a prototype expert system for traffic control in highway work zones known as TRANZ was developed [7]. The purpose of TRANZ is to select traffic control strategies and management techniques for highway work zones. TRANZ was built using Exsys® software and was designed to remove some of the engineering judgment based decisions that were typically required when determining traffic control and traffic management strategies in highway work zones. This system incorporated road parameters, construction parameters, and location environment characteristics along with the requirements in the MUTCD to produce recommendations for traffic control and management. TRANZ became a valuable resource in transportation engineering because expertise on determining traffic control strategies and management techniques for highway work zones is clustered in a few locations. With the advent of TRANZ, this expertise became more widely available [7].

People who have acquired a wealth of knowledge of a specific subject are considered experts. These experts can be valuable resources for other people in the same field due to their ability to share their knowledge. Experts are especially beneficial to those individuals who may not be as experienced with the subject as an expert. However, depending on the topic and the logistics of the situation, experts are not always accessible when needed.

One way to solve this challenge is by creating knowledge-based expert systems, or expert systems. Expert systems are a way to extract the knowledge of experts and make it more accessible to people in the same field. These systems are typically automated, so they are available twenty-four hours per day and in any location when experts may not be available. The user is able to tap into a knowledge base on a particular subject whenever the knowledge is needed. Heuristic rules designed by experts during the creation of the system are used to mimic the decision making process an expert would use when trying to solve the problem that the user is encountering.

The advantage of expert systems over other types of resources is that expert systems require user input throughout the process and guide the user to a recommendation based on their specific problem. The questions are based on expert identified logic where only the necessary questions are asked in order to make the process of determining the best solution as straightforward as possible. The user is also able to learn about the process of finding a solution through noting the questions asked by the expert system and the responses given based on the answers provided. The best applications of exert systems are when the problem solving logic is well understood, based on logical steps or procedures or business rule, and does not involve intuition, guesses, or personal taste decisions [5].

2.5 Summary of Chapter 2

The Highway Safety Manual is a valuable resource for transportation engineers to assist in making quantitative predictions of the effectiveness of safety countermeasures at intersections through the use of CMFs. While there are still some needs for further research, the Highway Safety Manual is moving toward becoming a nationally accepted resource. The Highway Safety Manual is also helpful in guiding the user through the process of completing an intersection safety study. In completing an intersection safety study, it is necessary to first determine what types of crashes are occurring at the intersection. The second step is to determine why these crashes are occurring, and the final step is to select countermeasures that could prevent crashes based on the unique site characteristics. While this process is outlined in the Highway Safety Manual, it is still not entirely straightforward.

The use of KBES dates back to the 1950's. KBES have been used in many fields and continue to become more widespread resources since their early development. One example of an early KBES in the medical field is used for pulmonary function analysis and known as PUFF. KBES have also become valuable in the field of transportation engineering. The system known as TRANZ that is used to select traffic control strategies in highway work zones is an example of a successful KBES in transportation engineering. The advantage of KBES over other types of resources is that KBES mimic the sequence of questions of a human expert so the knowledge of the human expert can be applied in situations when the expert is not available. KBES are designed to respond to the user inputs to avoid superfluous questioning that could result in a system that is not user responsive.

Chapter 3

COUNTERMEASURE OPTIONS

Once the analysis of the crashes at an intersection is complete, it is necessary to match the types of crash and reason for crash at the intersection with countermeasures that can improve safety. There are many types of countermeasures that are available, but it is important to note that not all of the countermeasures would be effective at every location. For example, a countermeasure that was very effective at a nearby intersection may not be the best choice for the next intersection because each intersection has unique traffic flow and geometric characteristics. The countermeasures presented in this Chapter include intersection lane narrowing, conversion to all-way STOP control, sight distance improvements, installing flashing beacons, signalization, roundabout conversion, advanced warning rumble strips, advanced warning pavement markings, intersection signing modification, dedicated left and right turn lanes, shoulder bypass lanes, intersection realignment, intersection illumination, and skid test for pavement quality.

3.1 Intersection Lane Narrowing

Studies have proven a correlation exists between lane width and average travel speed on a road [8]. As lane width decreases, the driver typically feels constrained and decreases his or her travel speed as an act of caution. The following figure shows a graphical representation of the relationship discovered in a study completed by the Texas Transportation Institute that compared the 85th percentile travel speed to the average lane width [8]. The data was collected at 36 locations on straight roads outside of urban areas in Texas. A positive correlation between lane width and travel speed was determine by this study.

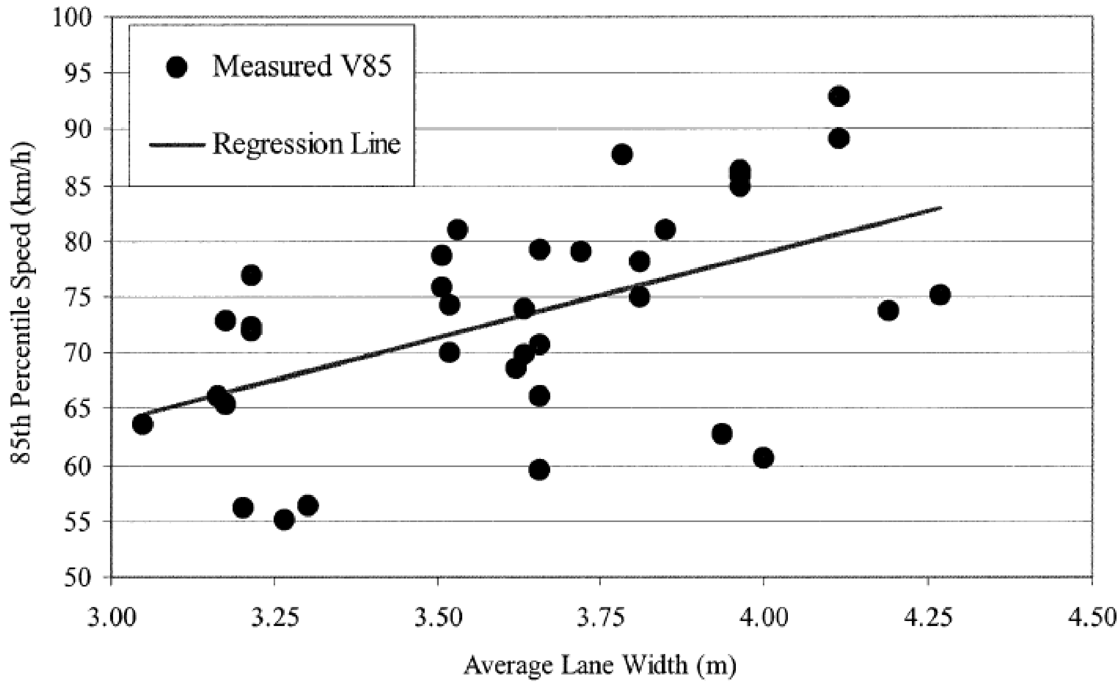

Figure 3.1: 85th percentile speed and average lane width [8]

Vehicles that are travelling above the posted speed limit in the vicinity of a two-way stop controlled intersection frequently exasperate problems at intersections that already have a high rate of angle crashes. This tendency is the result of drivers who are stopped at the stop sign and misjudging the amount of time they have to cross the main road before a car on the main road reaches the intersection when that car is travelling over the posted speed limit.

One way to combat the problem of speeding vehicles at rural intersections is to use rumble strips and a painted median to decrease the lane width and encourage drivers to slow down. A study completed by the Federal Highway Administration identified and reviewed the effectiveness of two different types of lane narrowing concepts at rural, unsignalized intersections [9]. Field trials of the lane narrowing concepts were completed in Maryland, Virginia, New Mexico, Illinois, Pennsylvania, Kentucky, Missouri, Florida, and California. Sites in the participating states were selected at locations that have proven to have problems with advanced perception of the intersection, locations where the average travel speed was significantly higher than the posted travel speed, and locations were a lack of compliance with STOP signs was observed. The first variation involving narrowing the major road approach at the intersection is shown below in Figure 3.2.

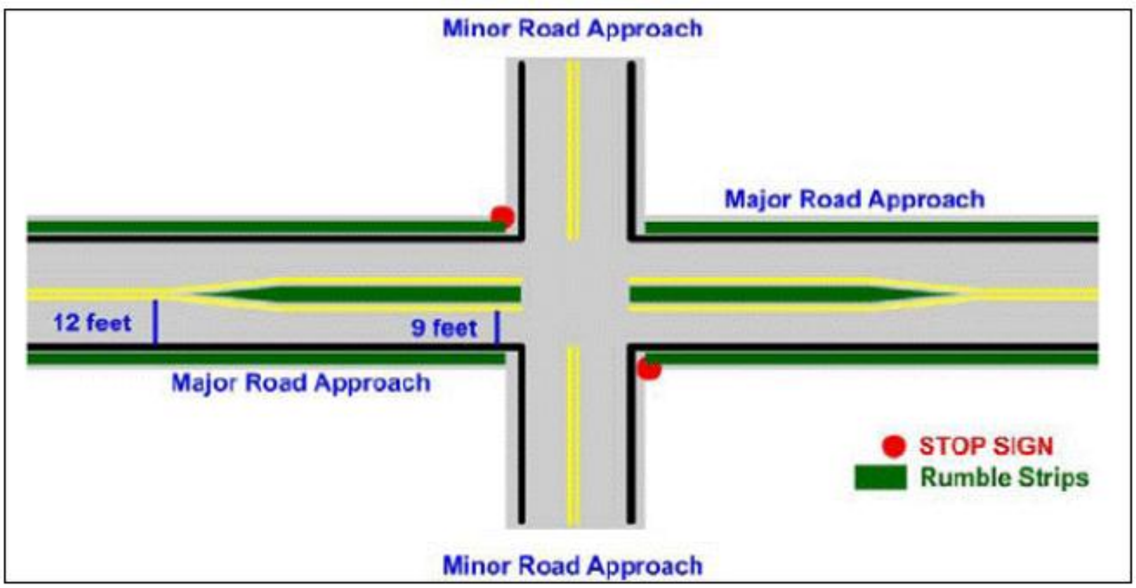

Figure 3.2: Lane narrowing concept one [9]

This treatment is intended to reduce speeds on the major road in the vicinity of the intersection through reducing the lane width from twelve feet to nine feet.

The second lane narrowing concept, shown in Figure 3.3, involves creating a channelizing separator island on the minor road approach and adding an extra stop sign on the new median to draw more attention to the intersection from the minor road approach. This measure would increase intersection awareness and improve driver alertness.

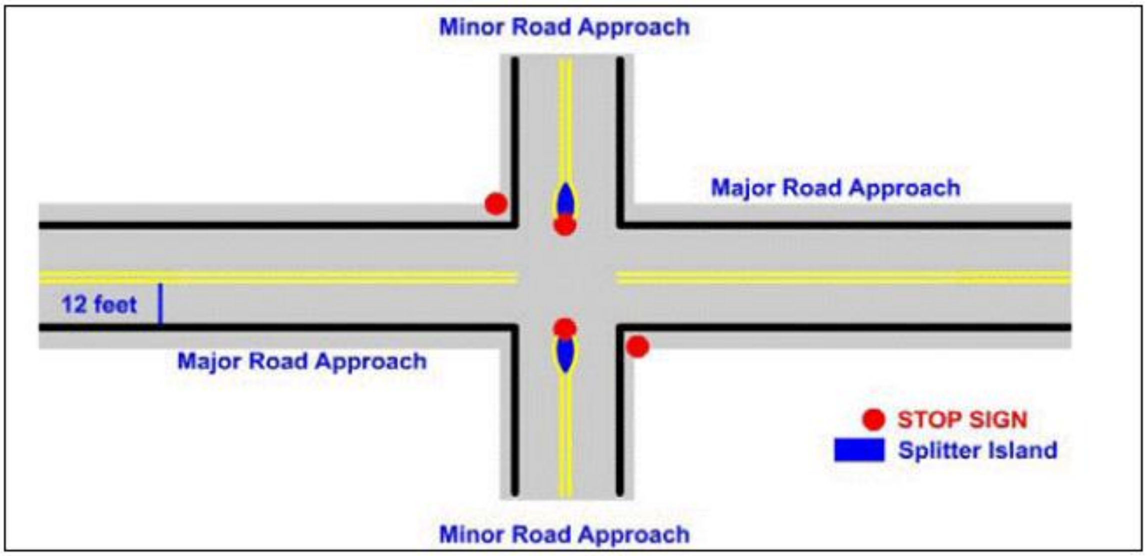

Figure 3.3: Lane narrowing concept two [9]

The final option for intersection lane narrowing identified by the Federal Highway Administration study involves combining the two previous shown concepts into one design as shown in Figure 3.4. This third option combines both the modifications to the intersection from the major road and minor road approaches to maximize speed reduction and intersection awareness.

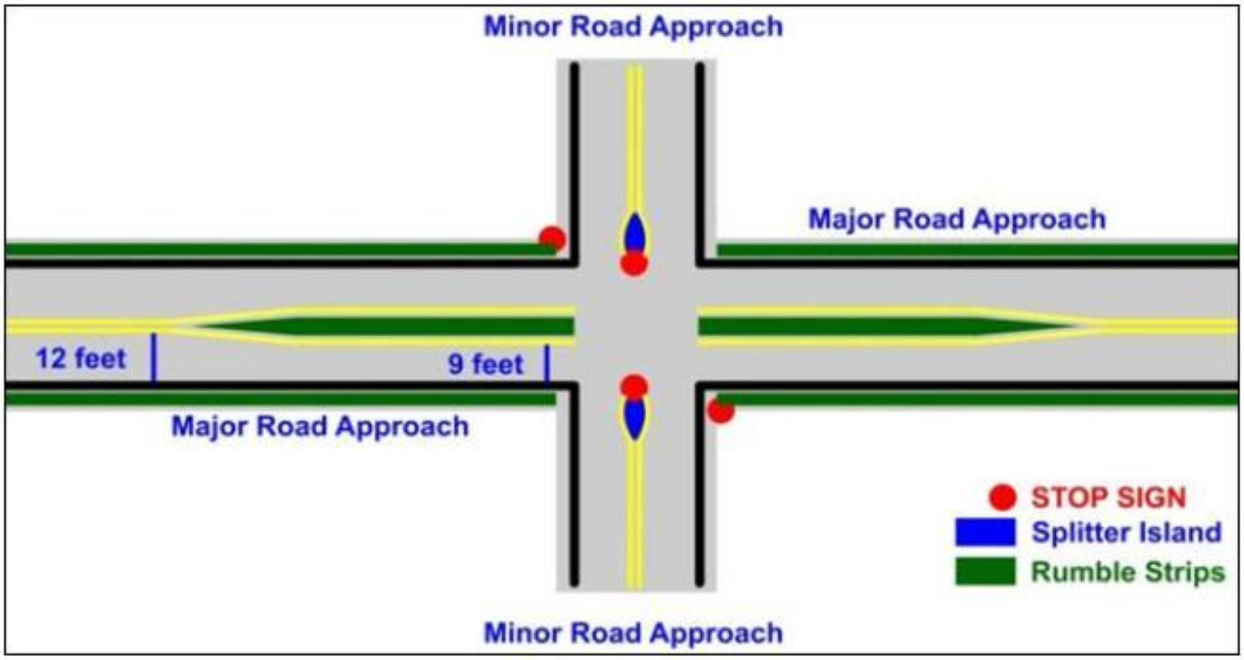

Figure 3.4: Combined lane narrowing concept [9]

The study of the effectiveness of the lane narrowing concept designs at reducing speed was done using nine sites in Pennsylvania, Kentucky, Missouri, and Florida. The study revealed statistically significant results at a 95th percentile confidence interval for reduction of speed on the major road through the implementation of lane narrowing concept one.

A study of the effect of lane narrowing concept one on crash reduction showed mixed, but generally positive results. For the three sites in Pennsylvania, total crashes were reduced between 30% and 83% [9]. Fatal crashes and related crashes were also reduced at all Pennsylvania sites. However, the sites in Kentucky, Missouri, and Florida observed an increase in rear-end collisions. Overall, the sites experienced a 31% decrease in total crashes and a 20% decrease in fatal/injury crashes [9].

Only one site in Virginia was studied for lane narrowing concept two on the minor road. This location experienced a decrease in both angle and rear-end collisions. Total crashes at this site decreased by 68% and fatal/ injury crashes decreased by 74% [9].

Using a lane narrowing concept can be advantageous at locations where the road already has a large enough pavement cross section to accommodate the improvement. In these types of locations, the cost of this countermeasure would be smaller because additional roadway paving is not required. Trucks can have particular difficulty navigating in narrow lanes because trucks are wider than most other vehicles and have a greater turning radius. However, if transverse pavement markings are used to delineate the lane width, trucks would be able to travel through the corridor more easily.

3.2 Convert to All-Way STOP Control

For many two-way STOP controlled intersections in rural areas that have frequent angle crashes, converting the intersection to all-way STOP control is a cost-effective way to prevent crashes. However, this countermeasure is not applicable in all locations. The MUTCD has outlined the requirements for warranting a conversion from a two-way STOP controlled intersection to an all-way STOP controlled intersection. The MUTCD offers the following requirements to be met to convert a two-way STOP controlled intersection to an all-way STOP controlled intersection.

"The decision to install multi-way stop control should be based on an engineering study.
The following criteria should be considered in the engineering study for a multi-way STOP sign installation:

A. Where traffic control signals are justified, the multi-way stop is an interim measure that can be installed quickly to control traffic while arrangements are being made for the installation of the traffic control signal.
B. Five or more reported crashes in a 12-month period that are susceptible to correction by a multi-way stop installation. Such crashes include right-turn and left-turn collisions as well as right-angle collisions.
C. Minimum volumes:
1. The vehicular volume entering the intersection from the major street approaches (total of both approaches) averages at least 300 vehicles per hour for any 8 hours of an average day; and
2. The combined vehicular, pedestrian, and bicycle volume entering the intersection from the minor street approaches (total of both approaches) averages at least 200 units per hour for the same 8 hours, with an average delay to minor-street vehicular traffic of at least 30 seconds per vehicle during the highest hour; but
3. If the 85th-percentile approach speed of the major-street traffic exceeds 40 mph, the minimum vehicular volume warrants are 70 percent of the values provided in Items 1 and 2.
D. Where no single criterion is satisfied, but where Criteria B, C.1, and C.2 are all satisfied to 80 percent of the minimum values. Criterion C.3 is excluded from this condition." [10]

The location, surrounding area, and speed limit should also be taken into consideration when considering conversion to all-way STOP control. The Highway Safety Manual gives the following values for the CMF for converting a two-way STOP controlled intersection to an all-way STOP controlled intersection shown in Table 3.1.

Table 3.1: CMFs for conversion of two-way STOP to all-way STOP

Treatment	Setting (Intersection Type)	Crash Type (Severity)	CMF	Standard Error
Convert minor-road stop control to all-way stop control	Rural (MUTCD warrants are met)	All types (All severities)	0.52	0.04

There are a few disadvantages of converting a two-way STOP controlled intersection into an all-way STOP controlled intersection. Problems can arise during the first two weeks following the conversion to all way STOP control because drivers are not used to the additional STOP signs. It can be helpful to use message boards or extra signing to warn drivers about the new STOP sign for the first two weeks until local drivers become familiar with the new traffic flow pattern. The addition of the extra STOP sign results in more delay at the intersection which could cause congestion problems in a highly travelled corridor. This delay can be especially apparent for trucks because trucks require a greater distance to return to speed after coming to a complete stop at the intersection. Also, noise at the intersection could increase as result of requiring more vehicles to stop at the intersection.

3.3 Improve Intersection Sight Distance

The Highway Safety Manual defines sight distance as “the length of roadway ahead visible to a driver” and sight triangle as “In plan view, the area defined by the point of intersection of two roadways, and by the driver’s line of sight from the point of approach along one leg of the intersection to the farthest unobstructed location on another leg of the intersection.” [2] Both of these concepts are important to determining the safety of an unsignalized intersection. A driver must have enough sight distance approaching the intersection to clearly see the intersection and STOP sign in order to safely stop at the intersection. Once the driver has stopped at the intersection, he or she must have a great enough sight triangle in order to judge when a gap in the traffic is large enough to enter the intersection. If the sight distance approaching the intersection is too small due to road curvature, road grade, or obstructions alongside the road, the intersection could have a problems with rear-end crashes or a high rate of drivers disregarding the STOP sign. If the sight triangle at the intersection is inadequate, drivers may need to guess whether or not a conflicting vehicle is approaching the intersection, leading to unsafe conditions at the intersection. Improving the sight distance at intersections is often used as a first step to improving intersection safety because it can frequently be completed quickly and with a minimal cost. Obstructions such as trees, embankments, and signs can typically be easily moved at an intersection, but utility poles and boxes are often more expensive to relocate. Although the Highway Safety Manual has not yet identified a CMF for increasing sight distance, a FHWA study [11] indicates that crashes increase by 5% for each quadrant in which sight distance is limited at a two-way STOP controlled intersection.

One potential obstacle associated with increasing sight distance is that trees or other sight distance obstructions can sometimes be located outside the right of way of the road. In such cases, it is necessary to work with the property owners near the intersection to remove the obstructions. Also, in rural locations, corn can reduce sight distance at intersections in August and September. In these locations, it is important to work with farmers to leave the land near an intersection unplanted to avoid obscuring sight distance when corn reaches its full height at the end of the summer.

3.4 Flashing Beacons

Flashing beacons refer to flashing lights installed at an intersection to draw attention to the intersection. There are multiples ways in which flashing beacons can be used at an intersection. Red lights can be directly mounted on the STOP sign on STOP controlled approaches to draw attention to the STOP sign or overhead in a location similar to a traffic signal. STOP controlled approaches typically have a flashing red light facing the traffic while approaches that are not required to stop at the intersection see a flashing yellow light. It is intended that flashing beacons increase intersection awareness and reduce both angle and rear-end collisions as a result.

However, the effectiveness of flashing beacons in practice is variable. A study performed by the Federal Highway Administration [12] took a more in depth look into the effectiveness of flashing beacons at 64 sites in North Carolina and 42 sites in South Carolina that previously had a problem with angle crashes prior to installing flashing beacons. The study used the Empirical-Bayes procedure to estimate the number of crashes expected at these intersections if flashing beacons were not installed and compared these values to the observed number of crashes after the installation of the flashing beacons. The results of this study are summarized in Figure 3.5 below.

	Angle	Rear-end	Injury & Fatal (K, A, B, C)	All Crash Types and Severities
EB estimate of crashes expected in the after period without strategy	689.2	221.6	648.8	1,297.0
Count of crashes observed in the after period	598	205	583	1,232
Estimate of percent reduction in crashes (standard error)	**13.3% (4.6)**	7.9% (8.9)	**10.2% (4.8)**	5.1% (3.6)
Estimate of reduction in crashes per site-year	0.21	0.04	0.15	0.15

NOTE: Bold denotes results that are statistically significant at the 95% confidence level.

Figure 3.5: Results of North Carolina and South Carolina flashing beacon effectiveness study [12]

The study further investigated the factors contributing to the effectiveness of flashing beacons at decreasing crashes at an intersection. The following conclusions were made by the study:

- Flashing beacons seem to be more effective at rural and suburban locations. The sample size for suburban and urban intersection is quite low, resulting in effects that are insignificant; therefore this result needs to be applied with caution [12].
- Flashing beacons may be more effective at reducing angle crashes at four-way STOP-controlled intersection compared to two-way STOP controlled intersections; however, the reduction in angle crashes at four-way STOP controlled intersections is insignificant [12].
- There seems to be a significant reduction in crashes at sites with standard beacons mounted on STOP signs. However, only five sites belong to this category, so it is not possible to make definitive conclusions regarding beacon location [12].

The Highway Safety Manual acknowledges the same uncertainty regarding the effectiveness of flashing beacons. The Highway Safety Manual provides the following CMFs for installing flashing beacons at a STOP controlled intersection shown in Table 3.2.

Table 3.2: CMFs for flashing beacons

Treatment	Setting (Intersection Type)	Crash Type (Severity)	CMF	Standard Error
Provide flashing beacons at stop-controlled intersections	All settings (Stop-controlled)	All types (All severities)	0.95*	0.04
		All types (Injury)	0.90*	0.06
		Rear-end (All severities)	0.92*	0.1
		Angle (All severities)	0.87	0.06
	Rural (Stop-controlled)	Angle (All severities)	0.84	0.06

* Observed variability suggest that this treatment could result in an increase, decrease, or no change in crashes.

Another concern about the effectiveness of flashing beacons surrounds driver perception of flashing beacons. In some locations, flashing beacons may have a large impact on safety initially, but after drivers grow accustom to the flashing beacons, crashes again increase at the intersection. Also, some drivers have reported to being confused by the flashing beacons and led to believe that the cross traffic will stop at a two-way STOP controlled intersection when it does not. While there is significant uncertainty in the effectiveness of flashing beacons, multiple sources suggest that for rural intersections with angle crash problems, flashing beacons have been shown to reduce crashes.

3.5 Signalization

Converting an unsignalized intersection to a signalized intersection results in significant changes to the traffic flow in a rural area; however, if install in a proper location, this countermeasure can greatly decrease crashes. First and foremost, it is necessary to determine whether an intersection reaches the minimum criteria for signalized as defined in Chapter 4C of the MUTCD. The MUTCD defines the following nine types of warrants for signalization [10]:

- Warrant 1 – Eight hour vehicular volume: This warrant condition includes situations where the intersecting volume is great enough to require a traffic signal or the main road volume is so great that an excessive queue forms on the minor road as a result of vehicles having only few opportunities to safely enter the intersection.
- Warrant 2 – Four hour vehicular volume: This warrant condition exists if the intersecting volume during any four one hour periods of the day is large enough to disrupt the traffic flow at the intersection and meets the minimum volume requirements as specified by the Highway Safety Manual.
- Warrant 3 – Peak hour- This warrant condition is designed for locations that have a particularly high volume over at least four consecutive fifteen minute intervals such as near manufacturing plants or industrial complexes that discharge a large volume of traffic over a short period of time.
- Warrant 4 – Pedestrian volume- This warrant condition occurs when pedestrians have enough difficulty crossing an unsignalized intersection to create an excessive delay. This can be measured over a four hour or one hour increment.
- Warrant 5 – School crossing – This warrant condition exists when a large volume of schoolchildren must cross the major road of an unsignalized intersection. Cases that require signalization occur when

there is a sufficient volume of both pedestrian and vehicle traffic or when adequate gaps to cross the major road are too infrequent.

- Warrant 6 – Coordinated signal system- This warrant condition exists when an unsignalized intersection disrupts the vehicle platoon along a corridor of coordinated signalized intersection.
- Warrant 7 – Crash experience- This warrant condition occurs at an intersection that has had a large number of severe crashes that could be prevented by a traffic signal and the volume on the roads meets minimum requirements.
- Warrant 8 – Roadway network- This warrant is used to justify signalization at locations where the signal would be intended to organized traffic flow across the network. The roads at the location must also meet minimum volume requirements.
- Warrant 9 – Intersection near a grade crossing- This warrant is intended to alleviate situations where traffic is forced to stop on railroad tracks due to a STOP or YEILD controlled intersection near an at grade railroad crossing.

In addition to the signalization warrants listed above, it is important to exercise engineering judgment when considering converting an unsignalized intersection to a signalized intersection. An engineering study should be performed before installing a traffic signal. A signal should not be installed if it is likely to seriously disrupt progressive traffic flow. For many of the volume related warrants, the required volumes may be reduced if the 85th percentile speed on the major road is greater than 40 mph, which is often the case on rural roads. One of the disadvantages of a traffic signal is that it can cause delay during the off peak hours, so this condition must also be brought into consideration in a signal warrant study.

The CMFs determined by the Highway Safety Manual for converting a rural unsignalized intersection into a signalized intersection are shown in Table 3.5 below.

Table 3.3: CMFs for installing a traffic signal

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Standard Error
Install a traffic signal	Rural (three and four legs)	Major Road 3,261 to 29,926 Minor Road 101 to 10,300	All types (All severities)	0.56	0.03
			Right-angle (All severities)	0.23	0.02
			Left-turn (All severities)	0.40	0.06
			Rear-end (All severities)	1.58	0.2

Traffic signals can be used effectively as a countermeasure when used in the correct location. Traffic signals have also been observed to decrease the severity of crashes at an intersection. However, when traffic signals are placed in an improper location, they can result in increased total crashes as a result of increased rear-end collisions and cause unnecessary added delay during off peak hours. It is often helpful to try other countermeasures before considering signalization because converting a

STOP controlled intersection to a signalized intersection is an expensive and time consuming improvement.

3.6 Roundabout Conversion

Roundabouts are becoming more popular in the United States because they have proven to be much safer than two way stop controlled intersections. Although roundabouts are sometimes the object of public scrutiny, public objection to roundabouts frequently diminish after drivers become more comfortable with roundabouts. According to the FHWA publication *Roundabouts: An Informational Guide* [13], along with the safety improvements roundabouts offer as compared to two-way STOP controlled intersections, capacity is increased and delay is reduced as compared to all-way STOP controlled intersections [13]. Roundabouts are particularly effective at decreasing injury crashes at an intersection because vehicles in the roundabout are typically travelling less 30 mph, so the chances of severe crashes is reduced. Since drivers are forced to reduce speeds when navigating a roundabout due to the curvature of the roadway, roundabouts can be used as traffic calming measures to control the travel speed of vehicles. Fuel consumption is also decreased at roundabouts due to the fact that drivers do not need to idle at a STOP sign if no other traffic is at the intersection. Roundabouts also typically reduce delay compared to a two-way STOP controlled intersection, which further decreased fuel use from vehicles which must wait to cross the major, free flowing road. One reason why the FHWA proposes that roundabouts are safer than conventional STOP controlled intersections is because roundabouts decrease the number of conflict points within the intersection. See Figures 3.6 and 3.7 below from *Roundabouts: An Informational Guide* to demonstrate the reduction in conflict points in a roundabout as compared to a STOP controlled intersection.

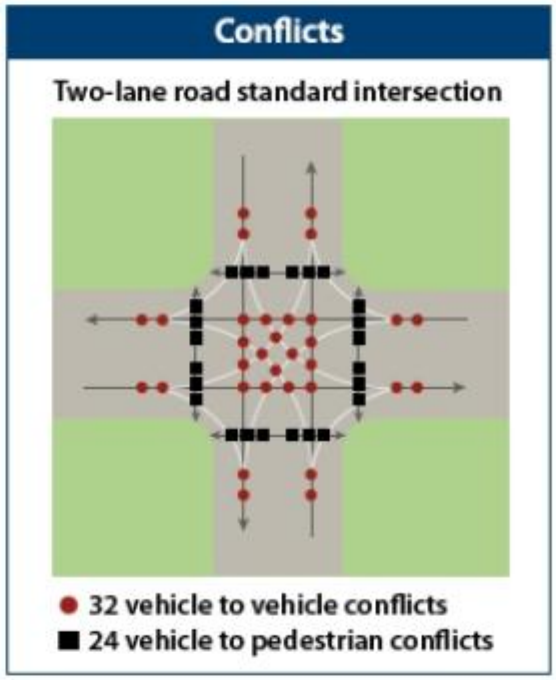

Figure 3.6: Conflict points in a standard STOP controlled intersection [13]

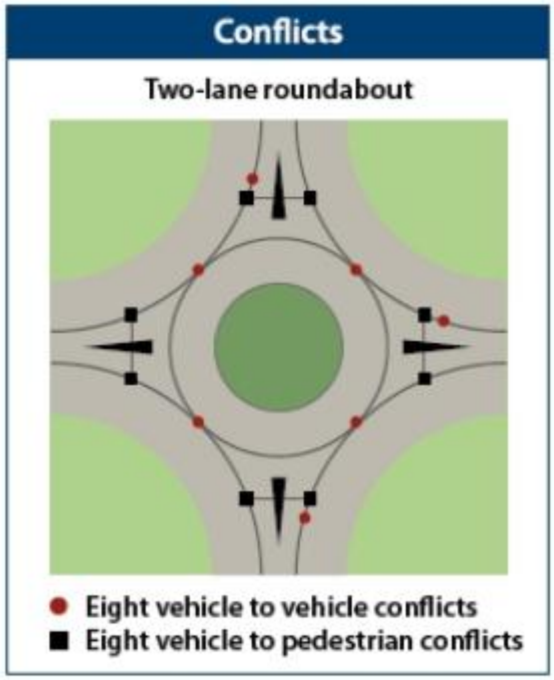

Figure 3.7: Conflict points in a roundabout [13]

As Figures 3.6 and 3.7 show, there are twenty-four fewer vehicle conflict points in a roundabout than in a STOP controlled intersection. For pedestrians, there are sixteen fewer conflict points.

While roundabouts offer noticeable safety improvements from STOP controlled intersections, it is also important to note that there are a few disadvantages of roundabouts. First, roundabouts require more land than STOP controlled intersections, so it is often necessary to acquire more right-of-way when converting a STOP controlled intersection to a roundabout. Second, roundabouts require entirely reconfiguring the intersection, so the conversion of a STOP controlled intersection to a roundabout would be expensive. Thirdly, public opposition must be dissuaded before the roundabout gains community approval. Finally, from a design viewpoint, roundabouts are sometimes not feasible in an area near an at-grade railroad crossing because backup from a roundabout that crosses an at-grade rail line can be very dangerous for vehicles that are not able to exit the train tracks when a train is approaching due to congestion in the upcoming roundabout. Another design concern associated with roundabouts involves looking from a large perspective and considering the type and proximity of other intersection in the area. If there are a large number of other intersections in the area that are STOP controlled, drivers would approach the next intersection with the expectation that this intersection would also be STOP controlled. If there intersection is a roundabout instead of STOP controlled, this could be contrary to driver expectations and lead to an unsafe situation. Pedestrians present another design concern for roundabouts. While a high pedestrian volume is unlikely in a rural setting, if there is significant pedestrian traffic volume, it needs to be addressed at the roundabout with crosswalks or a different countermeasure should be selected. However, the safety benefits of converting a minor road STOP controlled intersection into a one lane roundabout are easily apparent given the CMFs determined by the Highway Safety Manual shown in Table 3.4 below.

Table 3.4: CMFs for conversion to roundabout

Treatment	Setting (Intersection Type)	Crash Type (Severity)	CMF	Standard Error
Convert intersection with minor-road stop control to modern roundabout	Rural (One lane)	All types (All severities)	0.29	0.04
		All types (Injury)	0.13	0.04
Convert all-way, stop-controlled intersection to roundabout	All settings (One or two lanes)	All types (All severities)	1.03	0.2

3.7 Advanced Warning Rumble Strips

Advanced warning rumble strips are a type of countermeasure used to draw attention to an upcoming intersection, particularly in locations where there is a problem with driver compliance with the STOP sign and rear end collisions on a STOP controlled approach. An intersection where the STOP sign is not well visible is another example of a good location for rumble strips. Contrarily, rumble strips are typically less effective on major road approaches because over time, frequent drivers may become familiar with the location of the rumble strips and disregard them. The main concern with advanced warning rumble strips is the noise produced by vehicles travelling over the rumble strips. Therefore, engineers should be hesitant to install advanced warning rumble strips in residential areas where homeowners could be aggravated by the noise.

There are two different types of transverse rumble strips frequently used for intersection advanced warning. Thermoplastic rumble strips are made of built up layers of hot extruded alkyd or hydrocarbon thermoplastic road material [14]. These types of rumble strips are frequently installed in four or five sections with five strips per section. Milled in rumble strips which are frequently used on the centerline of a road or along the edge of the travel lane can be used as advanced warning for intersections [14]. However, thermoplastic rumble strips are less expensive and easier to remove.

3.8 Advanced Warning Pavement Markings

Advanced warning pavement markings refer to a message painted on the roadway such as “STOP AHEAD” when approaching the intersection. Similar to advanced warning rumble strips, the purpose of advanced warning pavement markings are intended to draw attention to the intersection and prevent both rear end crashes as well as crashes that result from drivers disregarding the STOP sign [6]. Table 3.5 below shows the CMFs determined by the Highway Safety Manual for advanced warning pavement markings.

Table 3.5: CMFs for advanced warning pavement markings

Treatment	Setting (Intersection Type)	Crash Type (Severity)	CMF	Standard Error
Provide “Stop Ahead” pavement markings	Rural (Stop-controlled)	Right angle (All severities	1.04*	0.3
		Rear-end (All severities)	0.71	0.3
		All types (Injury)	0.78	0.2
		All types (All severities)	0.69	0.1
	Rural (Stop-controlled four-leg)	All types (Injury)	0.88	0.3
		All types (All severities)	0.77	0.2
	Rural (All-way stop controlled)	All types (Injury)	0.58	0.3
		All types (All severities)	0.44	0.2
	Rural (Minor-road stop-controlled)	All types (Injury)	0.92*	0.3
		All types (All severities)	0.87	0.2

*Observed variability suggests that this treatment could result in an increase, decrease, or no change in crashes.

Standard pavement markings used on roadways and at intersections can also be improved to decrease the crash rate at an intersection. By making the pavement marking near an intersection more visible, it draws the drivers’ attentions to the road conditions. In an unlighted area where nighttime crashes are common, it is also helpful to check the visibility of the pavement markings at night and improve any markings that are not well visible in the dark.

3.9 Modify Intersection Signing

Signs near the a rural, unsignalized intersections are intended to alert drivers to the upcoming intersection and instruct drivers as to how they can safely proceed through the intersection [10]. Improving the signage at an intersection or adding additional signs is often used as a first step to decrease the crash rate at an intersection because it is inexpensive and requires minimal time. The MUTCD is the nationally accepted standard for sign design, sizing, and location [10]. Some states choose to adopt their own variation of the MUTCD, but they must be in compliance with the national standards. All pictures and standards referenced in this section are from the national MUTCD. Standard STOP signs are typically 30"x30" on single lane roads and 36"x36" on multiple lane roads. In locations where drivers are frequently not complying with the STOP sign, STOP signs at the intersection can be replaced with 48"x48" oversized STOP signs to attract greater attention to the signs [10]. Other signs can also be used to draw attention to an upcoming intersection such as the STOP AHEAD (W3-1) and YIELD AHEAD (W3-2) can be used on intersection approaches that are STOP or YIELD controlled. See examples of the STOP AHEAD (W3-1) and YIELD AHEAD (W3-2) signs in Figure 3.8 below.

Figure 3.8: STOP AHEAD (W3-1) and YIELD AHEAD (W3-2) signs [10]

On the major road approaches of two-way STOP controlled intersections, other signs can be used to alert drivers of the upcoming cross traffic. These signs give drivers the chance to slow down prior to the intersection and watch for vehicles trying to cross the intersection or drivers who disregard the minor road STOP sign. Some examples of signs that can be used on the major road approaches at two-way STOP controlled intersections are intersection warning signs such as the W2-1, W2-2, W2-3, and W2-4 shown in Figure 3.9 below. Intersection warning signs are typically 30”x30” or 48”x48” when installed as an oversized sign [10].

Figure 3.9: Intersection warning signs [10]

Signs can also be used to instruct drivers how to proceed through the intersection once they have already stopped at the STOP sign. These signs can be helpful in locations where drivers frequently report expectations of cross traffic stopping when it does not. See Figure 3.10 for examples of the W4-4P, W4-4aP, and W4-4bP sign plaques that can be used to alert drivers at an intersection to uncommon or unexpected traffic flow patterns. These sign plaques are typically installed below the STOP sign and range in size from 24”x12” at one lane road locations to 48”x24” when intended to be an oversized sign [10].

Figure 3.10: Driver educational plaques used at STOP controlled intersections [10]

Drivers at rural intersections are sometimes forced to contend with obstacles that drivers in urban areas are not such as animals in the roadway or farm machinery on the road. These obstacles can be distractions for drivers or come up unexpectedly, so the MUTCD includes signs than can be used near intersections that frequently have a problem with these types of hazards such as the W11-3 deer warning sign and the W11-5 and W11-5a farm machinery advisory signs as shown in Figure 3.11.

Figure 3.11: Rural driving hazards warning signs [10]

3.10 Dedicated Left and Right Turn Lanes

Separating turning traffic from the through traffic using dedicated turning lanes can reduce conflicts at rural unsignalized intersections. There are multiple different types of lane configurations that can be used to reduce the crash rate in areas where turning traffic makes up a large percentage of the volume or rear end collisions are a problem [11]. Budget and right-of-way acquisition are the main constraints on building dedicated right and left turning lanes at intersections. Utility poles that are frequently placed along the road can conflict with the design of left or right turn lanes in cases where it is necessary to expand the pavement cross section beyond its original dimensions. This problem can lead to the countermeasure becoming infeasible for the location or increasing the cost of the project.

The first way dedicated turning lanes can be used at a rural, unsignalized intersection is to provide a left turn lane on the major road approach. In cases where the intersection has minor road stop control, this would allow left turning vehicles to move into the dedicated turning lane and out of the flow of the rest of the traffic, thereby removing the possibility of following traffic to collide with the stopped vehicle if the driver of a following vehicle does not see the vehicle that is stopped and waiting to make a left turn. This countermeasure could also be beneficial in locations where making a left turn frequently results in delay prior to making the turn due to heavy traffic travelling in the opposite direction [11]. Table 3.6 below shows the effects of adding a left turn lane to a major road approach at minor road stop controlled unsignalized intersections.

Table 3.6: CMFs for adding a left turn lane on the major road approach

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Standard Error
Provide a left-turn lane on one major-road approach	Rural (Minor-road, stop-controlled three-leg intersections)	Major road 1,600 to 32,400 Minor road 50 to 11,800	All types (All severities)	0.56	0.07
			All types (Injury)	0.45	0.1
	Rural (Four-leg, minor-road stop controlled intersection)		All types (All severities)	0.72	0.03
			All types (Injury)	0.65	0.04
Provide a left-turn lane on both major-road approaches	Rural (Four-leg, minor road stop controlled intersection)	Major road 1,500 to 32,400 Minor road 50 to 11,800	All types (All severities)	0.52	0.04
			All types (Injury)	0.42	0.04

Another type of left turn lanes that can be provided at rural unsignalized intersections are channelized left turn lanes. A channelized lane is a traffic movement that is separated into a definite travel path away from the rest of the traffic. A physical barrier such as a median or painted pavement markings are used to separate the traffic. Channelized left turn lanes can be used on both major and minor road approaches, but are found to be more effective when used on the major road approach as shown in Table 3.7 below.

Table 3.7: CMFs for providing a channelized left-turn lane

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Standard Error
Provide a channelized left-turn lane on both major and minor road approaches	Rural (three-leg intersection two lane roads)	5,000 to 15,000	All types (Injury)	0.73	0.2
Provide a channelized left-turn lane on major-road approach and minor-road approach			All types (Injury)	1.16	0.2
Provide a channelized left-turn lane on both major and minor road approaches	Rural (four-leg intersection two lane road)		All types (Injury)	0.73	0.1
Provide a channelized left-turn lane on both minor road approaches			All types (Injury)	0.96	0.2

Right turn lanes can also be added to rural unsignalized intersections to remove some of the turning traffic from the rest of the traffic. Right turn lanes on the major road approach can reduce crashes by allowing right turning vehicles to move out of the way of the flow of traffic at intersections where there is a significant volume of right turning traffic and problem with rear-end crashes at the intersection have been reported. Table 3.8 below shows how the Highway Safety Manual predicts adding right turns to an intersection will impact the crash rate at the intersection.

Table 3.8: CMFs for providing a right turn lane at an intersection

Treatment	Setting (Intersection Type)	Traffic Volume AADT (veh/day)	Crash Type (Severity)	CMF	Standard Error
Provide a right turn lane on one major road approach	Rural and urban (three or four leg minor road stop controlled intersection	Major road 1,500 to 40,600 Minor road 25 to 26,000	All types (All severities)	0.86	0.06
			All types (Injury)	0.77	0.08
Provide a right turn lane on both major road approaches	Rural and urban (Minor road stop controlled intersection	Major road 1,500 to 40,600 Minor road 25 to 26,000	All types (All severities)	0.74	0.88

3.11 Shoulder Bypass Lanes

Shoulder bypass lanes are an added area of pavement along the outside of a lane of traffic on an approach that is not STOP controlled at an intersection. They are commonly used in rural areas. Shoulder bypass lanes are ideal in locations where frequent rear end collisions occur on the major road due to traffic that is unable to stop before striking another vehicle that is already stopped at the intersection and waiting to make a left turn. One reason why following vehicles would be unable to stop at the intersection could be reduced sight distance of the upcoming intersection due to horizontal or vertical curvature of the roadway. Locations where the speed limit is high could also be a good place for shoulder bypass lanes because following traffic must slow down a significant amount of time prior to reaching the stopped vehicle in the roadway. If the following driver is not paying attention, a severe crash could result when the inattentive following driver collides with the driver stopped at the intersection. Instead of forcing drivers to come to a complete stop at an intersection where the traffic is designed to flow freely, shoulder bypass lanes give drivers the ability to travel around the stopped vehicle. This is especially beneficial in locations where sight distance is compromised and speed is high. Shoulder bypass lanes would also reduce delay at the intersection because following drivers would not be forced to wait for the left turning traffic to exit the roadway before continuing through the intersection.

Shoulder bypass lanes are designed to provide the same outcome as dedicated left turn lanes in that the left turning traffic is separated from the thru traffic volume. In the case of shoulder bypass lanes, the thru traffic must move around a stopped vehicle to continue past the intersection where in the case of left turn lanes, the left turning vehicles separate themselves from the thru traffic volume. In situations where the left turning vehicle traffic is very large, left turn lanes could be a superior option to shoulder bypass lanes.

3.12 Intersection Realignment

Intersections where the roads do not meet at a ninety degree angle typically have a greater crash rate than intersections where the roads are ninety degrees apart[2]. This deviation from ninety degrees is referred to as the skew angle. In such cases, drivers need to turn their vehicles more than ninety degrees in order to move to the other road. Since most intersections are right angle intersections, this type of maneuver is contrary to driver expectations. As a result, drivers may underestimate the extra time needed to turn their vehicle the extra amount and select a gap in the traffic that is insufficient for the movement. Contrarily, drivers who are making a turn from the direction where the roads intersection at less than a ninety degree angle, drivers may recognize that the angle is smaller than usual and make the turn too quickly and result in the driver leaving the roadway. This is especially true in locations where the turning maneuver is not stop controlled. A skewed intersection often has reduced sight distance as compared to right angle intersections, and these intersections require drivers to turn their head more to see the conflicting traffic. This movement can be difficult for elderly drivers and make skewed intersections even more dangerous. The Highway Safety Manual has determined that the relationship between the increase in crash rate and the increase in skew angle at an intersection follows the trend lines shown in Figure 3.12 below. The skew angle is measured as the absolute value of the difference between ninety degrees and the actual intersection angle.

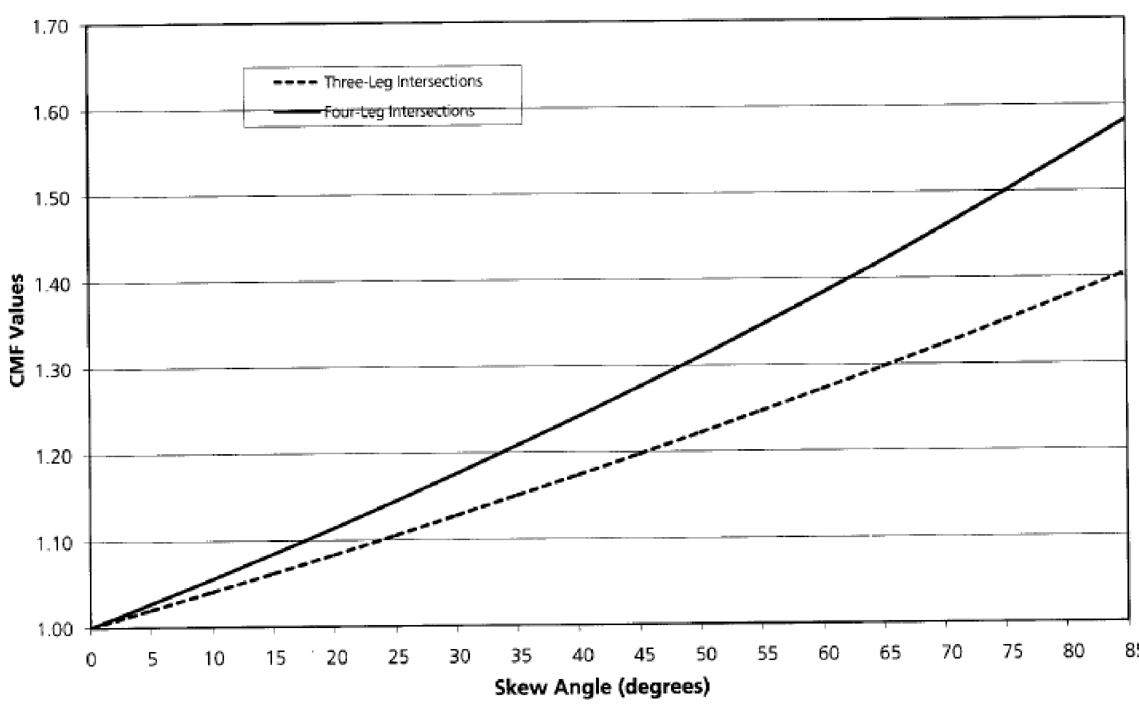

Figure 3.12: Potential crash effects of skew angle for intersections with minor-road STOP control on rural, two lane highways [2]

In order to calculate the exact value of the CMF, the following equation can be used for rural three-leg intersections with minor road stop control [2], [11]:

$$CMF = e^{(0.0040 * skew)}$$

For rural four-leg intersections with minor road stop control, the following equation can be used to calculate the value of the CMF [2], [11]:

$$CMF = e^{(0.0054 * skew)}$$

In order to determine the crash reduction if the intersection were reconfigured to remove the skew angle, find the CMF for the amount of skew angle that is to be removed by the reconfiguration and take the inverse of that value.

3.13 Intersection Illumination

Providing intersection illumination can reduce crashes in an area where the roadway is not well lit and night crashes are frequent. Whenever possible, it is typically best to use existing utility poles to provide lighting at an intersection. A Minnesota study [15] on rural intersection lighting encourages considering nighttime lighting at an intersection that experiences more than three night crashes per year. If utility poles are not already in the area, installing intersection lighting can be a costly improvement. A simple design for lighting an intersection that involves installing lighting at the four corners of the intersection can be used in lower crash rate or lower severity of crash intersections [16]. However, if the area continues to have a persistent crash problem, a complex lighting design which also illuminates the approaches to the intersection can be installed for a greater cost. The Highway Safety Manual suggests that adding lighting to an intersection will reduce crashes as shown in Table 3.9.

Table 3.9: CMFs for providing intersection illumination

Treatment	Setting (Intersection Type)	Crash Type (Severity)	CMF	Standard Error
Provide intersection illumination	All settings (All types)	All types-Nighttime (Injury)	0.62	0.1
		Pedestrian-Nighttime (Injury)	0.58	0.2

Aside from providing lighting at an intersection there a multiple other less invasive tactics that can be used to reduce night crashes at rural, unsignalized intersections. One of the first options to consider at an intersection with a high proportion of night crashes is to check the retroreflectivity, or nighttime visibility of the signs, at the intersections [17]. If the signs have too low retroreflectivity, it may result in drivers running the stop sign because they are unable to see the stop sign or advanced warning signs for the intersection with enough time to stop before reaching the intersection. Adding reflective strips on posts near the intersection can also be used to reduce run off road crashes at night. Other countermeasures such as increasing the size of the stop sign, adding intersection warning signs, and installing flashing beacons are frequently used to address nighttime crashes.

3.14 Skid Test for Pavement Quality

A skid resistance tester can be used to measure the quality of the pavement at the intersection. Poor pavement quality can result in drivers running the STOP sign if they are unable to stop in time due to the friction of the pavement. If there are a lot of crashes that occur when the roads are wet, poor pavement quality could compound this problem.

If it is determined that the pavement quality is below standard, the intersection can be repaved with standard paving or micro surfacing can be used to improve the pavement quality. Pavement deteriorates over time and loses some of its friction, so repaving the intersection would restore the pavement to its original condition. Micro surfacing is a polymer-modified cold mix paving system that can be applied to existing pavements to increase the pavement quality [18]. Since micro surfacing is more resistant to damage, it has a lower maintenance cost than traditional pavement. Other types of high friction pavements can be used to increase pavement friction and reduce wet road crashes and increase STOP sign compliance.

3.15 Summary of Chapter 3

Chapter 3 describes fourteen countermeasures that are commonly used for improving safety at rural, unsignalized intersections. These countermeasures include intersection lane narrowing, conversion to all-way STOP control, sight distance improvements, installing flashing beacons, signalization, roundabout conversion, advanced warning rumble strips, advanced warning pavement markings, intersection signing modification, dedicated left and right turn lanes, shoulder bypass lanes, intersection realignment, intersection illumination, and skid test for pavement quality. Intersection lane narrowing is designed to slow traffic speeds on the free approaches to an intersection and draw attention to the intersection. Flashing beacons are also intended to increase intersection awareness. Although flashing beacons have been shown to demonstrate mixed effectiveness, they have seen some success in rural applications. Signalization can be beneficial at a high volume intersection, but the requirements in the MUTCD must be met in order to warrant a traffic signal. Roundabout conversion is becoming a popular option in rural locations for intersections that have a significant problem with angle crashes. Advanced warning rumble strips are used to warn drivers of the upcoming intersection, but can be disruptive to residents when located near residential areas. Advanced warning pavement markings are also used to warn drivers of an upcoming intersection. Modifying intersection signing can be done on both free and STOP controlled approaches to an intersection to warn drivers of the conditions at the upcoming intersection. Dedicated right and left turn lanes are used to separate turning traffic from the thru traffic at an intersection. Shoulder bypass lanes are intended to provide room for vehicles to travel around a left turning vehicle at the intersection. If the left turning traffic at an intersection is very large, a left turn lane would typically be preferable to a shoulder bypass lane. Intersection realignment involves a reconstruction of the intersection to improve the geometric design. Realignment can be completed to give drivers more advanced visibility of the intersection or to remove a skew angle from an intersection. Intersection illumination is used to prevent night crashes at an intersection. Before proceeding to considering illumination, it is beneficial to check the nighttime visibility of the signs and pavement markings at the intersection because upgrading signs and pavement markings is a much less expensive improvement than adding illumination, but it can still be very effective at preventing night crashes. A skid test for pavement quality is used to measure the pavement friction at an intersection. This test can be useful if there are significant percentage of crashes that occur when the roads are wet or run off the road crashes are common. All of the countermeasures detailed in Chapter 3 can be beneficial at rural, unsignalized intersections, but it is important to make sure the correct countermeasure is matched to the specific problems at a given intersection.

Chapter 4

CREATION OF THE KNOWLEDGE BASED EXPERT SYSTEM VARIABLES

The program used to design the expert system in this thesis is CORVID, which is developed by Exsys® Inc. Exsys® Inc. was founded in 1983, and it has become one of the longest-lived knowledge automated expert systems development software in the United States [19]. Throughout its thirty years of existence, Exsys® Inc. was often at the forefront of the expert systems industry in incorporating new technology to make their systems more usable and available for widespread distribution. Exsys® systems such as CORVID are intended to use a pragmatic rule pattern for creating logic rules such that experts who are not well versed in computer programming languages are able to create expert systems. However, the systems created using the Exsys® software are also able to model complex, real world problems.

CORVID uses a rule-based approach to logic as opposed to an object-oriented approach because the rule-based approach allows the system to be designed using "IF…THEN…" logic which mimics the way people make decisions in real life [19]. The class hierarchy that results from the object-oriented approach is considered a less accurate way to model the human decision making process. CORVID does incorporate object-structured components when designing the software by using Microsoft's Visual Basic programming language, but the developer of the expert system still has the benefit of designing the expert system using the rule-based logic approach [19].

Variables are the smallest building blocks of an expert system using CORVID. There are seven types of variables that can be used in CORVID depending on the type of question posed by the system and the best way for the user to respond to the question. The seven types of variables are static list, dynamic list, numeric value, string value, data value, collection/ report, and confidence. The static list, dynamic list, numeric value, string value, and data value variables are used to build “IF” expressions [19]. The collection/ report and confidence variables are used to build “THEN” expressions [19].

Static list variables present a set list of selections from which users can choose [19]. The list can include just two choices such as “Yes” or “No” or many choices depending on the question. This type of variable is the most simple type and was used frequently in the creation of the KBES for determining intersection countermeasures. Dynamic list variables also appear to the user as a list of selections. However, instead of the list being the same every time the variable is used, the list is programmed to change depending upon the earlier user inputs. This type of variable can be complex to program and was not used in the creation of the Expert System for determining intersection countermeasures. Numeric variables ask the user to input a numerical response to the prompted question. The advantage of numeric variables is that the input in these variables can later be used in mathematical expressions. Numeric variables were commonly used in the creation of the KBES for determining intersection countermeasures. In string variables, the user must enter a text string as a response to a prompt. This type of variable was not used in the creation of the KBES for determining intersection countermeasures. Date variables are able to accept a user input of a date. The problem solving process for determining intersection countermeasures does not require the input of a date, so date variables were not used in the creation of the KBES.

Collection/ report variables give a response that is a list of strings [19]. This type of variable is often used to create reports or give free form advice to the user. This type of variable was not used in the creation of the KBES because the user is not intended to generate a report of the output given by the system. “THEN” statements to display the results to the user were created using confidence variables. Confidence variables give a confidence rating or certainty score to each outcome for the user to see [19]. The confidence score can help the user determine how to use the information given by the KBES.

Logic blocks are used to organize the variables into a string of “IF…THEN” logic statements. Multiple variables can be linked together to create an “IF…AND” structured chain before reaching a “THEN” variable [19]. The variables must first be created before they can be added to the logic chain in the logic block. The responses to a static list variable can be selected when the variable is added to the logic block. A mathematical logic expression must be created when a numeric variable is added to the logic chain. Each string of “IF…AND” sequences must be completed with a “THEN” variable such as a collection/ report variable or confidence variable before the system will run.

The command block is used to program how the results will be displayed to the user [19]. One of the most common and simple type of command blocks tells the system to calculate the confidence as set by the confidence variables or through mathematical expressions created in a logic block then to display the results. The format in which the results are displayed can be edited in the command block using a user friendly interface to select the desired output structure. This derive confidence and display results structure was used in the creation of the KBES for determining intersection countermeasures.

Static list, numeric, and confidence variables were used in the creation of the KBES for intersection countermeasure selection. All of the variables used for "IF" and "IF…AND" parts of the logic chains were created using static list variables and numeric variables. Dynamic list variables, string variables, and data variable were not used in the creation of the KBES for selecting intersection countermeasures.

4.1 Static List Variables

In the creation of the KBES to determine intersection countermeasures, many static list variables were created. This section describes the static list variables developed for the creation of the KBES to determine appropriate intersection safety countermeasures.

The variable "advanced_warning" asks the user "Have all of the following intersection warning measures been installed at this intersection to prevent crashes: Intersection warning signs, advanced warning rumble strips, and advanced warning pavement markings?" The user can select the options "Yes" or "No" to respond to this prompt.

The variable "angle_type" asks the user "Are the angle crashes at this intersection primarily due to drivers failing to stop at the STOP sign or due to drivers entering the intersection when there is not a large enough gap in cross or opposing traffic?" The choices from which the user can select are "Driver fail to stop at STOP sign" and "Driver accept too small of a gap."

The variable "all-way_stop_control" asks the user "Is the intersection all-way STOP controlled?" The user must select either "Yes" or "No" for this variable.

The variable “flashing_beacons” asks the user “Are flashing beacons present at this intersection?” The options available from which the user can select to answer the question are “Yes” and “No.”

The variable “intersection_warning_free” asks the user “Are there intersection advanced warning signs or pavement markings on the free approach to alert drivers that there may be a stopped vehicle ahead?” The user must respond with either “Yes” or “No” to this prompt.

The variable “left_turn” asks the user “Is there a significant amount of left turning traffic from one or both of the free approaches?” The choices for user response are “Yes” and “No.”

The variable “lighting” asks the user “Is the intersection lighted at night?” The user must select either “Yes” or “No” for this prompt. This variable is only asked if the user has already indicated that a large percentage of crashes occur at this intersection during the night. Therefore, before asking this question, the system encourages the user to check the nighttime visibility of signs and pavement markings prior to considering other countermeasures.

The variable “most_common_crash_type” asks the user “What is the most common type of crash?” The choices for the user to select are “Angle,” “Rear end collision on the STOP controlled approach,” “Rear end collision on the free approach,” “Run off the road,” and “Sideswipe.”

The variable “most_common_crash_type_AWSC” asks the user “What is the most common type of crash?” This variable asks the same question as the previous variable, but it is intended for different applications. The acronym “AWSC” stands for all-way STOP control. This variable is used when the user has previously indicated that the intersection is all-way STOP controlled. Therefore, the option "Rear end collision on the free approach" is not included in this variable since that type of crash is impossible at an all-way STOP controlled intersection. The remaining options for the variable, "most_common_crash_type" are "Angle" and "Rear end collision."

The variable "speed" asks the user "After reviewing speed studies or observing traffic, does the traffic on the uncontrolled approaches appear to be typically travelling 10 or more miles per hour above the posted speed limit?" The user must then select either "Yes" or "No" at this prompt.

Many other static list variables were created to display the countermeasure options selected to users after the necessary information is gathered about the intersection characteristics. A separate static list variable was created for each pattern of responses possible to be generated by the user inputs. All the possible countermeasure options are convert to all-way STOP control, install flashing beacons, add intersection illumination, lane narrowing, add a left turn lane, advanced warning pavement markings, advanced warning rumble strips, intersection realignment, conversion to roundabout, shoulder bypass lanes, increase sight distance, signalization, and perform a skid test for pavement quality. The way these countermeasures were mapped to the response the user enters is discussed in Chapter 5.

4.2 Numeric Variables

Numeric variables were also used in the creation of the KBES for determining intersection countermeasures. Four numeric variables were created. The following section details the numeric variables used in the KBES. When numeric variables are used in the system, users are able to freely type in a number into the space provided in response to the question.

The variable “confidence” asks the user “How many of the previous questions were you unsure of your response?” The user can enter a numerical integer value to respond to this prompt.

When the variable “night_crashes” is displayed, the user is prompted “What percentage of crashes were caused by drivers over the age of 60? (Enter value as an integer between 0 and 100).” The user may then enter the value that is correct for their specific intersection in the space provided.

The variable “sight_distance” prompts the user: “Select an integer value to describe the sight distance at the STOP controlled approach on a scale of 1 to 5 with 1 being very limited and 5 being not at all limited.” The variable for sight distance is best represented as a numeric variable to allow users to describe the sight distance at the intersection over a continuum. While assessing sight distance in this manner can be subjective, it is preferable that the sight distance be a numeric variable so the response can be incorporated to a mathematical equation.

The final numeric variable is called “weather.” When “weather” is displayed, the user is asked “What percentage of crashes occurred when the roads were wet? (Enter value as an integer between 0 and 100).” The user must enter the corresponding value for their intersection.

4.3 Confidence Variables

Confidence variables were used to generate the “THEN” statements to end the logic chains of “IF…AND” statements that were created using static list variables and numeric variables. The confidence variables display a final message to the user as well as a numerical confidence value for the recommendation. The highest confidence factor given by the system is 0.85, which represents 85% confidence. The confidence of the system is estimated to be 85% because there are some intersection characteristics that were not able to be included in the system and each intersection is a unique situation. The numeric variable, "confidence" asks the users to input the number of questions for which the user was unsure of the response. This information is used to decrease the confidence value of the recommendation. For each question the user indicates that he or she was unsure of the response, the confidence value of the recommendation is decreased by five percent. The formula "0.85-[confidence]*0.05" was programmed in to the system to determine the confidence value for the confidence variable.

If the user enters a negative value for the number of unsure response, the formula above would mathematically increase the confidence of the recommendation. Since this output is undesirable because it would be inaccurate, the confidence variable "Error" is displayed. The confidence value of the error message is zero because the user entered an invalid response. The message associated with this confidence variable is "Invalid response. Please enter a value zero or greater for the previous question." Aside from the error message, all of the other variables are the countermeasure recommendations. The message for these variables are described below.

The variable named "awsc_cm" recommends that the intersection be converted to an all-way STOP controlled intersection. The message for this recommendation is "The Highway Safety Manual provides a crash modification factor (CMF) of 0.52 with a standard error of 0.04 for all types and all severities of crashes when converting a two-way STOP controlled intersection to an all-way STOP controlled intersection if the MUTCD warrants are met. To use these values, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure. 95% of cases are expected to fall within two standard deviations of this average value."

The variable named "flashing_beacons_cm" recommends that flashing beacons be added to the intersection. The message for this variable is "The Highway Safety Manual provides a crash modification factor (CMF) of 0.84 with a standard error of 0.06 for installing flashing beacons at rural, STOP controlled intersections. To use these values, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure. 95% of cases are expected to fall within two standard deviations of this average value."

The variable "intersection_illumination_cm" recommends that lighting be added to the intersection to improve visibility during the night at the intersection. The message for this variable is "The Highway Safety Manual provides crash modification factors for adding intersection illumination to an intersection with a high rate of night crashes. The CMF for nighttime injury crashes is 0.62 with a standard error of 0.1. To use these values, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure. 95% of cases are expected to fall within two standard deviations of this average value."

The variable "improve_signing_cm" recommends that increasing the number of signs or size of the signs warning drivers of the upcoming intersection and how to proceed at the intersection could reduce crashes. The message for this variable is "The

Highway Safety Manual does not provide a crash modification factor (CMF) for improving intersection signing. Ways that intersection signing can be improved include adding additional intersection warning signing and increasing the size of the signs already at the intersection. These improvements are beneficial to increase intersection awareness and help elderly drivers navigating the intersection."

The variable "lane_narrowing_cm" recommends restriping the pavement near the intersection to narrow the lanes to nine or ten foot wide lanes with centerline rumble strips and a painted median to create the illusion to drivers that the road narrows near the intersection. This is intended to reduce vehicle travel speed on the major road and draw attention to the intersection. The message for this variable is "Studies estimate that this treatment could reduce total crashes by 30% and injury crashes by 20%." The Highway Safety Manual has not yet developed a crash modification factor for this treatment. More information about the data behind this recommendation and the study of its effectiveness can be found in Chapter 3.

The variable "left_turn_lane_cm" recommends that a left turn lane be added to one or two of the free approaches to a two-way STOP controlled intersection. The message for this variable is "The Highway Safety Manual provides crash modification factors (CMFs) for adding left turn lanes to an intersection. When a left turn lane is added to one approach to a four leg intersection, the CMF for all types and all severities of crashes is 0.72 with a standard error of 0.03. For all types of injury crashes, the CMF is 0.65 with a standard error of 0.04. When left turn lanes are added to both major road approaches of a four leg intersection, the CMF for all types and all severities of crashes is 0.52 with a standard error of 0.04. For all types of injury crashes, the CMF is 0.42 with a standard error of 0.04."

The variable "pavement_marking_cm" recommends that pavement markings be used to alert drivers of the upcoming intersection. The message for this variable is "The Highway Safety Manual provides crash modification factors (CMFs) for adding advanced warning pavement markings on the approaches to rural, unsignalized intersections. For all types and all severities of crashes, the CMF is 0.87 with a standard error of 0.04. For all types of injury crashes, the CMF is 0.92 with a standard error of 0.3. To use these values, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure. 95% of cases are expected to fall within two standard deviations of this average value." This variable is only used for two-way STOP controlled intersections because the Highway Safety Manual has developed separate CMF values for two-way STOP controlled intersections and all-way STOP controlled intersection.

The variable "pavement_markings_awsc_cm" recommends that advanced warning pavement markings be added to the approaches to the intersection to alert drivers of the upcoming STOP sign and intersection. This variable is specific to all-way STOP controlled intersection and is different from the variable "pavement_markings_cm" above. The message for this variable is "The Highway Safety Manual provides crash modification factors (CMFs) for adding advanced warning pavement markings to a rural, all-way STOP controlled intersection. The CMF for all types and all severities of crashes is 0.44 with a standard error is 0.2. The CMF for all types of injury crashes is 0.58 with a standard error of 0.3. To use these values, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure. 95% of cases are expected to fall within two standard deviations of this average value."

The variable "realign_1_cm" recommends that the intersection be realigned so drivers have more visibility of the upcoming intersection as they approach it. This type of treatment involves a complete reconstruction of the intersection and is only suggested when all other countermeasures have been unsuccessful. The message for this variable is "Realigning the intersection to improve the visibility of the upcoming intersection could be beneficial at this intersection because the crash rate did not drop as a result of adding conventional intersection awareness measures or flashing beacons. The Highway Safety Manual does not provide a crash modification factor for this treatment because it is very case specific." As stated in the variable message displayed, the Highway Safety Manual has not yet developed a CMF for this treatment, so no value for predicting the crash rate after the treatment is completed is offered to users.

The variable "realign_2_cm" recommends that the intersection be realigned; however, the goals of this realignment are different than in the variable "realign_1_cm" above. This variable is used to recommend that the realignment be completed to remove a skew angle at the intersection and reconstruct the intersection so the roads cross at approximately a ninety degree angle. The message for this variable is "Realigning the intersection to reduce the skew angle can improve the safety of an intersection. The Highway Safety Manual estimates the crash modification factor (CMF) for reducing the skew angle to be equal to 1/(e^0.0054*skew) where "skew" refers to the skew angle in degrees. To use this value, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure."

The variable "roundabout_cm" recommends that the intersection be converted to a roundabout. This variable is specific to the case of converting a two-way STOP controlled intersection into a one lane, rural roundabout because the Highway Safety Manual has developed numerous CMFs for different situations in which an intersection is converted to a roundabout. The message for this variable is "The Highway Safety Manual provides crash modification factors (CMFs) for converting a two-way STOP controlled intersection to a rural, one lane roundabout. For all types and all severities of crashes, the CMF is 0.29 with a standard error of 0.04. For all types of injury crashes, the CMF is 0.13 with a standard error of 0.02. To use these values, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure. 95% of cases are expected to fall within two standard deviations of this average value."

The variable "roundabout_awsc_cm" recommends the intersection be converted to a roundabout. This variable is different from the variable "roundabout_cm" above because it is specific to the case of an all-way STOP controlled intersection being converted into a one or two lane roundabout. While this CMF is not specific to rural locations, it was selected for this variable because it is specific to the beginning condition of an all-way STOP controlled intersection. In rural locations, there is typically not enough traffic volume to warrant a two-lane roundabout, so that is another shortcoming of this CMF application. However, there is currently no CMF developed by the Highway Safety Manual for the case of converting a rural, all-way STOP controlled intersection into a one-lane roundabout. The message for this variable is “The Highway Safety Manual provides a crash modification factor (CMF) for converting an all-way STOP controlled intersection to a one or two lane roundabout. This CMF is this type of roundabout conversion for all types and severities of crashes is 1.03 with a standard error of 0.2. To use these values, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure. 95% of cases are expected to fall within two standard deviations of this average value.”

The variable “rumble_strips_cm” recommends that advanced warning rumble strips be installed on STOP controlled approaches to the intersection to warn drivers of the upcoming intersection. The message for this variable “The Highway Safety Manual currently does not provide a crash modification factor for adding advanced warning rumble strips to a rural, unsignalized intersection. However, this countermeasure can still be effective at warning drivers of the upcoming intersection. Use caution when considering advanced warning rumble strips near a residential area because residents may be annoyed by the noise generated by vehicles traveling over the rumble strips.”

The variable “shoulder_bypass_lanes_cm” recommends that shoulder bypass lanes be installed to prevent rear end collisions and sideswipe collisions of the free approaches of two-way STOP controlled intersections. The message for this variable is “The Highway Safety Manual does not currently provide a crash modification factor (CMF) for shoulder bypass lanes. This countermeasure can be beneficial when sideswipe crashes are common resulting from drivers being unable to safely maneuver around a stopped vehicle waiting to turn left at an intersection or when rear end collisions on a major road approach are common.”

The variable “sight_distance_cm” recommends that obstructions to sight distance from STOP controlled approaches to two-way STOP controlled intersection be removed to improve visibility. The Highway Safety Manual has not yet developed a CMF for this treatment, so no specific value is given to users to estimate the future crash rate after the treatment. The message for this variable is” The Highway Safety Manual currently has not developed a crash modification factor for increasing sight distance at an intersection. However, increasing the sight distance is often a simple and effective way to improve safety at a rural unsignalized intersection.”

The variable “signalization_cm” recommends converting the intersection to a signalized intersection. The message for this variable is “The Highway Safety Manual provides crash modification factors (CMFs) for adding signalization to a rural unsignalized intersection if the MUTCD warrants are met. For all types of crashes, the CMF is 0.56 with a standard error of 0.03. For right angle crashes, the CMF is 0.23 with a standard error of 0.02. For left turn crashes, the CMF is 0.40 with a standard error of 0.06. For rear end crashes, the CMF is 1.58 with a standard error of 0.2. To use these values, multiply the average number of crashes experienced at this intersection per year by the CMF value to determine the average number of crashes that could occur per year after implementing the countermeasure. 95% of cases are expected to fall within two standard deviations of this average value.”

The variable “skid_test_cm” recommends that a skid test for pavement quality be performed to determine if there is sufficient friction in the pavement at the intersection. If the pavement quality is poor, the intersection can be resurfaced to improve the pavement friction and help drivers navigate the intersection more safely. The message for this variable is "The Highway Safety Manual does not currently provide a crash modification factor (CMF) for performing a skid test for pavement quality. The purpose of a skid test for pavement quality is to determine if there is a sufficient amount of friction in the pavement at an intersection. If the pavement is too slippery, drivers may be unable to stop abruptly at the stop sign or frequently collide with a stopped vehicle at the intersection. These types of crashes become even more likely when the roads are wet."

4.4 Summary of Chapter 4

Variables are the building blocks of a KBES in CORVID. Chapter 4 explains the variables that were created for the development of the KBES for intersection countermeasure selection. The three types of variables that were used in the system are static list variables, numeric variables, and confidence variables. Static list variables are linked together to form "IF…AND" statements, and confidence variables are used to complete a chain of "IF…AND" statement with a "THEN" statement. Static list variables pose a question to the user, and the user must select one of the predetermined responses to answer the question. Numeric variables allow the user to enter a numeric value to answer the question. Confidence variable suggest to the user what types of countermeasures could be best for the user's intersection given the data provided to the system. Table 4.1 provides a summary of the variables created in the KBES for intersection countermeasure identification.

Table 4.1: Summary of variables in KBES for countermeasure identification

Static List Variables	Numeric Variables	Confidence Variables
• advanced_ warning • angle_type • all-way_stop_ control • flashing_ beacons • intersection_ warning_free • left_turn • lighting • most_common _crash_type • most_common _crash_type_ AWSC • speed • Other variables for counter-measure options	• Confidence • night_crashes • sight_distance • weather	• awsc_cm • flashing_beacons_ cm • intersection_ illumination_cm • improve_signing_ cm • lane_narrowing_cm • left_turn_lane_cm • pavement_markings _cm • pavement_markings _awsc_cm • realign_1_cm • realign_1_cm • roundabout_cm • roundabout_awsc_ cm • rumble_strips_cm • shoulder_bypass_ lanes_cm • sight_distance_cm • signalization_cm • skid_test_cm

The variables described in Chapter 4 and summarized in Table 4.1 were mapped into the KBES for countermeasure identification as explained in Chapter 5.

Chapter 5

CREATION OF THE KNOWLEDGE BASED EXPERT SYSTEM LOGIC

Logic blocks in CORVID are created through connecting variables in a meaningful order to end in system outputs that are useful to the user of the system. The first variable the user encounters in the KBES for determining intersection countermeasures is “all-way_stop_control” at which point the user must indicate whether the intersection to be evaluated is all-way STOP controlled. After that, the user must select the choice that best represents the most common crash type using the variables “most_common_crash_type” or “most_common_crash_type_AWSC” depending upon the user response as to whether the intersection is all-way STOP controlled. If the user indicates that the intersection is all-way STOP controlled and the variable “most_common_crash_type_AWSC” is displayed the user must select whether the most common crash type at the intersection are angle crashes or rear end collisions at the STOP sign. If the user indicates that the intersection is not all-way STOP controlled, the variable “most_common_crash_type” is displayed and the user must select whether the most common crash type at the intersection is angle crashes, rear end collisions on a STOP controlled approach, rear end collisions on the free approach, run off the road crashes, or sideswipe crashes.

5.1 All-Way STOP Control: Angle Crashes as Most Common Crash Type

If angle crashes are the most common type of crash at an all-way STOP controlled intersection, the KBES then displays the variable “night_crashes” and asks the user what percentage of crashes occurred when it was dark outside. The responses to this prompt are divided into two different categories. If the user enters a value of thirty or greater, it is determined that night crashes are frequent at this intersection. If night crashes account for thirty or more percent of the crashes, the variable “lighting” is displayed and the user must respond whether the intersection has nighttime illumination.

Regardless of the user inputs for the night crashes and nighttime illumination questions, the user is then prompted with the variable “weather” and is then asked to enter the percentage of crashes that occurred at the intersection when the roads were wet. The responses to this question are again divided into two categories. If over thirty percent of the crashes occurred when the roads were wet, road condition is considered a primary factor in the crashes.

After the user responds to the variable “weather,” all users who have selected angle crashes at an all-way STOP controlled intersection to be most common are prompted with the variable “advanced warning” and asked to indicate whether the intersection has advanced warning signing, pavement markings, and rumble strips. If the user indicates that these countermeasures have already been employed the variable “flashing_beacons” is displayed and the user must answer whether flashing beacons are in place at this intersection.

If the user indicates in the “advanced_warning” variable prompt that the advanced warning measures were not yet tried, it is suggested to the user that improving signing, adding advanced warning pavement markings, and adding advanced warning rumble strips be considered as countermeasures. If the user indicates that the advanced warning measures were already tried, but flashing beacons were not, the suggested countermeasures include flashing beacons and roundabout conversion. If the user indicates that advanced warning measures and flashing beacons were already installed without success at this intersection, then intersection realignment, roundabout conversion, and signalization are suggested.

If the user entered a value of thirty or greater for the variable “night_crashes” indicating a high rate of night crashes and responded “No” to the “lighting” variable, intersection illumination is also added to the countermeasure suggestions. If the user entered a value of thirty of greater for the variable “weather” indicating a high rate of weather related crashes, it is recommended that a skid test for pavement quality be added as a potential countermeasure along with the other countermeasures recommended.

Based on the user responses, the appropriate countermeasures for the intersection are displayed as a static list variable. The user can select any one of the countermeasure options from the list provided. Regardless of the option selected, the user will encounter the numeric variable “confidence” and be required to rate the certainty of their previous responses. The user will then be directed to one of the end screens for the program that displays information about the countermeasure selected with the confidence value.

5.2 All-Way STOP Control: Rear End Collisions as Most Common Crash Type

If rear end collisions at the STOP sign are the most common type of crash at an all-way STOP controlled intersection, the KBES then displays the variable “night_crashes” and asks the user what percentage of crashes occurred when it was dark outside. The responses to this prompt are divided into two different categories. If the user enters a value of thirty or greater, it is determined that night crashes are frequent at this intersection. If night crashes account for thirty or more percent of the crashes, the variable “lighting” is displayed and the user must respond whether the intersection has nighttime illumination.

Regardless of the user inputs for the night crashes and nighttime illumination questions, the user is then prompted with the variable “weather” and is then asked to enter the percentage of crashes that occurred at the intersection when the roads were wet. The responses to this question are again divided into two categories. If over thirty percent of the crashes occurred when the roads were wet, road condition is considered a primary factor in the crashes.

After the user responds to the variable “weather,” all users who have selected rear end collisions at the STOP sign at an all-way STOP controlled intersection to be most common are prompted with the variable “advanced_warning” and asked to indicate whether the intersection has advanced warning signing, pavement markings, and rumble strips. After the user responds to the “advanced_warning” variable prompt, the countermeasure suggestions are displayed as a static list variable. If the user selected that all of the advanced warning options were tried without success, the countermeasures suggested include flashing beacons and intersection realignment. If the user indicates that the advanced warning measures were not yet in place, improving signing and adding advanced warning pavement markings are the countermeasures suggested.

If the user entered a value of thirty or greater for the variable “night_crashes” indicating a high rate of night crashes and responded “No” to the “lighting” variable, intersection illumination is also added to the countermeasure suggestions. If the user entered a value of thirty of greater for the variable “weather” indicating a high rate of weather related crashes, it is recommended that a skid test for pavement quality be added as a potential countermeasure along with the other countermeasures recommended.

Based on the user responses, the appropriate countermeasures for the intersection are displayed as a static list variable. The user can select any one of the countermeasure options from the list provided. Regardless of the option selected, the user will encounter the numeric variable “confidence” and be required to rate the certainty of their previous responses. The user will then be directed to one of the end screens for the program that displays information about the countermeasure selected with the confidence value.

5.3 Two-Way STOP Control: Angle Crashes as Most Common Crash Type

If angle are the most common type of crash at a two-way STOP controlled intersection, the KBES then displays the variable “night_crashes” and asks the user what percentage of crashes occurred when it was dark outside. The responses to this prompt are divided into two different categories. If the user enters a value of thirty or greater, it is determined that night crashes are frequent at this intersection. If night crashes account for thirty or more percent of the crashes, the variable “lighting” is displayed and the user must respond whether the intersection has nighttime illumination.

Regardless of the user inputs for the night crashes and nighttime illumination questions, the user is then prompted with the variable “weather” and is then asked to enter the percentage of crashes that occurred at the intersection when the roads were wet. The responses to this question are again divided into two categories. If over thirty

percent of the crashes occurred when the roads were wet, road condition is considered a primary factor in the crashes.

Angle crashes at unsignalized intersections typically are caused in one of two different ways. The first way angle crashes frequently occur is from drivers failing to stop at the STOP sign, continuing into the intersection, and striking a vehicle on the major road. The second way angle crashes frequently occur is when drivers do stop at the STOP sign, but move into the intersection when there is not a large enough gap in traffic. This could result from drivers misjudging the gap between vehicles or from drivers who are not being attentive enough to the traffic. In order to separate these two situations, the variable “angle_type” is displayed and the user is required to indicate whether crashes at the intersection result primarily from drivers failing to stop at the STOP sign or drivers accepting too small of a gap.

For users who responded that most angle crashes are caused by drivers failing to stop at the STOP sign, users are then prompted with the variable “advanced_warning” and asked if advanced warning signs, advanced warning pavement markings, and advanced warning rumbles strips have been put in place at this intersection. If the user responds that these measures have already been attempted, the variable “flashing_beacons” is displayed next and the user is asked to respond if there are flashing beacons at this intersection.

At this point, the countermeasure options recommended for the intersection are displayed. If the user responded that both the advanced warning measures and flashing beacons are already in place, the options for countermeasures are intersection realignment or conversions to all-way STOP control. If the user responded that advanced warning measures were tried unsuccessfully, but flashing beacons were not yet in place, the countermeasure options suggested are to install flashing beacons or realign the intersection.

For the prompt “angle_type,” the user could also select that crashes result from drivers accepting too small of a gap. If this option is indicated, the next variable the user would see is “speed,” and the user must select whether vehicles on the major road typically travel more than ten miles per hour above the speed limit. The possible answers to the static list variable are “Yes” or “No.” Regardless of the response selected to the question regarding the speed of vehicles on the major road, users are then asked to rate the sight distanced at the STOP controlled approaches on a one to five scale in the numeric variable “sight_distance.” If the user enters a value of four or five, the sight distance at the intersection is considered to be satisfactory. If the user enters a value of one, two, or three, the sight distance is considered to be limited and could contribute to angle crashes at the intersection.

After the user responds to the sight distance question, countermeasure options for the intersection are selected. If the user indicates that drivers frequently speed on the major road and sight distance is rated four or greater, the countermeasure options recommended are intersection lane narrowing, conversion to all-way STOP, and conversion to roundabout. If the user indicates that drivers frequently speed on the major road and the sight distance is rated lower than four, the countermeasure options recommended are intersection lane narrowing, sight distance improvements, conversion to all-way STOP control, and conversion to roundabout. If the user indicates that drivers do not frequently speed on the major road and the sight distance is rated four or greater, the countermeasure options recommended are conversion to all-way STOP and conversion to roundabout. If the user indicates that drivers do not frequently speed on the major road and the sight distance is rated below four, the countermeasure options recommended are sight distance improvements, conversion to all-way STOP control, and conversion to roundabout.

If the user entered a value of thirty or greater for the variable “night_crashes” indicating a high rate of night crashes and responded “No” to the “lighting” variable, intersection illumination is also added to the countermeasure suggestions. If the user entered a value of thirty of greater for the variable “weather” indicating a high rate of weather related crashes, it is recommended that a skid test for pavement quality be added as a potential countermeasure along with the other countermeasures recommended.

Based on the user responses, the appropriate countermeasures for the intersection are displayed as a static list variable. The user can select any one of the countermeasure options from the list provided. Regardless of the option selected, the user will encounter the numeric variable “confidence” and be required to rate the certainty of their previous responses. The user will then be directed to one of the end screens for the program that displays information about the countermeasure selected with the confidence value.

5.4 Two-Way STOP Control: Rear End Collisions at a STOP Controlled Approach as Most Common Crash Type

If rear end collisions at a STOP controlled approach are the most common type of crash at a two-way STOP controlled intersection, the KBES then displays the variable “night_crashes” and asks the user what percentage of crashes occurred when it was dark outside. The responses to this prompt are divided into two different categories. If the user enters a value of thirty or greater, it is determined that night crashes are frequent at this intersection. If night crashes account for thirty or more percent of the crashes, the variable “lighting” is displayed and the user must respond whether the intersection has nighttime illumination.

Regardless of the user inputs for the night crashes and nighttime illumination questions, the user is then prompted with the variable “weather” and is then asked to enter the percentage of crashes that occurred at the intersection when the roads were wet. The responses to this question are again divided into two categories. If over thirty percent of the crashes occurred when the roads were wet, road condition is considered a primary factor in the crashes.

The next variable displayed for all users who selected rear end collisions at the STOP controlled approach is “advanced_warning.” The user must indicate whether there are already advanced warning signs, advanced warning pavement markings, and advanced warning rumble strips at this location. If the user responds that the advanced warning measures are already in place at the intersection, the countermeasure recommendations that follow include installing flashing beacons and realigning the intersection to increase visibility as the driver approaches the intersection. If the user indicates that intersection advanced warning measures are not yet in place at this intersection, it is recommended that signing improves, advanced warning pavement markings, and advanced warning rumble strips be considered as potential countermeasures in this location.

If the user entered a value of thirty or greater for the variable “night_crashes” indicating a high rate of night crashes and responded “No” to the “lighting” variable, intersection illumination is also added to the countermeasure suggestions. If the user entered a value of thirty of greater for the variable “weather” indicating a high rate of weather related crashes, it is recommended that a skid test for pavement quality be added as a potential countermeasure along with the other countermeasures recommended.

Based on the user responses, the appropriate countermeasures for the intersection are displayed as a static list variable. The user can select any one of the countermeasure options from the list provided. Regardless of the option selected, the user will encounter the numeric variable “confidence” and be required to rate the certainty of their previous responses. The user will then be directed to one of the end screens for the program that displays information about the countermeasure selected with the confidence value.

5.5 Two-Way STOP Control: Rear End Collision at a Free Approach as Most Common Crash Type

If rear end collisions at a free approach are the most common type of crash at a two-way STOP controlled intersection, the KBES then displays the variable “night_crashes” and asks the user what percentage of crashes occurred when it was dark outside. The responses to this prompt are divided into two different categories. If the user enters a value of thirty or greater, it is determined that night crashes are frequent at this intersection. If night crashes account for thirty or more percent of the crashes, the variable “lighting” is displayed and the user must respond whether the intersection has nighttime illumination.

Regardless of the user inputs for the night crashes and nighttime illumination questions, the user is then prompted with the variable “weather” and is then asked to enter the percentage of crashes that occurred at the intersection when the roads were wet. The responses to this question are again divided into two categories. If over thirty

percent of the crashes occurred when the roads were wet, road condition is considered a primary factor in the crashes.

The next variable displayed to a user who indicated that rear end collisions at a free approach are the most common type of crashes is “intersection_warning_free” which asks the user if advanced warnings signs and pavement markings are in place to warn traffic on the major road that there may be stopped vehicles at the upcoming intersection. Users may respond either “Yes” or “No” to this prompt, but all users are then asked if there is a significant volume of left turning traffic using the variable “left_turn.”

If the user indicated that advanced warning measures on the major road approach are already in place and there is a large volume of left turning traffic at the intersection, the countermeasures suggested are adding a left turn lane and installing flashing beacons. If the user indicated that advanced warning measures on the major road approach are already in place, but there is not a large volume of left turning traffic at the intersection, the countermeasures suggested are adding shoulder bypass lanes and installing flashing beacons. If the user responded that advanced warning measures were not used on the major road approaches and there is a large volume of left turning vehicles, the countermeasures suggested are improving signage on the major road approach and adding a left turn lane. If the user responded that advanced warning pavement markings are not used on the major road approaches, but there is not a large volume of left turning vehicles, the countermeasures suggested are improving signage on the major road approach and adding shoulder bypass lanes.

If the user entered a value of thirty or greater for the variable “night_crashes” indicating a high rate of night crashes and responded “No” to the “lighting” variable, intersection illumination is also added to the countermeasure suggestions. If the user entered a value of thirty of greater for the variable "weather" indicating a high rate of weather related crashes, it is recommended that a skid test for pavement quality be added as a potential countermeasure along with the other countermeasures recommended.

Based on the user responses, the appropriate countermeasures for the intersection are displayed as a static list variable. The user can select any one of the countermeasure options from the list provided. Regardless of the option selected, the user will encounter the numeric variable "confidence" and be required to rate the certainty of their previous responses. The user will then be directed to one of the end screens for the program that displays information about the countermeasure selected with the confidence value.

5.6 Two-Way STOP Control: Run Off the Road Collisions as Most Common Crash Type

If run off the road collisions are the most common type of crash at a two-way STOP controlled intersection, the KBES then displays the variable "night_crashes" and asks the user what percentage of crashes occurred when it was dark outside. The responses to this prompt are divided into two different categories. If the user enters a value of thirty or greater, it is determined that night crashes are frequent at this intersection. If night crashes account for thirty or more percent of the crashes, the variable "lighting" is displayed and the user must respond whether the intersection has nighttime illumination.

Regardless of the user inputs for the night crashes and nighttime illumination questions, the user is then prompted with the variable "weather" and is then asked to enter the percentage of crashes that occurred at the intersection when the roads were wet. The responses to this question are again divided into two categories. If over thirty percent of the crashes occurred when the roads were wet, road condition is considered a primary factor in the crashes.

Users who selected run off the road collisions as the most common crash type are next asked to indicate whether the roads at the intersection intersect at nearly a ninety degree angle using the variable “skew.” Run off the road collisions are common at skewed intersections, so it is important to determine whether skewed intersection geometry could be causing some of the run off the road crashes at this intersection.

If user responds “Yes” to the variable “skew” indicating that the roads intersect at roughly a ninety degree angle, the suggestions for countermeasures at this intersection include increasing the sight distance on the major road of the upcoming intersection and performing a skid test for pavement quality. If user responds “No” to the variable “skew” to indicate that the roads do not intersect at a ninety degree angle, the suggestions for countermeasures at this intersection include performing a skid test for pavement quality, increasing sight distance on the major road of the upcoming intersection, and realigning the intersection so the roads meet at a ninety degree angle.

If the user entered a value of thirty or greater for the variable “night_crashes” indicating a high rate of night crashes and responded “No” to the “lighting” variable, intersection illumination is also added to the countermeasure suggestions. If the user entered a value of thirty of greater for the variable “weather” indicating a high rate of weather related crashes, it is recommended that a skid test for pavement quality be added as a potential countermeasure along with the other countermeasures recommended. However, in the case of run off the road crashes, it is already encouraged to perform a skid test for pavement quality at this intersection because slippery road conditions even in dry weather could be contributing to the crashes at this intersection.

Based on the user responses, the appropriate countermeasures for the intersection are displayed as a static list variable. The user can select any one of the countermeasure options from the list provided. Regardless of the option selected, the user will encounter the numeric variable “confidence” and be required to rate the certainty of their previous responses. The user will then be directed to one of the end screens for the program that displays information about the countermeasure selected with the confidence value.

5.7 Two-Way STOP Control: Sideswipe Collisions as Most Common Crash Type

If sideswipe collisions are the most common type of crash at a two-way STOP controlled intersection, the KBES then displays the variable “night_crashes” and asks the user what percentage of crashes occurred when it was dark outside. The responses to this prompt are divided into two different categories. If the user enters a value of thirty or greater, it is determined that night crashes are frequent at this intersection. If night crashes account for thirty or more percent of the crashes, the variable “lighting” is displayed and the user must respond whether the intersection has nighttime illumination.

Regardless of the user inputs for the night crashes and nighttime illumination questions, the user is then prompted with the variable “weather” and is then asked to enter the percentage of crashes that occurred at the intersection when the roads were wet. The responses to this question are again divided into two categories. If over thirty

percent of the crashes occurred when the roads were wet, road condition is considered a primary factor in the crashes.

All users who indicated that sideswipe collisions at a two-way STOP controlled intersection are the most common type of crashes are then prompted to respond whether there is a large volume of left turning traffic from the major road approaches at this intersection using the variable “left_turn.” If the user responds that there is a large volume of left turning traffic on the major road, the countermeasure recommendations are adding a left turn lane and improve intersection signing. If the user responds that there is not a large volume of left turning traffic on the major road, the countermeasure recommendations are adding shoulder bypass lanes and improving intersection signing.

If the user entered a value of thirty or greater for the variable “night_crashes” indicating a high rate of night crashes and responded “No” to the “lighting” variable, intersection illumination is also added to the countermeasure suggestions. If the user entered a value of thirty of greater for the variable “weather” indicating a high rate of weather related crashes, it is recommended that a skid test for pavement quality be added as a potential countermeasure along with the other countermeasures recommended.

Based on the user responses, the appropriate countermeasures for the intersection are displayed as a static list variable. The user can select any one of the countermeasure options from the list provided. Regardless of the option selected, the user will encounter the numeric variable “confidence” and be required to rate the certainty of their previous responses. The user will then be directed to one of the end screens for the program that displays information about the countermeasure selected with the confidence value.

5.8 Summary of Chapter 5

The variables defined in Chapter 4 are organized into a logical questioning sequence in the KBES that is described in Chapter 5. The first question for users asks if the intersection is all-way STOP controlled in order to separate the two-way STOP controlled intersections from the all-way STOP controlled intersections in the analysis. The next step in the system is to determine what types of crashes are most common at the intersection. For all-way STOP controlled intersections, the crashes types are typically angle crashes and rear end crashes. If angle crashes are the most common, the user is asked to indicate whether advanced warning measures are in place at the intersection. If rear end crashes are the most common, the user is also asked if advanced warning measures such as pavement markings, signs, or rumble strips are in place.

For two-way STOP controlled intersections, angle crashes, rear end crashes at a STOP controlled approach, rear end crashes at a free approach, sideswipe crashes, and run off the road crashes are common. If the user selects angle crashes as the most common type of crash, the user is asked if the crashes at the intersection are the result of drivers failing to stop at the STOP sign or drivers accepting too small of a gap in cross traffic. If drivers frequently fail to stop at the STOP sign, users are asked if advanced warning measures are employed at this intersection. If drivers do stop at the STOP sign, but proceed into the intersection when there is not a large enough gap in the traffic, the user is asked to rate the sight distance at the intersection and comment on the average travel speed of the traffic on the major road. If rear end collisions at a

STOP controlled approach or free approach are the most common type of crash, the user is asked if advanced warning measures are in place at this intersection. If sideswipe crashes are the most common crash type at the intersection, the user is asked if there is a large volume of left turning traffic on the major road at this intersection. If run off the road crashes are the most common type of crash at the intersection, the user is asked if the intersection has a large skew angle.

Regardless of crash type and number of STOP controlled approaches, users are asked what percentage of crashes occurred at night and when the roads were wet. If a significant number of crashes occurred during the night, the user is asked if there is nighttime illumination at this intersection. Once all of the necessary intersection characterization information is gathered, the user is presented with a list of countermeasures that could be beneficial at the intersection. The user can then select one of the options to learn more about it. Before the information about the countermeasure is displayed, the user is asked one final question to determine the confidence of the recommendation. In this question, the user is asked to enter the number of previous questions for which he or she was unsure about the answer. This information is used to calculate the confidence score presented on the final screen along with the information about the selected countermeasure. If CMF values from the Highway Safety Manual are available for the selected countermeasure, they are displayed on the last screen along with instructions on how to correctly use the values. The KBES for countermeasure identification can be completed within a few minutes, so it is easy for the user to repeat the system if he or she unsure of an answer or to investigate all of the suggested countermeasures for the intersection.

Chapter 6

TRIAL APPLICATIONS OF THE KNOWLEDGE BASED EXPERT SYSTEM

The KBES for countermeasure identification detailed in the previous section is evaluated using three sample intersections which are intended to demonstrate the effectiveness of the KBES. The three intersections are Delaware 10 & Delaware 15, Delaware 15 & Andrews Lake Road, and Delaware 30 & Zoar Road. These three intersections were identified by DelDOT and a part of a 2012 study of rural, unsignalized intersection that have experienced a high crash rate over the past three years. Crash records reviewed for each other these intersections were provided by DelDOT for the dates October 11, 2008 to October 11, 2011. Sample crash reports can be found in the Appendix.

Since expert systems became widely used in the field of transportation engineering, the FHWA published a guide to how such systems should be verified, validated, and evaluated [20]. It is important that KBES be verified, validated, and evaluated before they become available for use to ensure their quality. A system needs to be verified to show that the system was built correctly, validated to show that the right system was built, and evaluated to demonstrate the usefulness of the system. The FHWA publication explains in detail how this process should occur. The purpose of verification is to ensure there are no programming errors, or "bugs" in the system. During validation, the information produced by the KBES is tested by the knowledge of human experts to approve the accuracy and comprehensiveness of the system. The evaluation of the system is completed to make sure that the tool that has been created is useful to the transportation community and achieves its intended objectives. An outline of the process the FHWA requires for verification, validation, and evaluation is shown in Figure 6.1 below.

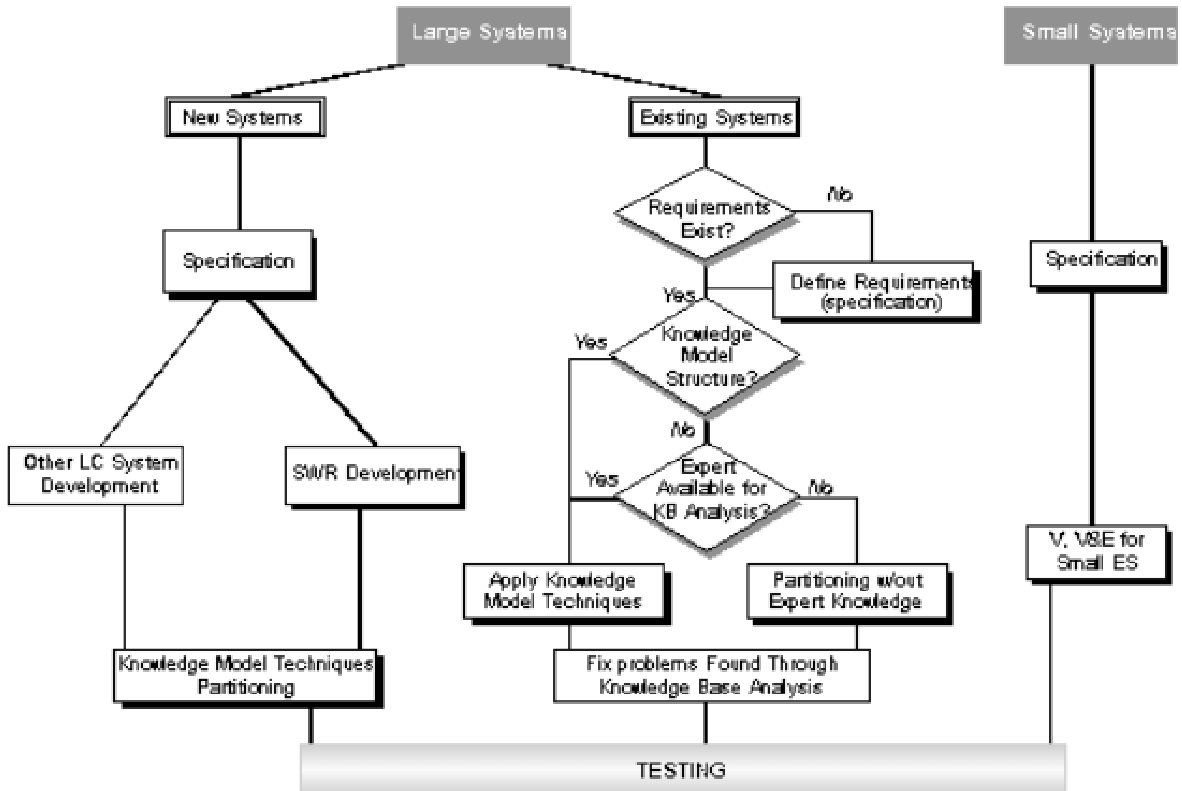

Figure 6.1: FHWA verification, validation, and evaluation process for expert systems [20]

Further research would be required for the KBES for countermeasure identification to reach the process of the FHWA verification, validation, and evaluation procedure. However, if this research were to become marketable, the FHWA procedure must be followed. For the purpose of this thesis, the KBES for countermeasure identification is evaluated using data from the three sample intersections in Delaware and compared to the 2012 DelDOT study results of the same intersections.

6.1 Delaware 10 & Delaware 15

Delaware 10 & Delaware 15 is a four way intersection located in Kent County south of Dover, Delaware. Delaware 10 runs eastbound and westbound in the vicinity of the intersection and is named Willow Grove Road at this location. The northbound approach to the intersection on Delaware 15 is known as Dundee Road, and the southbound approach to the intersection on Delaware 15 is referred to as Moose Lodge Road. The major road is Delaware 10 which has an average annual daily traffic (AADT) value of 5,062 vehicles per day. Delaware 15 is STOP controlled at the intersection and has an AADT value of 2,634 vehicles per day. The speed limit on Delaware 10 in the vicinity of the intersection is 50 miles per hour, and the speed limit on Delaware 15 is 35 miles per hour. In the past three years, twenty-five crashes have occurred at this intersection.

The user is first asked if the intersection is all-way STOP controlled. In the case of Delaware 10 & Delaware 15, the traffic on Delaware 15 must stop at the intersection, but the traffic at Delaware 10 does not need to stop, so the intersection is not all-way STOP controlled. The “No” option is selected.

The next prompt for the user is asking what the most common type of crash is at the intersection. Table 6.1 below shows the most common types of crash at Delaware 10 & Delaware 15.

Table 6.1: Most common crash types at Delaware 10 & Delaware 15

Type of Crash	Frequency	Percentage
Failure to remain stopped	13	52%
Rear end collision	5	20%
Ran stop sign	3	12%
Failure to yield right of way	2	8%
Deer in roadway	1	4%
Improper passing on right	1	4%

Crashes that are characterized as "failure to remain stopped" indicate that a vehicle stops at the STOP sign then proceeds into the intersection when there is not a large enough gap in the cross traffic to safely cross the intersection. These crashes, as well as crashes that result from running the STOP sign all result in angle crashes. Therefore, the most common type of crash at this intersection are angle crashes. The option "Angle" is selected.

The next question asked by the KBES requires the user to enter the percentage of crashes that occur during the night. Table 6.2 shows the time of day breakdown of crashes at Delaware 10 & Delaware 15.

Table 6.2: Period of day of crashes at Delaware 10 & Delaware 15

Time of Day	Number of Crashes	Percentage
Day	18	72%
Night	5	20%
Dusk	2	8%

Over the past three years, at the intersection of Delaware 10 & Delaware, 20% of crashes occur at night. The value "20" is entered in to the KBES.

The next prompt asks the user to enter the percentage of crashes that occurred when the roads at the intersection were wet. Table 6.3 shows the weather conditions during the crashes that occurred at Delaware 10 & Delaware 15.

Table 6.3: Road conditions at Delaware 10 & Delaware 15 during crashes

Road Condition	Number of Crashes	Percentage
Dry	20	80%
Wet	5	20%

Table 6.3 shows that 20% of the crashes at Delaware 10 & Delaware 15 occurred when the roads were wet over the past three years. The value “20” is entered in to the KBES.

The system then asks the user “Are angle crashes at this intersection primarily due to drivers failing to stop at the STOP sign or due to drivers entering the intersection when there is not a large enough gap in cross or opposing traffic?” Referring to Table 6.1, 52% of crashes at Delaware 10 & Delaware 15 were caused by drivers who failed to wait at the STOP sign until there was a large enough gap in cross traffic. The option “drivers accept too small of a gap” is selected.

The next question for the user is to determine or estimate whether traffic frequently travels ten or more miles per hour above the posted speed limited on the free approaches to the intersection. This information can be obtained through speed studies or traffic observation at the intersection. No speed studies were performed at Delaware 10 & Delaware 15, but the site visit revealed that traffic at this intersection appeared to be travelling above the posted speed limit because the free approach, Delaware 10, is a straight, flat road with passing permitted near the intersection. The option "Yes" is selected.

The next prompt asks the user to rate the sight distance at this intersection on a scale of one to five with a rating of one corresponding to an intersection with very limited sight distance and a rating a five corresponding to an intersection with entirely unobstructed sight distance. The site visit to Delaware 10 & Delaware 15 revealed that the sight distance is limited from the southbound approach due to trees and signs to the left, and the sight distance is also obstructed from the northbound approach due to a silver utility box. A rating of "4" for the sight distance at this intersection is entered.

The system then gives the user three suggestions for countermeasures that could be beneficial at this intersection. The recommendations are:

- Intersection lane narrowing
- Convert to all-way STOP control
- Convert to roundabout

These recommendations are similar to the options considered in the 2012 DelDOT study that did not make use of a KBES model to select countermeasures. Converting the intersection to a roundabout was the preferred option for DelDOT. This intersection has a very high rate of crash for a rural, unsignalized intersection and the volume is great enough and well distributed for smooth traffic flow in a roundabout. This intersection likely does meet the warrants for all-way STOP control due to the high volume and crash rate, but roundabout conversion has a lower CMF value in the Highway Safety Manual, meaning that roundabout conversion would be more effective at reducing crashes than all-way STOP control conversion. Increasing sight distance could be beneficial at this intersection, but since the crash rate is so high, it is unlikely that just increasing the sight distance alone in this case would cause a significant enough reduction in crashes. Intersection lane narrowing could also be an option at this intersection if roundabout conversion is not feasible; however roundabout conversion is preferable to lane narrowing because of the crash reduction potential at this very high crash location.

The user then has the opportunity to select one of the countermeasures to determine the confidence of the recommendation and find information about the Highway Safety Manual's CMFs for the countermeasure. Once a countermeasure is selected, the user is asked to enter a value for the number of previous responses the user was unsure about. Since no speed data was recorded to determine the speed of vehicles on the main road, the value "1" is entered for the number of unsure responses.

The final screen uses the response to the confidence question to give a confidence value for the recommendation and information about the CMF values, if applicable, as well as instructions how to use the values are given. For this simulation of Delaware 10 & Delaware 15, the confidence value is 0.80. The information about the CMF values for each countermeasure the same as the information given in Chapter 3.

6.2 Delaware 15 & Andrews Lake Road

The intersection of Delaware 15 & Andrews Lake Road is located outside of Riverview, Delaware in Kent County. Delaware 15 is known as Canterbury Road in this area, and Andrews Lake Road is the name of the road from both the eastbound and westbound approaches to the intersection. The AADT on Delaware 15 at this intersection is 4,300 vehicles per day, and the AADT on Andrews Lake Road is 1,170. Andrews Lake Road has a stop sign at both the eastbound and westbound approaches, but the traffic on Delaware 15 from the northbound and southbound approaches does not stop. The posted speed limit on Delaware 15 is increased to 50 miles per hour at this intersection. Ten crashes have occurred at this intersection in the past three years with six crashes occurring in 2010.

The user is then asked if the intersection is all-way STOP controlled. In the case of Delaware 15 & Andrews Lake Road, the traffic on Andrews Lake Road must stop at the intersection, but the traffic at Delaware 15 does not need to stop, so the intersection is not all-way STOP controlled. The “No” option is selected.

The next prompt for the user asks what type of crashes are most common at this intersection. The choices include angle crashes, rear end crashes at a STOP controlled approach, rear end crashes on the free approach, run off the road crashes, and sideswipe crashes. Table 6.4 below shows the most common types of crashes at Delaware 15 & Andrews Lake Road.

Table 6.4: Most common crash types at Delaware 15 & Andrews Lake Road

Type of Crash	**Frequency**	**Percentage**
Failure to remain stopped	4	40%
Failure to yield right of way	2	20%
Ran off road	1	10%
Improper turn	1	10%
Rear end collision	1	10%
Unknown	1	10%

The crashes that occur due to a “failure to remain stopped” and “failure to yield right of way” result in angle crashes, so angle crashes are the most common type of crash at Delaware 15 & Andrews Lake Road. The option “Angle” is selected in the system.

The next question posed by the KBES asks what percentage of crashes occurred at this intersection when it was dark. Table 6.5 below shows the distribution of the time of day of the crashes at Delaware 15 & Andrews Lake Road.

Table 6.5: Period of day of crashes at Delaware 15 & Andrews Lake Road

Time of Day	Number of Crashes	Percentage
Day	4	40%
Night	6	60%

As Table 6.5 shows, 60% of the crashes over the past three years at Delaware 15 & Andrews Lake Road occurred during the night. The value “60” is entered into the KBES.

The system then asks whether the intersection is lighted at night. The user is also encouraged to check the nighttime visibility of signs and pavement markings at this intersection because it has experienced a high rate of night crashes. The site visit to Delaware 15 & Andrews Lake Road as well as the crash reports indicate that the intersection is not lighted at night. The option “No” is selected.

The next prompt by the system asks the user what percentage of crashes occurred at the intersection when the roads were wet. Table 6.6 below shows the distribution of the road conditions for the crashes at Delaware 15 & Andrews Lake Road.

Table 6.6: Road conditions at Delaware 15 & Andrews Lake Road during crashes

Road Condition	Number of Crashes	Percentage
Wet	1	10%
Dry	9	90%

During the past three years, 10% of the crashes that happened at Delaware 15 & Andrews Lake Road occurred when the road was wet. The value “10” is entered in to the system.

The next prompt for the users asks “Are the angle crashes at this intersection primarily due to driver failing to stop at the STOP sign or due to drivers entering the intersection when there is not a large enough gap in cross or opposing traffic?” The two options the user can select from are “Drivers fail to stop at the STOP sign” and “Drivers accept too small of a gap.” Referring back to Table 6.4, no crashes were reported to have occurred from a driver failing to stop at the STOP sign at Delaware 15 & Andrews Lake Road, so the angle crashes at this intersection were caused by drivers who entered the intersection when there was not a large enough gap in the traffic to make the desired turning or crossing maneuver. The option “Drivers accept too small of a gap” is selected.

The next prompt requires the user to determine or estimate whether traffic on the free approach is typically travelling at a speed of ten miles per hour above the posted speed limit. Although a speed study was not performed at Delaware 15 & Andrews Lake Road, observing traffic during the site visit revealed that drivers did appear to be travelling near the posted speed limit. There is a STOP controlled intersection less than a mile north of the intersection on Delaware 15 that causes drivers to slow down. Also, the speed limit increases from 35 mile per hour to 50 miles per hour shortly before the intersection in the southbound direction, so vehicles may increase speed, but not typically in excess of the 50 miles per hour speed limit. The option “No” is selected for this response.

The next question asks the user to enter a value between one and five describing the sight distance at the STOP controlled approaches to the intersection. A rating of one indicates that sight distance at one or more STOP controlled approaches to the intersection is very limited, and a rating of five indicates that sight distance is unobstructed from all approaches. The visit to the site revealed that the largest challenge to sight distance results from the fact that the Andrews Lake Road approaches do not intersect with Delaware 15 at a right angle. From the westbound approach, drivers must turn their head significantly more than ninety degrees to see the northbound traffic on Delaware 15. There are also trees that obstruct the visibility of traffic from this approach. The value of "3" is entered in the system for this response.

The system then returns the user four recommendations for improving safety at this intersection. The recommendations are the following:

- Add intersection illumination
- Increase sight distance
- Convert to all-way STOP control
- Convert to roundabout

In the case of Delaware 15 & Andrews Lake Road, the KBES achieves comparable results to the 2012 DelDOT study of this intersection. In the DelDOT study, checking the nighttime visibility of signs and pavement markings was strongly encouraged as was considering illuminating the intersection at night. Delaware 15 & Andrews Lake Road is not expected to meet the warrants for all-way STOP control, roundabout conversion, or signalization, so these options were not considered in the study of this intersection. However, the KBES does not offer the option of realigning the intersection to remove the skew angle that was considered in the study of this intersection. While realigning the intersection of Delaware 15 & Andrews Lake Road is likely too costly to be seriously considered by DelDOT, this option does address the skew angle concern directly while the KBES does not. The KBES suggests increasing the sight distance that is limited due to the skew angle, but not realigning the intersection to remove the skew angle.

The user then has the opportunity to select one of the countermeasures to determine the confidence of the recommendation and find information about the Highway Safety Manual's CMFs for the countermeasure. Once a countermeasure is selected, the user is asked to enter a value for the number of previous responses the user was unsure about. Since no speed data was recorded to determine the speed of vehicles on the main road, the value "1" is entered for the number of unsure responses.

The final screen shows the confidence value of 0.80 for the recommendation based on the user input to the previous confidence related question. This screen also shows the CMF values for the countermeasure selected by the user. All of the countermeasure options have CMF values except for increasing intersection sight distance because the Highway Safety Manual does not provide a CMF for this treatment. The user can repeat the system to learn about the different countermeasures identified for this intersection and compare their effectiveness.

6.3 Delaware 30 & Zoar Road

The intersection of Delaware 30 & Zoar Road is located outside of Millsboro, Delaware in Sussex County. Delaware 30 is the northbound and southbound approaches to the intersection and is referred to as Gravel Hill Road at the intersection of Zoar Road. Zoar Road is the name of the eastbound and westbound approaches to the intersection. The AADT on Delaware 30 is 3,900, and the AADT on Zoar Road is 2,800. As of January 2012, the traffic on Zoar Road stopped at a stop sign at the intersection with Delaware 30, and the traffic at Delaware 30 did not stop. Seventeen crashes have occurred at the intersection of Delaware 30 and Zoar Road during the past three years.

The user is then asked if the intersection is all-way STOP controlled. In the case of Delaware 30 & Zoar Road, the traffic on Zoar Road must stop at the intersection, but the traffic at Delaware 30 does not need to stop, so the intersection is not all-way STOP controlled. The “No” option is selected.

The next prompt for the user asks what type of crash is most common at this intersection. The choices include angle crashes, rear end crashes at a STOP controlled approach, rear end crashes on the free approach, run off the road crashes, and sideswipe crashes. Table 6.7 below shows the most common types of crashes at Delaware 30 & Zoar Road.

Table 6.7: Most common crash types at Delaware 30 & Zoar Road

Type of Crash	**Frequency**	**Percentage**
Failure to remain stopped	10	58.8%
Failure to yield right of way	2	11.8%
Deer in roadway	2	11.8%
Ran off road	1	5.9%
Careless driving	1	5.9%
Inattentive driving	1	5.9%

Failure to remain stopped crashes result in angle crashes. This type of crash is the most common at Delaware 30 & Zoar Road. The option “Angle” is selected.

The system then asks the user to input the percentage of crashes that occur during the night. Table 6.8 shows the distribution of daytime and nighttime crashes at Delaware 30 & Zoar Road.

Table 6.8: Period of day of crashes at Delaware 30 & Zoar Road

Time of Day	Number of Crashes	Percentage
Day	14	82.35%
Night	3	17.65%

Approximately 18% of crashes that occurred at Delaware 30 & Zoar Road during the past three years happened when it was night. The value “18” is entered in to the system for this prompt.

The system then asks what percentage of crashes occurred when the roads were wet. Table 6.9 below shows the road conditions at Delaware 30 & Zoar Road during crashes.

Table 6.9: Road conditions at Delaware 30 & Zoar Road during crashes

Road Condition	Number of Crashes	Percentage
Wet	2	11.76%
Dry	15	88.24%

As Table 6.9 shows, approximately 12% of the crashes that occurred at Delaware 30 & Zoar Road were when the roads were wet. The value “12” is entered into the system for this response.

The next prompt for the users asks “Are the angle crashes at this intersection primarily due to driver failing to stop at the STOP sign or due to drivers entering the intersection when there is not a large enough gap in cross or opposing traffic?” The two options the user can select from are “Drivers fail to stop at the STOP sign” and “Drivers accept too small of a gap.” As Table 6.7 shows, nearly 60% of crashes at Delaware 30 & Zoar Road occurred as a result of drivers failing to wait at the STOP sign until there was a large enough gap in traffic, so the option “Driver accept too small of a gap” is selected.

The next prompt asks the user if traffic is typically moving faster than ten miles per hour above the posted speed limit on the free approach. This information can be obtained from a speed study or estimated through field observation. In the case of Delaware 30 & Zoar Road, a speed study was not performed during the study of the intersection. Site observations suggested that traffic generally obeyed the posted speed limit at this intersection, so the option “No” is selected in the system.

The user is then asked to enter a value between one and five as an assessment of the sight distance from the STOP controlled approaches at the intersection. A value of one corresponds to very limited sight distance and a value of 5 corresponds to unrestricted sight distance. The site visit to Delaware 30 & Zoar Road revealed that sight distance at this intersection is generally good. The only obstructions to sight distance are a few small signs that conflict with the sight distance from the westbound approach. The value “4” is entered to the system for this response.

The KBES then offers the user the following suggestions to improve safety at this intersection:

- Convert to all-way STOP control
- Convert to roundabout

In February 2012, DelDOT converted this intersection to all-way STOP control as is suggested by the KBES in this trial. Delaware 30 & Zoar Road do not meet the volume warrants for signalization, so it is unlikely that this intersection will be signalized if crashes persist despite the all-way STOP conversion, but roundabout conversion could be a potential future option at this intersection.

The user then has the opportunity to select one of the countermeasures to determine the confidence of the recommendation and find information about the Highway Safety Manual’s CMFs for the countermeasure. Once a countermeasure is selected, the user is asked to enter a value for the number of previous responses the user was unsure about. Since no speed data was recorded to determine the speed of vehicles on the main road, the value “1” is entered for the number of unsure responses.

The final recommendation screen shows the confidence value of 0.80. The Highway Safety Manual has developed CMFs for both the conversion to all-way STOP control as well as the conversion to roundabout. These values are displayed on the last screen along with instructions for the user to properly use the values. The user can repeat the system to learn more about the other countermeasure option that was not selected as well as input different values for answers to the question to compare the different results.

6.4 Summary of Chapter 6

The KBES for countermeasure identification produced generally similar results to the 2012 DelDOT study of Delaware 10 & Delaware 15, Delaware 15 & Andrews Lake Road, and Delaware 30 & Zoar Road. All of these intersections were two-way STOP controlled intersections with a high rate of angle crashes, so the pattern of questioning was similar for all three intersections. For Delaware 10 & Delaware 15, DelDOT has identified roundabout conversion as the preferred countermeasure option, and roundabout conversion was one of the countermeasures suggested by the KBES for countermeasure identification. For Delaware 15 & Andrews Lake Road, the options of increasing sight distance and adding nighttime illumination were countermeasures that were considered by both the KBES and the DelDOT study. However, the DelDOT study also suggested realigning the intersection to remove the skew angle and the KBES for countermeasure identification did not. DelDOT has already converted Delaware 30 & Zoar Road to an all-way STOP controlled intersection. The KBES for countermeasure identification suggested all-way STOP conversion as one of the options for Delaware 30 & Zoar Road. The KBES also suggested signalization, which would not be an option at Delaware 30 & Zoar Road because this intersection does not meet the MUTCD signalization warrants.

Chapter 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Summary

Intersections are typically high crash locations on the road network due to the nature of an intersection being a location where two conflicting flows of traffic cross. While there are many types of intersections, rural, unsignalized intersections are the focus of this thesis. Rural, unsignalized intersections are usually either all-way STOP controlled or two-way STOP controlled. There are many factors that lead to an intersection becoming a high crash location. Transportation engineers are often tasked with the problem of reducing crashes at a dangerous intersection. Safety countermeasures are treatments that can be used to vary the intersection geometry or provide additional awareness at the intersection. The Highway Safety Manual was published by AASHTO in 2010 and is currently the only national source of reliable, quantitative information to predict the performance of safety countermeasures. CMFs are multiplicative factors used to predict the effectiveness of a countermeasure at an intersection. The process of selecting an effective countermeasure for an unsafe intersection typically requires judgment or experience on the part of the engineer because the geometric characteristics and traffic flow characteristics of each intersection is unique. The Highway Safety Manual also offers some guidance on how to complete an intersection safety study to select the most effective countermeasures for a site, but to an engineer who is inexperienced with intersection safety countermeasures, this process can still seem ambiguous. The purpose of this thesis is to create a KBES that will help engineers identify countermeasures that could be beneficial given the intersection characteristics and familiarize the user with the CMF values in the Highway Safety Manual.

KBES are a branch of artificial intelligence that was first developed in the 1950's. John McCarthy is credited with coining the term artificial intelligence at a conference at Dartmouth in 1956. During the second half of the twentieth century, use of artificial intelligence has spread to many fields, including transportation. Transportation problems of efficiency, safety, and environmental compatibility can be modeled using KBES. The purpose of KBES is to harness the knowledge of an expert into a system that can be accessed at any time and in any place when a human expert is not available. Due to the specialization of many fields within transportation engineering, the availability of expert knowledge without an expert present is valuable. The advantage of KBES over other types of resources is that KBES mimics the questioning pattern of an expert which eliminates unnecessary questioning and helps the user learn about the questioning process.

Research into fourteen countermeasures that can be used at rural, unsignalized intersection was completed to determine what types of situations in which each of the countermeasures would be most effective. The countermeasures considered in this thesis are intersection lane narrowing, conversion to all-way STOP control, sight distance improvements, installing flashing beacons, signalization, roundabout conversion, advanced warning rumble strips, advanced warning pavement markings, intersection signing modification, dedicated left and right turn lanes, shoulder bypass lanes, intersection realignment, intersection illumination, and skid test for pavement quality. Intersection lane narrowing is used to draw attention to the intersection and reduce the speed of traffic on the free approaches. Conversion to all-way STOP control, conversion to roundabout, and signalization are used when there is a significant amount of angle crashes at an intersection. Before considering any of these three options, it is necessary to check the MUTCD warrant guidelines. Improving intersection sight distance can be helpful at two-way STOP controlled intersections where sight distance is limited and angle crashes are common. Advance warning rumble strips, advanced warning pavement markings, and improving intersection signing are all intended to increase the awareness of the intersection. Dedicated left and right turn lanes as well as shoulder bypass lanes can be used to separate turning traffic from thru traveling traffic. Intersection realignment can be used to increase sight distance of an upcoming intersection or to remove the skew angle of an intersection. Intersection illumination and checking the nighttime visibility of signs and pavement markings are useful treatments at intersections that have a high rate of night crashes. A skid test for pavement quality can be beneficial when there are a large number of crashes occurring when the roads are wet or run off the road crashes are frequent. While all of the countermeasures can be effective at rural, unsignalized intersections, it is important to select the correct countermeasure for the location based on the specific site characteristics.

The KBES for countermeasure selection developed in this thesis was created using the software CORVID that is produced by the company Exsys® Incorporated. CORVID is designed to be user friendly so that experts who do not have experience in computer programming languages are still able to create a KBES. Variables created in CORVID are linked together in the logic block to create a string of “IF…AND” statements that are completed with a “THEN” statement. The three different types of variables that were used in CORVID in developing the KBES for countermeasure identification are static list variables, numeric variables, and confidence variables. Static list variables ask the user a question and require the user to select one of the options from a predetermined list of responses. Numeric variables are formatted so the user can enter a numerical value in the space provided to answer the question posed by the variable. Confidence variables are used to produce the “THEN” links in the logic chain and present the results to the user.

The KBES for countermeasure identification was tested by comparing the results of the system to the results of a 2012 DelDOT study of rural, unsignalized intersections. The three intersections involved in this comparison are Delaware 10 & Delaware 15, Delaware 15 & Andrews Lake Road, and Delaware 30 & Zoar Road. The results of the KBES were generally comparable to the results of the 2012 DelDOT study. However, at Delaware 15 & Andrews Lake Road, intersection realignment to reduce the skew angle was not identified as a possible countermeasure, and at Delaware 30 & Zoar Road, signalization was suggested, but this intersection likely does not meet the MUTCD requirements for signalization. While this type of testing can be used to suggest the accuracy of the system, it is typically necessary to complete the process detailed by the FHWA for verification, validation, and evaluation of KBES that requires more rigorous and comprehensive testing.

7.2 Conclusions

Selecting effective countermeasures for rural, unsignalized intersections with chronic safety problems can be a challenge for engineers and local government officials who are entrusted with the responsibility of ensuring the safety of drivers in their community. These challenges arise from the lack of structure within the current practice of countermeasure identification and selection. The KBES developed in this thesis begins to bridge the gap in the process between determining that an intersection is unsafe and finding ways in which to improve safety at the intersection. The KBES also aids users in quantitatively evaluating the countermeasures proposed for an intersection.

The KBES for countermeasure identification is useful for many reasons. The system successfully examines both two-way STOP controlled intersection and all-way STOP controlled intersections. While there are a few other types of rural, unsignalized intersections in practice, these two types of intersections are by far the most common, so the system could be considered generally comprehensive. Investigating more specifically into all-way STOP controlled intersections, the two most common types of crash, angle crashes and rear end collisions are both addressed in the system analysis. For two-way STOP controlled intersection, angle crashes, rear end collisions at a STOP controlled approach, rear end collisions at a free approach, sideswipe collisions, and run off the road collisions are considered as these are the most common crash types. The review of scholarly literature and consultations with practicing traffic engineers revealed fourteen countermeasures which are beneficial at rural, unignalized intersections. This list includes advanced warning rumble strips, advanced warning pavement markings, flashing beacons, signing improvements at and approaching the intersection, conversion to roundabout, signalization, conversion to all-way STOP control, addition of right and left turn lanes, addition of shoulder bypass lanes, improvements to sight distance, intersection illumination, lane narrowing concepts, and performing a skid test for pavement quality. All of these countermeasures were researched thoroughly before being carefully included in the KBES for countermeasure identification.

The merits of the KBES include providing quantitative assessment and structure to a previously unstructured and qualitative process. An advantage of the KBES for countermeasure identification is the quantitative data provided to users along with the system recommendations. The Highway Safety Manual provides CMFs for many commonly used intersection countermeasures. These values as well as standard error values for the CMFs are provided as part of the recommendation to the user at the end of the system along with instructions on how to apply the values to the data for the user's intersection. This feature of the KBES for countermeasure identification is a unique feature which helps link the newly published information in the Highway Safety Manual with current practice in the selection of intersection countermeasures. A confidence value for each recommendation which is based on user response as well as confidence inherent to the recommendations of the system as a whole is another numeric value which adds quantitative analysis to a field previously dominated by qualitative assessment and instinct.

One of the demerits is the inability of the system to effectively and accurately capture subjective factors in countermeasure selection. An example of this challenge is demonstrated in the variable used to assess the sight distance at STOP controlled approaches to two-way STOP controlled intersections. This information is currently entered into the system based on a one to five scale as identified by the user. The weakness of this is that two different users may assess the sight distance of the same intersection differently due to the individual's personal experiences and judgment. In trying to address this problem, the system is structured so responses of one, two, and three signal an intersection with poor sight distance. By including the middle value of three in the poor category, the system is erring on the side of being conservative. Another demerit is that the KBES for countermeasure identification does not include all factors that could be used when analyzing an intersection due to system limitation. A different version of CORVID would be able to include more variables to make the recommendations more accurate and narrow down the list of possible countermeasures.

Whenever possible, the system is designed to ask factual questions such as asking the user to input the percentage of crashes that occurred when the roads were wet. This information can be determined exactly from the crash reports for the intersection with few exceptions for unreported crashes or crashes that were not well documented. By asking these types of questions, the information in the system is based on concrete information and has less reliance on subjective responses. In some cases, subjective responses are necessary due to the nature of the information, but the system tries to focus on numerical and precise information as much as possible to improve accuracy.

The KBES for countermeasure identification developed in this thesis has broad applications and has potential to become a valuable tool in transportation engineering. For engineers who are unfamiliar with the process of studying an unsafe intersection with the goal of recommending strategies to improve the safety of the intersection, this tool can help walk the engineer through the process that a more experienced engineer might use. For a more experienced engineer, this tool could help provide a starting point for a more in depth analysis of the study intersection. The KBES for countermeasure identification can be completed relatively quickly, so results can be easily obtained in less time due to the streamlined approach to an otherwise subjective process.

7.3 Recommendations

The KBES for countermeasure identification makes an important first step toward streamlining and quantifying the process of countermeasure selection for rural, unsignalized intersections. However, there are many ways in which this tool can be expanded and made more powerful for practical application. One of the goals of this thesis was to include as many factors as possible to determine exactly what kinds of problems are occurring at an intersection, but despite the best attempts in programming, there are numerous factors that were not able to be included due to program space limitations and other design challenges. For example, examining the land uses nearby the study intersection and considering the age of the drivers causing crashes at the intersection could be information that is useful in determining the most effective countermeasure for a given intersection, and these variables were not able to be included in the system.

The KBES developed in this thesis is specifically tailored to rural, unsignalized intersections. Expansions upon this work could include making a system which analyzes signalized intersections, roadway segments, and unsignalized intersections in non-rural settings to result in a tool that is even more beneficial to the transportation engineering community. The Highway Safety Manual provides CMF values for countermeasures for roadway segments and more general intersection types, so these values could be incorporated into a system that investigates other types of high crash locations within a transportation network. Since the KBES for countermeasure identification focuses on rural areas, pedestrians and bicyclists were not considered to have a large presence at the study intersections and were not incorporated into this tool. In order to apply the intersection safety countermeasures and study process to non-rural locations, it would be important to consider pedestrian and bicycle traffic as these modes of transportation are becoming more prevalent.

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Appendix

SAMPLE CRASH REPORT

State of Delaware Crash Report

Identification

Classification	Complaint Number	Headquarters Number	Alcohol Involved
02 - Property Damage Only	0309027437		N

Location

Date of Crash	Time of Crash	County	Crash occurred within corporate limits of:	Private Property?	Hit and Run?	Intersection?
Aug 21, 2009	17:18	Kent		N	No	No

On Road, Street, or Highway:	At Intersection With:	Direction
53 - WILLOW GROVE RD		5

Specific Location	Milepost	Definable intersection, bridge, or railroad crossing
	10.11	

Literal Description
WILLOW GROVE ROAD and DUNDEE ROAD

XY Coordinates
185780.259, 121489.57

Functional Class	System Class	NHS
5 - Major Collectors	1	

Environment

Primary Contributing Circumstance

First Harmful Event
13 - Motor Vehicle in Transport - Collision With Person, Motor Vehicle, or Non-Fixed

Location of First Harmful Event	Manner of Impact
01 - On Roadway	01 - Front to rear

Directional Analysis
51 - Two-Vehicle, Non-Intersection Crash - From Same Direction, Both Moving

Ambient Light	Weather Condition(s)	Surface Conditions
01 - Daylight	04 - Rain	02 - Wet
Contrib. Circ. Environment	**Contrib. Circ. Roadway**	**Type of Roadway Junction**
02 - Weather Conditions	02 - Road Surface Condition (wet, icy, snow, slush, etc	02 - Intersection
Work Zone Related?	**Workers Present?**	**Type of Work Zone**

Work Zone Location of Crash	School Bus Related?
	No

Incident Information

Date Crash Reported to Police Agency	Time Crash Reported to Police Agency	Time Officer Notified of Crash	Time Officer Arrived at Scene
Aug 21, 2009	17:18	17:25	17:33
Investigation Made at Scene?	**Source of Information**	**Report Given to all Drivers?**	**Other Technical Investigation Agency**
Y	Police agency	Y	

Reporting Police Agency Identifier
DSP Troop 3

Date Of Report	Officer	Badge No.
Aug 21, 2009		

Complaint Number: 0309027437

State of Delaware Crash Report

Person Driver - Vehicle Unit #001				
DriverName(First, Middle, Last)		**Date of Birth** Oct 22, 1991	**Gender** M	**Injury Status**
Address Street	**Address City**	**Address State**	**Address Zip**	**DaytimePhone**
	EASTON	MD	21601	
Driver's License Number	**License State** MD	**Class** C	**Endorsements**	**Restrictions**
DriverCondition 01 - Apparently Normal	**Source of Transport**	**Medical Facility ID**	**EMS Resp. Agency ID**	**EMS Resp. Run No.**
Alcohol / Drugs Suspected				**Sobriety**
Alcohol Test Status 99 - Unknown if tested		**Alcohol Test Type**		**Alcohol Test Results**
Drug Test Status		**Drug Test Type**		**Drug Test Results**
Occupant Protection SystemUse		**Airbag Deployment**	**Airbag Switch Status**	
Trapped		**Ejection**	**Ejection Path**	
Cited 01 - Yes				
Violations INADEQUATE BRAKES				

Complaint Number: 0309027437

State of Delaware Crash Report

Owner - Vehicle Unit # 001					
Owner Name(First, Middle, Last)		**Owner Company Name**			
Address Street		**Address City** EASTON		**Address State** MD	**Address Zip** 21601
Insurance Company Name	**Insurance Policy #**	**Approximate Cost** 2,000	**License Plate #**	**License Plate State** MD	**License Plate Year** 2009
VIN 1HGEG8558RL043762		**Year** 1994	**Make** Honda - HOND	**Model** CIVIC	**Style** 01 - Passenger Car
Cargo Body Type 99 - Unknown		**EmergencyVehicle'** 2 - No	**EmergencyUse?** 2 - No	**EmergencyVehicle Type** N/A	
Direction of Travel Before Crash 08 - Westbound		**Vehicle Maneuver/Action** 01 - Movements Essentially Straight Ahead		**Speed Limit** 50	**Speed Limit Unit Of Measure** mph
Point(s) of Impact 12 - Front Center				**Most Damaged Area** 12 - Front Center	**Extent of Damage** 03 - Functional Damage
Contributing Circumstance(s), Driver 88 - Other Contributing Action					
Most Harmful Event 13 - Motor Vehicle in Transport - Collision With Person, Motor Vehicle, or Non-Fixed				**Total Occupants** 2	**Traffic Control DeviceType**
First Event 22 - Motor Vehicle In Transport - Collision with person, vehicle, or object not fixe			**Second Event**		
Third Event			**Fourth Event**		

Complaint Number: 0309027437

State of Delaware Crash Report

Person Driver - Vehicle Unit #002				
DriverName(First, Middle, Last)		**Date of Birth** Mar 11, 1958	**Gender** M	**Injury Status**
Address Street	**Address City**	**Address State**	**Address Zip**	**DaytimePhone**
	DOVER	DE	19901	
Driver's License Number	**License State** DE	**Class** D	**Endorsements**	**Restrictions**
DriverCondition 01 - Apparently Normal	**Source of Transport**	**Medical Facility ID**	**EMS Resp. Agency ID**	**EMS Resp. Run No.**
Alcohol / Drugs Suspected				**Sobriety**
Alcohol Test Status 99 - Unknown if tested		**Alcohol Test Type**		**Alcohol Test Results**
Drug Test Status		**Drug Test Type**		**Drug Test Results**
Occupant Protection SystemUse		**Airbag Deployment**	**Airbag Switch Status**	
Trapped		**Ejection**	**Ejection Path**	
Cited 02 - No				
Violations				

Complaint Number: 0309027437

State of Delaware Crash Report

Owner - Vehicle Unit # 002					
Owner Name(First, Middle, Last)		**Owner Company Name**			
Address Street		**Address City** DOVER		**Address State** DE	**Address Zip** 19901
Insurance Company Name FARM FAMILY CASUALTY	**Insurance Policy #** 0701P113901	**Approximate Cost** 1,500	**License Plate #**	**License Plate State** DE	**License Plate Year** 2009
VIN 1GCDT19X7V8132342		**Year** 1997	**Make** Chevrolet - CHEV	**Model** S10 PICKUP	**Style** 01 - Passenger Car
Cargo Body Type 99 - Unknown		**EmergencyVehicle'** 2 - No	**EmergencyUse?** 2 - No	**EmergencyVehicle Type** N/A	
Direction of Travel Before Crash 08 - Westbound		**Vehicle Maneuver/Action** 06 - Turning Left		**Speed Limit** 50	**Speed Limit Unit Of Measure** mph
Point(s) of Impact 06 - Rear Center				**Most Damaged Area** 06 - Rear Center	**Extent of Damage** 03 - Functional Damage
Contributing Circumstance(s), Driver 01 - No Contributing Action					
Most Harmful Event 13 - Motor Vehicle in Transport - Collision With Person, Motor Vehicle, or Non-Fixed				**Total Occupants** 1	**Traffic Control DeviceType**
First Event 22 - Motor Vehicle In Transport - Collision with person, vehicle, or object not fixe			**Second Event**		
Third Event			**Fourth Event**		

Complaint Number: 0309027437

State of Delaware Crash Report

Person

Person Name (First, Middle, Last)	
Date of Birth	
Gender	
Injury Status	
Addres Street	
Address City	DOVER
Address State	DE
Address Zip	199040000
Daytime Phone	
Source of Transport	
Medical Facility ID	
EMS Resp. Agency ID	
EMS Resp. Run No.	
Person Type	09 - Witness
Unit No.	
Seating Position	
Alcohol / Drugs Suspected	
Sobriety	
Alcohol Test Status	
Alcohol Test Type	
Alcohol Test Results	
Drug Test Status	
Drug Test Type	
Drug Test Results	
Occupant Protection System Use	
Airbag Deployment	
Airbag Switch Status	
Trapped	
Ejection	
Ejection Path	
Non-Motorist Type	09 - Witness
Unit # of Vehicle Striking Non-Motorist	
Non-Motorist Location Prior to Impact	
Non-Motorist Condition	
Non-Motorist Action	
Safety Equipment, Non-Motorist	
Contributing Circumstance(s), Non-Motorist	

State of Delaware Crash Report

Narrative

V1 WAS TRAVELING EAST ON WILLOW GROVE IN THE AREA OF MOOSE LODGE ROAD V2 WAS STOPPED FACING E/B ON WILLOW GROVE RD ABOUT TO MAKE A LEFT TURN ON MOOSELODGE RD. V1 STRUCK V2 IN THE INTERSECTION 12' N/O SEO WILLOW GROVE ROAD FOR POI1. V1 AND V2 SAFELY PULLED OFF THE ROADWAY ON MOOSE LODGE ROAD FOR FRP. OP1 ADVISED THAT THE ROADS WERE WET BECAUSE OF THE RAIN AND HE APPLIED HIS BRAKES AND PUSHED THE PEDAL TO THE FLOOR BUT DID NOT HAVE ENOUGH PRESSURE TO STOP HIS VEHICLE AND STRUCK V2. OP2 ADVISED THAT HE WAS STOPPED IN THE INTERSECTION AND WAS ATTEMPTING TO MAKE A LEFT HAND TURN ONTO MOOSE LODGE AND WAS STRUCK FROM BEHIND. W1 ADVISED THAT SHE WAS STOPPED BEHIND V2 AND SWERVED TO THE RIGHT BECAUSE SHE OBSERVED V1 COMING BEHIND AND DID NOT LOOK LIKE IT WAS GOING TO STOP. W1 AVOIDED THE COLLISION BUT V2 WAS STRUCK IN THE REAR BUMPER. OP1 WAS CITED FOR 21/4303 V1 WAS TOWED TO CHAMBERS. NO INJURIES WERE SUSTAINED.

Complaint Number: 0309027437