Report No. K-TRAN: KSU-99-5
FINAL REPORT

# EFFECTIVENESS OF TWO-WAY STOP CONTROL AT LOW-VOLUME RURAL INTERSECTIONS

Robert W. Stokes, Ph.D.

Kansas State University
Manhattan, Kansas

MARCH 2004

**K-TRAN**

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:
KANSAS DEPARTMENT OF TRANSPORTATION
KANSAS STATE UNIVERSITY
THE UNIVERSITY OF KANSAS

**1 Report No.**
K-TRAN: KSU-99-5

**2 Government Accession No.**

**3 Recipient Catalog No.**

**4 Title and Subtitle**
EFFECTIVENESS OF TWO-WAY STOP CONTROL AT LOW-VOLUME RURAL INTERSECTIONS

**5 Report Date**
March 2004

**6 Performing Organization Code**

**7 Author(s)**
Robert W. Stokes, Ph.D., Kansas State University

**8 Performing Organization Report No.**

**9 Performing Organization Name and Address**
Kansas State University
Department of Civil Engineering
Manhattan, KS 66506-5000

**10 Work Unit No. (TRAIS)**

**11 Contract or Grant No.**
C1106

**12 Sponsoring Agency Name and Address**
Kansas Department of Transportation
Bureau of Materials and Research, Research Unit
2300 Southwest Van Buren Street
Topeka, Kansas 66611-1195

**13 Type of Report and Period Covered**
Final Report
October 1998-October 2003

**14 Sponsoring Agency Code**
RE-0173-01

**15 Supplementary Notes**
For more information write to address in block 9.

**16 Abstract**
The goal of this research effort was to investigate the development of specific (i.e., quantifiable) warrants for the installation of 2-way STOP control at low volume rural intersections in Kansas. It is the recommendation of this study that state and local agencies continue to use the guidelines in the Manual for Uniform Traffic Control Devices (MUTCD) as the basis for assessing the need for 2-way STOP control at low volume intersections.

This report provides a general methodology that the traffic engineer can use to assess the sight distance and crash history considerations addressed in the MUTCD warrants, as well as driver error and other human factors that might influence the decision to use STOP control. The study further recommends the use of Commentary Driving as a means to address these various factors in a systematic and comprehensive manner.

In assessing the need for STOP control in terms of intersection crash history, the following additional guidelines should be considered. For low speed rural intersections, STOP control may be effective in reducing traffic crashes. In the case of high-speed intersections, there is evidence which suggests that STOP control may not be an effective means of reducing traffic crashes. However, until this issue is resolved, it is suggested that STOP control be considered for intersections with three to four crashes in a 3-year period. This general guideline is applicable to crash types that may be correctable by application of STOP control (i.e., side swipe, angle and rear end collisions).

In evaluating this guideline, the engineer should also consider other countermeasures that have been shown to be effective in addressing safety problems at rural intersections. These countermeasures could include sight distance improvements, speed control measures, and/or geometric improvements such as increased curb radii. At high-speed roadway intersections, the engineer may also wish to consider advance warning or advisory signing on the major roadway approaches to the intersection.

**17 Key Words**
Intersection, Low Volume Roads, Message Signs, MUTCD, Rural, Speed Limits, Stop Sign, Traffic Accidents, Traffic Safety, and Traffic Signs.

**18 Distribution Statement**
No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

**19 Security Classification (of this report)**
Unclassified

**20 Security Classification (of this page)**
Unclassified

**21 No. of pages**
60

**22 Price**

Form DOT F 1700.7 (8-72)

# EFFECTIVENESS OF TWO-WAY STOP CONTROL AT LOW-VOLUME RURAL INTERSECTIONS

Final Report

Prepared by

Robert W. Stokes, Ph.D.
Professor
Kansas State University

A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS

March 2004

# PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

# NOTICE

The authors and the state of Kansas do not endorse products or manufacturers. Trade and manufacturers names appear herein solely because they are considered essential to the object of this report.

This information is available in alternative accessible formats. To obtain an alternative format, contact the Office of Transportation Information, Kansas Department of Transportation, 915 SW Harrison Street, Room 754, Topeka, Kansas 66612-1568 or phone (785) 296-3585 (Voice) (TDD).

# DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or the policies of the state of Kansas. This report does not constitute a standard, specification or regulation.

# ACKNOWLEDGMENTS

The author gratefully acknowledges the contributions of the following individuals who served on the project advisory committee: Paul Bodner, Project Monitor, Kansas Department of Transportation (KDOT); David Church (KDOT); Bob Alva, Federal Highway Administration (FHWA); Norman Bowers, Johnson County Public Works Department; and Rod Meredith, Riley County Public Works Department.

# ABSTRACT

The goal of this research effort was to investigate the development of specific (i.e., quantifiable) warrants for the installation of 2-way STOP control at low volume rural intersections in Kansas. It is the recommendation of this study that state and local agencies continue to use the guidelines in the Manual for Uniform Traffic Control Devices (MUTCD) as the basis for assessing the need for 2-way STOP control at low volume intersections.

This report provides a general methodology that the traffic engineer can use to assess the sight distance and crash history considerations addressed in the MUTCD warrants, as well as driver error and other human factors that might influence the decision to use STOP control. The study further recommends the use of Commentary Driving as a means to address these various factors in a systematic and comprehensive manner.

In assessing the need for STOP control in terms of intersection crash history, the following additional guidelines should be considered. For low speed rural intersections, STOP control may be effective in reducing traffic crashes. In the case of high-speed intersections, there is evidence which suggests that STOP control may not be an effective means of reducing traffic crashes. However, until this issue is resolved, it is suggested that STOP control be considered for intersections with three to four crashes in a 3-year period. This general guideline is applicable to crash types that may be correctable by application of STOP control (i.e., side swipe, angle and rear end collisions).

In evaluating this guideline, the engineer should also consider other countermeasures that have been shown to be effective in addressing safety problems at rural intersections. These countermeasures could include sight distance improvements, speed control measures, and/or

geometric improvements such as increased curb radii. At high-speed roadway intersections, the engineer may also wish to consider advance warning or advisory signing on the major roadway approaches to the intersection.

# Table of Contents

# List of Tables



# List of Figures

# Chapter 1

# Introduction

STOP signs, which require traffic to stop regardless of whether conflicting traffic is present or approaching the intersection, are the primary form of traffic control at intersections in the United States. On a national basis, approximately 700,000 police-reported motor vehicle crashes occur annually at STOP controlled intersections (Retting et al., 2002). Approximately one-third of these crashes involve injuries (U.S. Department of Transportation, 2002). Although many more crashes occur at traffic signals than at STOP signs, there are more fatal crashes at STOP controlled intersections – 3,424 fatal crashes at STOP signs versus 2,785 at traffic signals in 2000 (U.S. Department of Transportation, 2002). Despite the large numbers of crashes at STOP signs and their relatively severe nature, the warrants for the use of STOP signs are very broad in nature and lack the specificity that many feel is necessary to objectively assess the need for STOP signs.

There is a need to develop specific warrants for the use of 2-way STOP control at low volume intersections. In particular, specific guidance is needed concerning minimum crash rate/frequency threshold values necessary to justify the installation of STOP signs. In addition, guidance is needed concerning the potential effectiveness of STOP control in eliminating or reducing intersection traffic crashes.

The goal of this research effort was to investigate the development of specific (i.e., quantifiable) warrants for the installation of 2-way STOP control at low volume rural intersections in Kansas. Specifically, the goal of this research was to develop guidelines to assist traffic engineers in evaluating the need for STOP control at low volume rural intersections in Kansas on the basis of motor vehicle crash histories, sight distance, roadway speed and other factors.

# Chapter 2

## Identifying Problem Intersections

The Manual on Uniform Traffic Control Devices (MUTCD)(FHWA, 2001) states that STOP signs should not be used unless engineering judgment indicates that one or more of the following conditions exist:

A. Intersection of a less important road with a main road where application of the normal right-of-way rule would not be expected to provide reasonably safe operation.
B. Street entering a through highway or street.
C. Unsignalized intersection in a signalized area.
D. High speeds, restricted view, or crash records indicate a need for control by the STOP sign.

In the case of low volume roads (AADT < 400), the MUTCD (FHWA, 2001) provides the following guidance concerning the application of STOP and YIELD signs:

- An intersection of a less important road with a main road where application of the normal right-of-way rule might not be readily apparent.
- An intersection that has restricted sight distance for the prevailing vehicle speeds.

Note that the MUTCD guidelines for low volume roads do not specifically reference intersection crash records as a consideration in evaluating the need for STOP or YIELD control.

The MUTCD warrants are very broad in nature and lack the specificity that many feel is necessary to objectively assess the need for STOP signs. This is particularly evident for warrant "D" ("High speeds, restricted view, or crash records..."). The problem is one of interpretation or definition of the "need" for a STOP sign in terms of safety and the economic impacts of the sign on traffic operations (i.e., vehicle delay). The primary difficulty encountered in applying the MUTCD warrants for STOP signs lies in quantifying the need for a STOP sign in terms of a minimum number of crashes. Specific guidance concerning the potential effectiveness of STOP control and other countermeasures in reducing intersection crashes also is needed.

This section of the report describes a framework for conducting the basic traffic engineering studies needed to assess the need for STOP control at rural intersections in terms of intersection sight distance conditions, crash histories, and other factors. The basic framework presented in this section is based, in large part, on information extracted from previous research studies, as described in Section 3 of this report.

## 2.1 Intersection Crash History

In assessing the need for intersection traffic control as a means to improve intersection safety, intersection crash histories must be examined to determine the number, type and severity of crashes. The analyst must then determine whether these data are indicative of a problem that may be correctable by application of STOP control, and/or other engineering countermeasures. The following sections of this report provide a general framework to guide the analyst through this process. For a more detailed description of procedures to identify, analyze and correct problems at high crash locations, the reader should consult the Kansas manual on *Identification, Analysis and Correction of High-Accident Locations* (“HAL” Manual) (Russell and Mulinazzi, 1994).

### *2.1.1 Crash Frequency, Type and Severity*

Crash data for intersections can be expressed in terms of numbers of crashes (crash frequency) or as a crash rate. Crashes are normally expressed in terms of a crash rate rather than crash frequency because rates account for differences in traffic volumes between intersections. Crash rates are commonly expressed as “*crashes per million vehicles entering the intersection*” (for intersections), or *"crashes per million vehicle-miles of travel"* (for non-intersection locations).

***When evaluating low-volume intersections with similar geometric features and traffic volumes, a comparison of crash frequencies is acceptable.***

To illustrate the importance of using crash rates when comparing intersections with significantly different traffic volumes, consider the following situation:

- In 2003, Intersection #1 experienced a total of 20 crashes. The average daily traffic (ADT) entering the intersection = 1500 veh/day.
- In 2003, Intersection #2 experienced a total of 30 crashes. The average daily traffic (ADT) entering the intersection = 3000 veh/day.
- In 2003, Intersection #3 experienced a total of 17 crashes. The average daily traffic (ADT) entering the intersection = 1200 veh/day.

Based on these data one might conclude that Intersection #2, with 30 crashes, is the most "hazardous" of the three intersections. However, an examination of crash rates leads to a different conclusion, as shown in the following calculations:

$$\text{Annual Intersection Crash Rate (R)} = (\text{No. of Crashes} \times 10^6)/(\text{ADT} \times 365 \text{ days/yr})$$

For Intersection #1, $R = (20 \times 10^6)/(1500 \times 365) = 36.5$ crashes per million vehicles.

For Intersection #2, $R = (30 \times 10^6)/(3000 \times 365) = 27.4$ crashes per million vehicles.

For Intersection #3, $R = (17 \times 10^6)/(1200 \times 365) = 38.8$ crashes per million vehicles.

Based on crash rates, Intersection #3 is the most hazardous.

Crash data can be expressed in terms of crash severity and crash type. Crash severity is commonly expressed in terms of:

- fatalities,
- personal injuries, and
- property damage only (PDO) crashes.

Crash (collision) type is generally defined as:

- angle,
- head on,
- rear end,
- sideswipe (same direction),
- sideswipe (opposite direction),
- left turn,
- overturned,
- fixed object,
- pedestrian, or
- parked vehicle collisions.

Angle, rear end, sideswipe, and left turn crashes are crash types that may be correctable by application of STOP control, and/or other engineering countermeasures.

***As a general guideline, STOP control may be warranted for intersections with 3 to 4 crashes in a 3 year period (see Table 3 in Section 3 of this report). This general guideline is applicable to crash types that may be correctable by application of STOP control (i.e., sideswipe, angle and left turn collisions). In evaluating this guideline, the engineer should also assess the need for other countermeasures that have been shown to be effective in addressing intersection safety problems. These countermeasures could include sight distance improvements, speed control measures, geometric improvements such as increased curb radii and turn lanes, and "other" factors as discussed in Section 2.3 of this report .***

An alternative to examining the crash frequencies of a single intersection is to base the analysis on a comparison of the crash experiences of several intersections with similar geometric and traffic characteristics. One such tool that is frequently used to identify locations with "high" crash frequencies is *Expected Value Analysis*. This basic technique is described in the following sections of this report. The Appendix provides an example application of *Expected Value*

*Analysis* and contains example *Expected Value Tables* for Kansas and other states. Additional information on *Expected Value Analysis* can be found in the following references: Garber and Hoel (1988), Parker (1991), Parsonson (1993), Stokes (1995) and South Dakota DOT (1999).

### ***2.1.2 Expected Value Analysis***

*Expected Value Analysis* is conducted by determining the average number of a specific type of crash occurring at several locations with similar geometric and traffic characteristics. This average, adjusted for a given level of confidence, indicates the "expected" value for the specific type of crash. Locations with crash frequencies that exceed the "expected" value are considered to have "higher than expected" crash frequencies. Such locations should be targeted for a detailed engineering study to determine the nature of the crash problem and what countermeasures should be implemented to address the safety problem.

***When using Expected Value Analysis as a tool to assess the need for STOP control, it is important that the analysis focus on crash types that may be correctable by application of STOP control. For example, right angle and left-turn collisions are crashes types that may be correctable by application of STOP control. However, the conditions contributing to these types of crashes may be corrected by means other than STOP control. The engineer also should evaluate countermeasures relating to sight distance conditions, approach speeds, and intersection geometry (e.g., curb radii) as possible solutions to the problem(s). There are a number of excellent resource documents that provide guidance in identifying appropriate countermeasures for frequently encountered intersection safety problems [see Table 4 in this report, Russell and Mulinazzi (1994) and Virkler and Bernhardt (1999)].***

The expected value used in the analysis is computed as follows.

$$EV = A + Zs$$

Where:

EV = expected number of crashes,

A = average number of crashes per year per location,

s = standard deviation of crash frequencies,

Z = number of standard deviations corresponding to the required confidence level.

Expected values at the 90% (Z = 1.65) and 95% (Z = 1.96) confidence levels are commonly used.

The Appendix presents an example that illustrates the use of *Expected Value Analysis* to determine if a particular location has a higher than expected crash frequency.

Expected Value Analysis has been applied on a very limited basis to state and local intersections in Kansas and other states (see Appendix for example *Expected Value Tables*). Some representative results of these applications are summarized in Table 1. This information is presented to provide some perspective concerning the range of values that might be observed at certain classes of roadway intersections and to illustrate the importance of developing expected values based on local data.

In 1996, the City of Manhattan (KS) analyzed crash data for the period 1991-95 from 103 uncontrolled residential city street intersections. The City reported an expected 95$^{th}$ percentile crash frequency of 1.5 *angle* crashes/intersection/year.

In 1995, Stokes calculated expected crash frequencies for Kansas State Highway Intersections using crash data for the period 1992-94. Stokes (1995) estimated an expected 95$^{th}$ percentile crash frequency of 1.3 *angle* crashes/intersection/year. This value represents intersections of State Transportation Plan (STP) Road Classes D and E (ADT < 3000). The estimate is based on roughly 4800 intersections that included intersections of state and non-state highways and intersection traffic controls ranging from signalized intersections to uncontrolled intersections.

While the data in Table 1 are clearly limited and very "generic" in nature (i.e., they are not based on data taken exclusively from low volume, uncontrolled rural intersection), they do lend a measure of credence to the use of the "3 or more crashes in 3-years" threshold suggested by other researchers [see Stockton et al. (1981) and Chalupnik (1998)] as a basis for considering the need for some type of intersection control at low volume intersections.

*Expected Value Analysis* can be a useful tool for identifying high crash frequency locations. However, the method does not consider differences in exposure levels (i.e., traffic volumes) and should, therefore, only be used to compare sites with similar characteristics (e.g., geometrics, traffic volumes, traffic control).

**TABLE 1: Typical Expected Crash Frequencies for 4-Leg Intersections**

| Conditions | Expected Frequency (Crashes/Year) 95th Percentile* | Source |
|---|---|---|
| Angle crashes at 7 rural 2-way Stop controlled intersections in SD. | 0.2 | South Dakota DOT (1999) |
| Angle crashes at 7 rural 4-way Stop controlled intersections in SD. | 0.4 | South Dakota DOT (1999) |
| Angle crashes at 103 uncontrolled residential intersections in Manhattan, KS. | 1.5 | City of Manhattan (1996) |
| Angle crashes at 4800 State Highway intersections in KS with various levels of control and ADT < 3000. | 1.3 | Stokes (1995) |
| Angle crashes at 66 unsignalized intersections in Atlanta, GA with entering ADT < 10,000. | 2.1 | Parsonson (1993) |
| Angle crashes at 144 unsignalized intersections at unspecified location(s) with entering ADT < 10,000. | 2.2 | Parker (1991) |

* Similar locations with crash frequencies that exceed the "expected" value are considered to have "higher than expected" crash frequencies. Such locations should be targeted for a detailed engineering study to determine the nature of the crash problem and what countermeasures should be implemented to address the safety problem.

## 2.2 Intersection Sight Distance

The sight distance at intersections can be affected by obstructing foliage, buildings too close to the intersection, changes in vertical and horizontal alignment and signs near the intersection. Studies have shown that crashes at most intersections will generally decrease when sight obstructions are removed. A Federal Highway Safety Program indicated that, of a total of 34 different improvement types, the improvement of sight distances at intersections was the most cost-effective; with improvement benefits exceeding costs by a factor of five (Fitzpatrick et al., 2000). Agent et al. (1996) suggest that intersection sight distance improvements could result in a 30 percent reduction in crashes; a reduction comparable to that which could be achieved by installing two-way STOP control (see Table 4 in Section 3 of this report).

Clear sight distance areas should be established at all intersections to ensure that obstructions do not infringe on the sight lines needed by motorists approaching the intersection. These areas usually take the form of triangles. The sight triangles should be sufficient to allow motorists approaching the intersection to see each other in time to accelerate, slow down, or stop before a collision occurs.

Table 2 shows the lengths of the intersection sight triangle legs recommended by the AASHTO (American Association of State Highway and Transportation Officials) *Green Book* (AASHTO, 2001) for intersections with no control. ***If the AASHTO intersection sight distances cannot be provided, the following countermeasures should be evaluated*** (Fitzpatrick et al., 2000).

- Cut back vegetation and/or embankments to achieve the *Green Book* sight distance values.
- Reduce speeds on approach(es) to the intersection. [Note: This countermeasure should be used with caution, as previous studies have shown that simply posting a reduced speed limit does not necessarily result in reduced approach speeds. Most drivers will drive at a speed they

perceive to be safe for the prevailing conditions. As a result, some drivers may not comply with speed limits that are perceived to be unreasonably low.]

- Install two-way STOP signs where *Green Book* sight distance values cannot be provided in all four quadrants of the intersection.

**TABLE 2: AASHTO (2001) Length of Intersection Sight Triangle Legs (No Traffic Control)**

| Metric | | US Customary | |
|---|---|---|---|
| **Design Speed (km/h)** | **Length of Leg (m)** | **Design Speed (mph)** | **Length of Leg (ft)** |
| 20 | 20 | 15 | 70 |
| 30 | 25 | 20 | 90 |
| 40 | 35 | 25 | 115 |
| 50 | 45 | 30 | 140 |
| 60 | 55 | 35 | 165 |
| 70 | 65 | 40 | 195 |
| 80 | 75 | 45 | 220 |
| 90 | 90 | 50 | 245 |
| 100 | 105 | 55 | 285 |
| 110 | 120 | 60 | 325 |
| 120 | 135 | 65 | 365 |
| 130 | 150 | 70 | 405 |
| | | 75 | 445 |
| | | 80 | 485 |

### *2.2.1 New MUTCD YIELD Sign Warrants*

Section 2B-8 of the 1988 Edition of the MUTCD (FHWA, 1988) states that "The YIELD sign may be warranted at the entrance to an intersection where it is necessary to assign right-of-way and where the *safe approach speed on the entrance exceeds 10 miles per hour*" [emphasis added].

Section 2B-09A of the Millennium Edition of the MUTCD (FHWA, 2001) states that YIELD signs may be installed "When the ability to see all potentially conflicting traffic is sufficient to allow a road user traveling at the *posted speed, the 85th-percentile speed, or the statutory speed* [emphasis added] to pass through the intersection or to stop in a safe manner."

Some traffic engineering professionals have suggested that the new MUTCD warrants for YIELD signs ***"will virtually eliminate YIELD signs as legitimate traffic control devices and require review of most YIELD sign installations for possible conversion to STOP control"*** [see "Stop signs and yield signs" discussion area at mutcd.fhwa.dot.gov].

The new (2001) MUTCD warrants for YIELD signs are mentioned here as these changes could result in significant increases in the use of STOP signs. The guidelines presented in this report could be extremely useful to local traffic engineers by providing a general framework to objectively and systematically assessing the need for STOP control at rural intersections in terms of intersection sight distance conditions, crash histories, and other factors.

### 2.3 Other Factors

The results of some previous studies suggest that crashes at two-way STOP controlled intersections may be more closely related to ***human factors and driver error***, such as failure to accurately judge the speed of major roadway vehicles, than to roadway geometry, sight distance and driver compliance with traffic control devices. For example, Retting et al. (2002) report that based on an analysis of nearly 1800 crash reports at 2-way STOP controlled intersections in four U.S. cities, about two-thirds of STOP violation crashes involve drivers who said they stopped before proceeding into the intersection. A relatively small proportion of crashes (12 percent) involved drivers who failed to stop, but these collisions were more likely to result in injury (Retting et al., 2002). Retting et al. (2002) conclude drivers don't always judge correctly whether it's safe to enter the intersection. "The most common situation we found was that a driver just didn't see the other vehicle coming" (Retting et al., 2002).

Drivers younger than 18 as well as drivers 65 and older were disproportionately found to be at fault in crashes at STOP signs, according to Retting et al. (2002). A study of Texas highway crashes conducted by Pezoldt (2003) concluded that "Young and older drivers statistically appear to have a higher fatality rate per capita than other drivers". Pezoldt (2003) found that relative to 21-64 year-olds, drivers 65 and older were: nearly two and a half times more likely to have disregarded a stop sign/light or signal, almost six times more likely to have failed to yield right of way, and about three times as likely to have died in crashes in which two vehicles were approaching at an angle. Stokes et al. (2000) report similar age-related findings from a study of "fail-to-yield" crashes at rural intersections in Kansas.

***When considering the installation of STOP signs, or when evaluating the effectiveness of existing STOP sign installations, the traffic engineer should consider the following additional, supplemental countermeasures:***

- In some cases, the shape or design of a roadway can make it difficult for drivers to see approaching traffic. Parked vehicles, shrubbery, or even glare can obstruct drivers' views. Periodic site visits should be conducted to assess the extent to which these factors could be contributing to intersection crashes.
- To the extent that some crashes result from failure to see STOP signs, efforts are needed to ensure the signs are sufficiently visible to approaching drivers. STOP signs should be inspected routinely to ensure they are not obscured by trees or other objects. Some STOP signs may lack adequate retroreflective properties; this is suggested by findings that crashes in which drivers failed to stop were more than twice as likely to occur at night (Retting et al., 2002). Supplemental pavement markings including the "STOP" message and "stop line" as well as "stop ahead" signs also can be used to increase driver awareness of sign locations. Installing an additional STOP sign on the left side of a road has been reported to be an effective countermeasure in some cases (Polanis, 1992).
- At locations where drivers may have difficulty judging whether it's safe to enter the intersection (e.g., at high speed intersections), the engineer may wish to consider advance warning or advisory signing on the major

roadway approaches to the intersection [see Figure 1 and accompanying text in Section 3 of this report].

- Other ways to reduce intersection crashes include use of all-way stops and conversion from STOP-control to roundabouts at appropriate locations. Compared with two-way STOP, all-way STOP can reduce overall crashes by 40 to 60 percent and injury crashes by 50 to 80 percent. Converting STOP-controlled intersections to roundabouts can reduce crashes by 40 percent and improve traffic flow at the same time (Retting et al., 2002). *Conversion to all-way STOP control and/or roundabouts must, of course, be based on detailed engineering studies to determine their suitability for a given intersection.*

## 2.4 Commentary Driving

The preceding sections of this report have outlined the basic factors that should be evaluated in conjunction with MUTCD (FHWA, 2001) criteria in assessing the need for intersection traffic control. This section of the report provides an introduction to a procedure that can used to assess these various factors in a systematic and comprehensive fashion. This procedure is referred to as "Commentary Driving". The material in this section of the report has been extracted from Russell et al. (1996).

A detailed description of the Commentary Driving procedure is beyond the scope of the present study. Detailed training in Commentary Driving is available in the self-taught interactive video with workbook developed by Russell (1993) at Kansas State University.

### ***2.4.1 Basic Procedure***

The information that a driver receives from the road must be correct, pertinent, concise and presented in such a way that it is readily understood and usable to the driver. In many cases, however, this information is not consistent with what the driver expects to receive or should receive. If the driver's expectancy of the roadway environment is violated, a potentially hazardous situation exists. A person whose expectancy is violated may react incorrectly, react more slowly, or not react at all.

***Commentary Driving has been shown to be an effective means for identifying locations where driver expectancies may be violated. When used in conjunction with other data, Commentary Driving also can be very effective in identifying potential countermeasures aimed at correcting certain deficiencies related to driver expectancies.***

Commentary Driving is a procedure in which at the beginning of the section of road to be evaluated for potentially hazardous locations, the driver (evaluator) states his/her "expectancies" of the road and as he/she proceeds along the road he/she "comments" on locations/conditions which violate his/her expectancy. After performing the "commentary" on a section of road, the evaluator returns (at a later date) and conducts a more detailed study of problem locations identified in the "commentary." The Commentary Driving Procedure, as developed by Hostetter et al. (1985), has been found to be a highly effective tool for conducting safety evaluations of low volume rural (LVR) roads.

The first step in the Commentary Driving procedure is to *Establish Initial Expectancies* for any road section being evaluated for information deficiencies or potentially hazardous locations. The driver (evaluator) makes statements [within first 0.8 to 1.6 kilometers (1/2 to 1 mile)] concerning the general nature of the roadway environment and initial expectancies. The principal elements upon which expectancies could be established are:

- <u>Alignment</u> – The presence or absence of horizontal curves and vertical curves, crests, etc. establishes how much sight distance will be available and the need for warning signs. Drivers establish expectancies regarding their speed, need for speed changes, attention to driving, and their overall level of comfort based on design features.
- <u>Width</u> – The lane width or the full pavement or travel width also has an affect on the driver's attention and feeling of comfort. On narrow roads,

especially those without centerlines, the motorist is more concerned about the vehicle's position on the road when there is opposing traffic.

- <u>Shoulder</u> – The presence or absence of a shoulder and shoulder condition will also have an effect on the driver's attention and feeling of comfort. Drivers will equate paved wide, and/or smooth shoulders with higher geometrics and high speeds.
- <u>Pavement</u> – Drivers establish expectancies based on the type and condition of the pavement. In general, for unpaved roads motorists expect little traffic, slow speeds and few or no warning signs. On a smooth paved surface, motorists may expect to have better geometrics and perhaps to be able to drive faster.
- <u>Speed and Speed Changes</u> – Based on the geometrics (alignment, width, shoulder, etc.) and pavement condition, the driver establishes expectancies about the safe speed, which may or may not be confirmed by the speed limit, and the need for speed changes.
- <u>Signs and Markings</u> – The mere presence or absence of signs and markings along the first part of a road establishes an expectancy of what the driver will experience for the remainder of the road. For example, if the first two curves are appropriately signed with curve warning signs, then the driver could reasonably expect the remainder of curves to be signed as well. Roads with well-marked centerlines and edgelines establish an expectancy that the road will have ample signing and markings whenever needed.

There is no precise way these expectancies should be stated. Two hypothetical examples to illustrate how one might comment on initial expectancies are presented:

1. "Now traveling on Rt. 101, Northbound. The road has a smooth surface with a 0.6 to 1.2-meter (2 to 4-foot) paved shoulder and open terrain. The road is generally straight with a few gentle curves and short crests with generally good sight distance. The road is marked with centerline and edgeline. I expect to be able to travel at 90 km/h (55 mph) even though a speed limit is not posted. I am not concerned about on-coming traffic. If

there are curves or other situations requiring a speed reduction, I expect to be warned through appropriate signing."

2. "Now traveling on Jones Bride Road, Southbound. The road is paved but there are occasional breaks in the pavement. There is no shoulder or centerline and I am not certain as to my lane limits. The road is curvilinear with several crests and dips that limit the sight distance. Except for some locations my safe speed is about 80 km/h (50 mph). There will be several occasions where I will have to reduce my speed but I expect to receive curve warning signs with speed advisory only at those locations that are really severe."

Following the statement of initial expectancies concerning the road, the driver continues through the section providing continuous (running) commentary as a method to identify potential information deficient locations. (Obvious information deficient locations within the first mile or two should be identified as a result of the expectancy statement commentary.) This procedure is recommended because it forces the driver/evaluator to verbally state what is expected of the road ahead and how it should be handled. By doing so, the driver becomes more sensitive to locations and situations where the road is not as expected and needed warning information was not provided. The comments should be oriented towards:

1) what the drivers expect of the road ahead relative to any of the following items: direction (straight, curve left, curve right; sharpness of curve); approaching vehicles; bridge width; right-of-way at intersection; other roadway conditions (e.g., pavement condition, shoulders, etc.)
2) what actions are required of the driver regarding speed changes, turns, passing, etc., and
3) if there is any uncertainty as to any item related to 1) or 2).

The commentary need not be long or continuous. On very long straight sections of road with good sight distance, there may not be any need for comments except for an occasional restating of the general expectancies for the road. The driver should travel at the speed limit, or as close to it as is comfortable.

Although not necessary, it is suggested that the commentary be audio or video-taped and kept on file. The comments could be replayed whenever the site is being further evaluated. Furthermore, it could serve as evidence that an evaluation of signing needs was made if such evidence is ever required for a tort liability case.

The next step in the process is to conduct a more detailed survey of those sites identified as potential problems (i.e., information-deficient locations) during the commentary driving. Upon returning to each potential problem site, a more detailed assessment should be made to confirm or modify the initial problem identification and information deficiency. The detailed survey should focus on the nature of the problem and preliminary recommendations as to how it could be resolved. The reader is directed to Russell et al. (1993) for sample “Checklists” that have been developed to assist the evaluator in completing this phase of the process.

# Chapter 3

# Effectiveness of Stop Control

A number of studies have been conducted to identify the factors that might affect the safety and operations of rural intersections. Previous studies also have evaluated the potential effectiveness of various measures that can be used to improve the safety of rural intersections. Some studies suggest that application of STOP control can result in significant reductions in intersection crashes. On the other hand, there is evidence suggesting that intersection crashes may be independent of the type of traffic control used. For example, while several previous studies have shown that STOP sign violation rates decrease with increasing traffic volumes on the major (uncontrolled) roadway, there is evidence that suggests that crash frequency is not correlated with STOP sign violation rates. The results of some previous studies suggest that crashes at two-way STOP controlled intersections are more closely related to driver error, such as failure to accurately judge the speed of major roadway vehicles, than to roadway geometry, sight distance and driver compliance with traffic control devices.

A summary of the findings from previous research efforts concerning the potential effectiveness of STOP control and related countermeasures at rural intersections is presented in the following sections of this report.

## 3.1 National Studies

It has been suggested that one of the causes of crashes at rural intersections is driver confusion concerning right-of-way conditions. Picha et al. (1996) conducted laboratory and field studies to determine ways to improve two-way STOP-controlled (TWSC) intersections that either experience high/severe crash frequencies or driver confusion concerning right-of-way conditions. Based on the results of their study, Picha et al. (1996) formulated several general guidelines concerning traffic control devices at TWSC intersections. Picha et al. (1996) suggest that the existence of any one of the following seven conditions may be indicative of a location where drivers may misinterpret a TWSC intersection as being an all-way STOP-controlled intersection.

1) The intersection of two single-jurisdictional roadways in a rural or isolated area.
2) Average daily volumes on all approaches are similar but not large enough to warrant the use of a traffic signal (volumes of 5,000 to 10,000 ADT)
3) A rate of four traffic conflicts (one or both drivers take evasive action to avoid a collision) for every 1000 vehicles.
4) Right-angle crash frequency of three or more per year.
5) A system of roadway intersections that is not consistent with respect to traffic control schemes.
6) Similar, high speeds (greater than 80 km/h) on all approaches.
7) Similar cross-sectional elements (number of lanes, width, etc) on all approaches.

If one of these conditions is met, Picha et al. (1996) recommend adding the supplemental sign “CROSS TRAFFIC DOES NOT STOP” to the STOP sign installation.

Gattis (1995) also has examined the effectiveness of supplemental signing for STOP signs. The researchers performed the study by 1) reviewing the literature on the topic of supplemental signs that display the general message “CROSS TRAFFIC DOES NOT STOP”, 2) mailing out a survey to identify agencies that use supplemental signing on STOP signs, and 3) surveying state and local highway officials concerning the effectiveness of supplemental signing for STOP signs. Over 300 traffic officials responded to the survey.

Gattis (1995) concluded that the “CROSS TRAFFIC DOES NOT STOP” type of supplemental signing should be used on a limited basis. It should be in place at locations where there are repeated occurrences of possible misunderstandings regarding the assignment of intersection right of way.  Otherwise, drivers may expect the sign at all two-way STOP-controlled intersections.

Gattis (1995) cites a study by Pietrucha et al. that addressed the question of why drivers violate STOP controls.  Using data from field studies of 142 urban sites over 528 hours of observation, Pietrucha et al. found a 67.6 percent STOP sign violation rate.  Over a third of the drivers who violated the STOP sign stated they did so because cross-street volumes were low. Gattis notes that Pietrucha et al. reported that for major roadway volumes under 6000 vehicles per day, STOP sign violation rates decreased with increasing traffic volumes on the major roadway.  Mounce (1981) reports similar results.

Kalakota et al. (1994) studied variations in crashes as a function of geometric variables. The following summarizes their findings concerning variations in crash rates.

1) An increase in average daily traffic is the most significant factor in increasing the number of injury and fatality accidents at signalized intersections.
2) Nonsignalized intersections with higher posted speed limits (50 to 55 mph) are prone to more accidents than comparable low speed intersections.
3) The wider the pavement, the fewer the accidents.
4) Shoulder width is not a significant factor in accidents on curves.

Jarvis et al. (1990) assessed the effectiveness of yellow bar markings as a speed-reducing device for drivers on approaches to isolated rural intersections.  In their study, Jarvis et al. placed 30 yellow bar markings beginning 35 m from the stop bar of the study intersection approaches. They found that the yellow bar markings significantly reduced driver speeds.  Reduction in driver approach speed reached a maximum at 200 m from the stop (50 m after the beginning of the markings).  The maximum reductions varied from three to five km/h.  However, the researchers suggested that the greatest benefit of the markings was to increase driver awareness, rather than directly causing drivers to reduce speed.

Solomon (1974) studied the relationships between factors affecting the crash rates on major rural highways. The most relevant findings of the study are:

1) The greater the difference in speed of a vehicle relative to the average roadway speed, the greater the chance of that vehicle being in an accident.
2) Local drivers tended to have higher accident rates than other drivers.
3) Passenger cars with low horsepower had higher involvement rates in accidents, possibly due to low acceleration capability.
4) Nearly half of all accidents were either rear-end collisions or same-direction sideswipes.
5) The proportion of angle collisions was highest at low speeds (less than 25 mph).
6) Drivers of older cars were more likely to be involved in an accident than drivers of newer vehicles.

Zaidel et al. (1986) studied the effectiveness of transverse paint stripes and similarly placed rumble strips in inducing drivers to decrease speed and stop at intersections. They found either application, rumble strips or paint stripes, had positive effects on driver behavior. The primary change in driver behavior attributed to the paint stripes was an increase in the percentage of drivers that stopped. In the before condition, 79 percent of the drivers made a complete stop, 11 percent made a rolling stop, and 10 percent did not stop. After application of the paint stripe treatment, 85 percent stopped, 7 percent rolled through, and 8 percent did not stop. The main effect of the rumble strips was a reduction in driver speeds. Specifically, intersection approach speeds were reduced by an average of 40 percent following the application of the rumble strips.

Stockton et al. (1981) have proposed criteria for the application of two-way STOP, YIELD, and No Control at low-volume intersections. The researchers determined that intersection geometry does not play a significant role in either safety or operational considerations for choosing between control type (STOP, YIELD, or No Control). However, major road volume did significantly affect crash potential at low-volume intersections and should be included in the criteria for determining the appropriate type of traffic control device. Stockton et al. (1981) also concluded that sight distance had no significant effect on crashes, as long as the sight distance was based on the "safe approach speed" of 10 mph recommended by the 1988 MUTCD for STOP signs. [See related discussion in Section 2.2.1 of this report].

The criteria suggested by Stockton et al. (1981) for determining the appropriate control for low volume intersections are summarized in Table 3. It should be noted that the material in Table 3 is intended to be used in conjunction with appropriate MUTCD criteria is assessing the need for STOP or YIELD control.

**TABLE 3: Summary of Suggested Control Criteria**
**(Stockton, et al., 1981)**

<table>
<tr><th rowspan="2">Sight Distance</th><th rowspan="2">Accident History<br>(Last 3 Years)</th><th colspan="2">Major Roadway Volume</th></tr>
<tr><th>£ 2000 vpd</th><th>> 2000 vpd</th></tr>
<tr><td rowspan="4">Adequate</td><td>0</td><td>No Control</td><td></td></tr>
<tr><td>≤ 2</td><td colspan="2">YIELD</td></tr>
<tr><td>3</td><td colspan="2">STOP*</td></tr>
<tr><td>4+</td><td colspan="2" rowspan="2">STOP</td></tr>
<tr><td>Not Adequate</td><td>Not Applicable</td></tr>
</table>

* If minor roadway volume is greater than 300 vpd, YIELD control is appropriate for intersections with less than 4 accidents in 3 years.
Note: The material in this table is intended to be used in conjunction with appropriate MUTCD criteria is assessing the need for STOP or YIELD control.

Mounce (1981) reports that the data from 2,830 observations at 66 intersections indicate that: 1) the STOP sign violation rate decreases with increasing major roadway volume; 2) the violation rate is significantly higher when sight distance is unrestricted than it is when sight distance is restricted; and 3) there is no correlation between STOP sign violation rates and crashes.

Mounce (1981) concluded that the operational effectiveness of low volume intersections could be enhanced without negatively affecting intersection safety by the application of NO CONTROL sign control when major roadway volumes are less than 2000 vpd, application of YIELD sign control at major roadway volumes between 2000 - 5000 vpd, and, depending on minor roadway volume, application of STOP sign control or signalization when major roadway volumes exceed 5000 vpd.

Chalupnik, in a 1998 study of the use of traffic control at low volume (< 500 ADT) intersections in Minnesota, reports findings very similar to those of Stockton et al. (1981) and Mounce (1981).

Specifically, Chalupnik found that for high speed, rural intersections, the type of control (STOP, YIELD, and No Control) has no appreciable effect on crash rates. A summary of Chalupnik's findings follows.

1) Of the low speed intersections sampled, the 25 intersections with STOP control experienced the fewest number of crashes (one crash) during the 1991-1995 study period.
2) Of the low speed intersections sampled, the 25 intersections with YIELD control and the 25 UNCONTROLLED intersections experienced a total of 16 and 25 crashes, respectively, during the 1991-1995 study period.
3) In some cases, YIELD control and NO CONTROL can be effective methods of traffic control at low volume, low speed intersections. There were no crashes at 17 of the 25 YIELD controlled intersections and at 17 of the 25 UNCONTROLLED intersections during the 1991-1995 study period.
4) It is suggested that low speed UNCONTROLLED intersections with three or more crashes associated with right-of-way control in the past three years be studied to determine whether more control is needed.
5) It is suggested that low speed YIELD controlled intersections with three or more crashes associated with right-of-way control in the past three years

be studied to determine whether the intersection should be converted to STOP control.

6) Control type had no appreciable effect on crash experience at the high speed intersections sampled.

7) It is suggested that UNCONTROLLED high speed intersections with three or more crashes associated with right-of-way control in the past three years be studied to determine whether more control is needed.

8) It is suggested that YIELD controlled high speed intersections with three or more crashes associated with right-of-way control in the past three years be studied to determine whether the intersections should be converted to STOP control.

Note: Chalupnik provides no specific criteria to substantiate the number of crashes used as the threshold in items 4, 5, 7 and 8 above. However, three crashes in three years is within the range suggested by Stockton et al. (1981) and other researchers.

A number of researchers have developed crash reduction factors associated with various types of highway safety improvements [see Fitzpatrick et al. (2000), Agent et al. (1996), Russell and Mulinazzi (1994), Virkler and Bernhardt (1999)]. Table 4 provides a summary of typical crash reduction factors that may be applicable to rural intersection improvements. While these reduction factors can be useful in assessing the potential effectiveness of various improvements, it must be recognized that the improvements must be based on sound engineering judgment and traffic studies if the potential benefits are to be fully realized. Note also that not all researchers are in agreement concerning the potential effectiveness of STOP control in reducing intersection crashes.

**TABLE 4: Typical Crash Reduction Factors for Intersection Improvements**

| Type of Improvement | Percent Crash Reduction* |
|---|---|
| STOP Ahead Warning Signs | 30 |
| STOP Sign (Two-way) | 35 |
| All-Way STOP | 55 |
| YIELD Sign | 45 |
| Sight Distance Improvement | 30 |
| Add Acceleration/Deceleration Lane | 10 |
| Add Left-Turn Lane | 25 |
| Left-Turn Related Crashes | 50 |
| Add Right-Turn Lane | 25 |
| Right-Turn Related Crashes | 50 |
| Increase Turning Radii | 15 |

* Refers to "All Accidents" unless a specific crash type is noted.
Source: Agent et al. (1996).

### 3.2 Kansas Studies

In recent years, the Kansas Department of Transportation (KDOT) has sponsored several research studies that have examined safety issues at the state's rural intersections. The results of two of those studies with potential applications to the current research effort are summarized below.

Stokes et al. (2000) examined rural intersection crashes in Kansas caused by STOP sign violation and failure to yield the right-of-way. The objectives of that study were 1) to identify the factors that contribute to accidents caused by failure to stop and failure to yield the right-of-way at rural two-way STOP-controlled intersections on the state highway system, and 2) to determine what traffic control devices or other measures could be effective in reducing the frequency of these crashes. The results of the study (and previous studies) suggest that disregard for STOP signs and other traffic control devices is not the primary cause of accidents at rural two-way STOP controlled intersections. The majority of the accidents appear to be due to drivers who enter the major roadway and do not (or cannot) accelerate quickly enough to avoid being struck by major roadway vehicles. This would suggest that drivers on the minor roadway either did not see oncoming vehicles or failed to accurately estimate the speeds of oncoming vehicles on the major roadway. Retting et al. (2002) report similar findings. On the basis of these preliminary conclusions, the following general recommendations were put forth for the department's [KDOT] consideration: 1) the department should continue to follow its current signing practices on the minor roadway approaches of rural intersections; and 2) in the case of rural two-way STOP controlled intersections where crash histories indicate characteristics similar to those reported in this study, the department should consider implementing signing treatments directed at advising motorists on the major roadway of the intersection ahead.

Concerning potential signing treatments for the major roadway, Lyles (1980) has evaluated five basic signing strategies in terms of their effectiveness in reducing motorists' speeds on the major roadway approaches of intersections. The sign treatments evaluated by Lyles included the standard intersection "cross" symbol, 3 variations of the "VEHICLES ENTERING" sign and the "REDUCED SPEED AHEAD" sign. The basic treatments evaluated by Lyles are shown in Figure 1. Lyles found that the "VEHICLES ENTERING" sign with additional "WHEN FLASHING" plaque and beacons activated by side road traffic was the most effective in reducing motorists' speeds in the vicinity of the intersection and increasing their awareness of both the signs and conditions at the intersection.

In an effort to improve the safety of at-grade intersections in Kansas, KDOT has constructed "wide" median intersections on several 4-lane divided state highways. These "wide" medians were constructed by widening the "normal" median width of 60 feet to approximately 150 feet. Stokes and Robinson (2000) have examined the safety benefits of these widened median intersections relative to non-widened (i.e., "normal") median intersections. When considering all crash classifications, Stokes and Robinson (2000) observed slightly higher angle collision crash rates at widened medians than at non-widened median sites. It should be noted that the higher crash rates may not be directly attributable to the design of the widened medians.

The nature of the widening project resulted in a general upgrading of the highways examined and other operational consequences (e.g., higher operating speeds and increased traffic volumes) resulting from the improvements may have contributed to the observed increases in overall crash rates. Furthermore, the widened medians represent substantial upgrades from basic uncontrolled "median openings" to STOP-controlled "intersections". This upgrade requires motorists to accomplish a crossing or turning maneuver from a stopped position, as compared to the possibility of completing these maneuvers from a "running start" when using the narrower median openings. The results from a previous KDOT study [see Stokes et al. (2000)] suggest that one of the causes of crashes at STOP controlled rural intersections may be related to the driver's inability to accurately judge the speed of oncoming vehicles and the failure or inability to accelerate quickly enough to avoid being struck by vehicles on the major roadway.

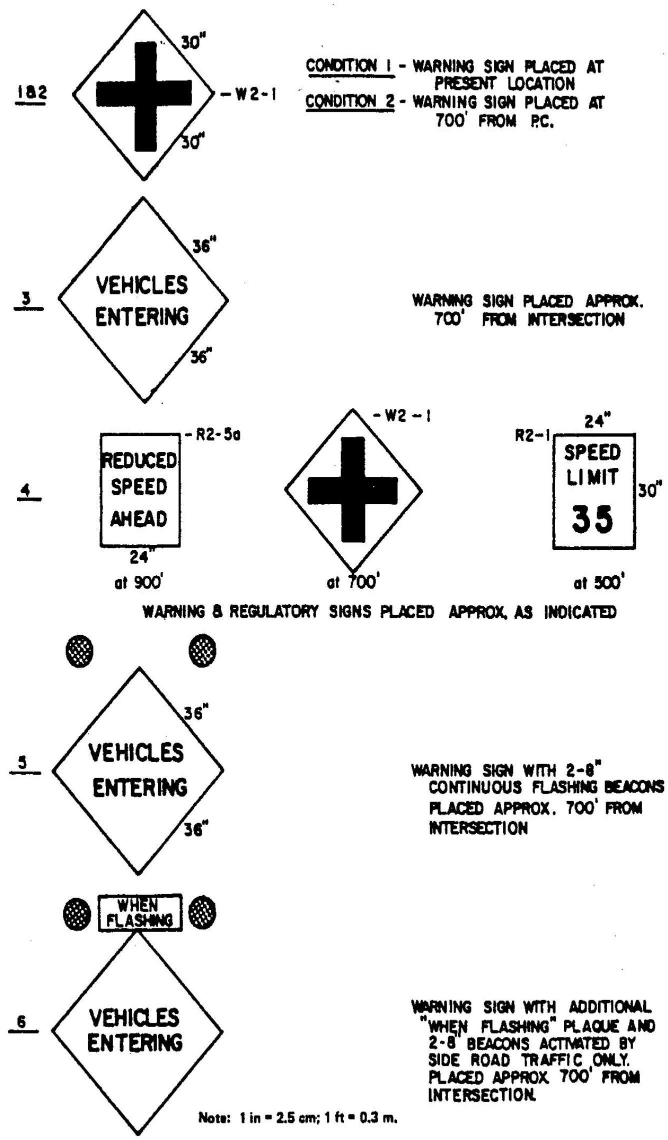


**Figure 1. Major Roadway Signing Treatments Evaluated by Lyles**

# Chapter 4

# Conclusions and Recommendations

## 4.1 Conclusions

The goal of this research effort was to investigate the development of specific (quantifiable) warrants for the installation of 2-way STOP control at low volume rural intersections in Kansas. A review of the four basic MUTCD warrants for the installation of 2-way STOP signs (see Section 2 of this report) suggests that the most difficult of the warrants to assess is likely to be the warrant concerning "high speeds, restricted view, and crash records". In addition, the new (2001) MUTCD warrants for YIELD signs (see discussion in Section 2.2.1 of this report) could result in a significant increase in the use of STOP signs. Therefore, the guidelines presented in this report could be extremely useful to local traffic engineers by providing a general framework to objectively and systematically assess the need for STOP control at rural intersections in terms of intersection sight distance conditions, crash histories, and other factors.

While several previous studies have shown that STOP sign violation rates decrease with increasing traffic volumes on the major (uncontrolled) roadway, there is some evidence that suggests that crash frequency may not be correlated with STOP sign violation rates. The results of some previous studies suggest that crashes at two-way STOP controlled intersections are more closely related to driver error, such as failure to accurately judge the speed of major roadway vehicles, than to roadway geometry, sight distance and driver compliance with traffic control devices.

The results of the exploratory analyses conducted as part of this research effort suggest that the safety benefits of STOP, YIELD and NO CONTROL could be quite different at low vs. high speed, low volume intersections. For example, at low speed intersections, STOP control may be effective in reducing traffic crashes. For high-speed roadways, there is a growing body of evidence that suggests that STOP controlled intersections may not experience fewer crashes than comparable intersections with YIELD or NO CONTROL. Specifically, some research findings suggest that for low volume, high-speed intersections, control type may have no appreciable effect on crash experience [see Mounce (1981), Chalupnik (1998)]. This preliminary evidence indicates that measures directed at improving safety at high speed, low volume rural intersections may have to consider a broader range of options than traditional traffic control strategies that focus on the controlled approach to the intersection. These may include expanded consideration of driver behavior and human factors issues, and/or the use of traffic control devices on the major roadway approaches to rural intersections.

## 4.2 Recommendations

1) State and local agencies should continue to use the guidelines in the MUTCD as the basis for assessing the need for 2-way STOP control at low volume intersections. The basic framework outlined in Section 2 of this report provides guidance in assessing the sight distance and crash history considerations addressed in the MUTCD warrants. In assessing the need for STOP control in terms of intersection crash history, the following additional guidelines should be considered.

   There is evidence to suggest that STOP control may not be an effective means of reducing traffic crashes at high-speed roadway intersections. However, until further research is conducted, it is suggested that STOP control may be warranted for intersections with 3 to 4 crashes in a 3-year period (refer to Table 3 in this report). This general guideline is applicable to crash types that may be correctable by application of STOP control (i.e., sideswipe, angle and rear end collisions). In evaluating this guideline, the engineer should also assess the need for other countermeasures that have been shown to be effective in addressing intersection safety problems. These countermeasures could include sight distance improvements, speed control measures, and/or geometric improvements such as increased curb radii. At high-speed roadway intersections, the engineer may also wish to consider advance warning or advisory signing on the major roadway approaches to the intersection. At locations with many younger (under 21) and/or older (65 and older) drivers, the engineer should consider countermeasures directed at the problems encountered by these specific age groups.

2) KDOT should encourage local transportation agencies to compile crash data before-and-after the installation of 2-way STOP signs at low volume rural intersections. These data would be extremely valuable in assessing the safety benefits of 2-way STOP control.

3) KDOT should encourage local transportation agencies to develop *Expected Value Analysis Tables* for local intersections. Such tables would be useful in assessing the need for STOP control at rural intersections.

4) KDOT should consider initiating research efforts to assess the potential effectiveness of major roadway signing treatments as a means to improve the safety of high speed 2-way STOP controlled intersections.

5) Some traffic engineering professionals have suggested that the new (2001) MUTCD warrants for YIELD signs "will virtually eliminate YIELD signs as legitimate traffic control devices and require review of most YIELD sign installations <u>for possible conversion to STOP control</u>" [emphasis added]. KDOT should initiate efforts to clarify the interpretation of the new YIELD Sign warrants and assess the potential implications of these warrants as they relate to State and local signing policies and practices.

# Chapter 5

# Implementation

The results of this study and K-TRAN Study, K-TRAN: KSU-98-6: Analysis of Rural Intersection Accidents Caused by Stop Sign Violation and Failure to Yield the Right-of Way, should be evaluated for possible incorporation into the next edition of the Kansas *Low Volume Roads (LVR) Handbook*.

# BIBLIOGRAPHY

ADJ Limited. "Manual of Low-cost Roadway Safety Improvements for Rural Highways." Fredericton, New Brunswick. May 1981.

Agent, K.R., N. Stamatiadis and S. Jones. "Development of Accident Reduction Factors." Research Rept. KTC-96-13. Kentucky Transportation Center, Lexington, KY. June 1996.

American Association of State Highway and Transportation Officials (AASHTO). "A Policy on Geometric Design of Highways and Streets" *(Green Book).* Washington, DC. 2001.

Buhman, D.C., J.H. Flowers and R. Bishu. "Vehicle Velocity Estimation by the Stationary Observer: Field and Laboratory Comparisons." Univ. of Nebraska-Lincoln. Dept. of Psychology. Undated.

Chalupnik, I. A. "The Use of Traffic Control at Low Volume Intersections in Minnesota." Rept. No. MN/RC-1998-23. Minnesota Dept. of Transportation. St. Paul, MN. August 1998.

Chrissikopoulos, V., Darzentas, J., and McDowell, M. "Deceleration of Major-road Vehicles Approaching a T-junction." Traffic Engineering and Control. September 1983.

City of Manhattan (KS). "Neighborhood Traffic Controls". Public Works Dept., Engineering Division. Manhattan, KS. Oct. 1996.

Cooper, P. "Predicting Intersection Accidents." Transport Canada. Ottawa. September 1973.

Federal Highway Administration (FHWA). "Manual on Uniform Traffic Control Devices" (MUTCD). US Department of Transportation, Washington, DC. 2001.

Federal Highway Administration (FHWA). "Manual on Uniform Traffic Control Devices" (MUTCD). US Department of Transportation, Washington, DC. 1988.

Fitzpatrick, K., K. Balke, D.W. Harwood and I.B. Anderson. "Accident Mitigation Guide for Congested Rural Two-Lane Highways." NCHRP Rept. 440. Transportation Research Board, Washington, DC. 2000.

Garber, N.J. and L.A. Hoel. "Traffic and Highway Engineering." West Publishing Co. St. Paul, MN. 1988.

Gattis, J. "Supplemental Signing for Stop Signs." University of Arkansas. Fayetteville, AR. October 1995.

Hall, K. "Analysis of Traffic Accidents within the Functional Area of Intersections and Driveways." Rept. No. TRANS-1-95. Portland State University. Portland, OR. 1995.

Hostetter, R.S., H. McGee, K. Crowley and W. Hughes. "Driver Needs on Two-Lane Rural Highways, Vol. II - Simplified Location of Information Deficiencies (SLIDE): A

Procedure." U.S. Department of Transportation. Federal Highway Administration. Washington, DC. 1985.

Jarvis, J. and Jordan, P. "Yellow Bar Markings: Their Design and Effect on Driver Behavior." Proceedings of the 15th ARRB Conference, Part 7. 1990.

Kalakota, K. and Seneveratne, P. "Accident Prediction Models for Two-lane Rural Highways." North Dakota State University. Bismarck, ND. May 1994.

Lyles, R. "Evaluation of Signs for Hazardous Rural Intersections." Transportation Research Record 782. Transportation Research Board. Washington, DC. 1980.

McShane, W.R., R.P. Roess and E.S. Prassas. "Traffic Engineering, 2nd ed." Prentice Hall. Upper Saddle River, NJ. 1998.

Mounce, J.M. "Driver Compliance with Stop-Sign Control at Low-Volume Intersections." Transportation Research Record 808. Transportation Research Board. Washington, D.C. 1981.

Pant, P. "Comparative Study of Advance Warning Signs at High Speed Signalized Intersections." Transportation Research Record 1495. Transportation Research Board. Washington, DC. 1995.

Parker, M. "Highway Safety Engineering Studies: Procedural Guide." Rept. No. FHWA-HI-88-39. Federal Highway Administration, U.S. Department of Transportation. Washington, DC. 1991.

Parsonson, P.S. "Expected Values for Accident Analyses at Atlanta Intersection." Project No. E-20-X73. Georgia Institute of Technology, School of Civil Engineering. Atlanta, GA. Final Progress Rept., December 15, 1993.

Pezoldt, V. "Younger and Older Drivers: Where are the Greatest Crash Risks?" In: *Texas Transportation Researcher*, Vol. 39, No. 2. Texas Transportation Institute, College Station, TX. 2003.

Picha, D., Shuckel, C., Parham, A. and Mai, C. "Traffic Control Devices at Two-way Stop-Controlled Intersections." Rept. No. 1374-1F, Texas Transportation Institute. Texas Department of Transportation. Austin, TX. November 1996.

Polanis, S.F. "Reducing Traffic Accidents through Traffic Engineering." Transportation Quarterly. Vol. 46. 1992.

Radwan, A., Sinha, K. and Michael, H. "Development and Use of a Computer Simulation Model for the Evaluation of Design and Control Alternative for Intersections of Minor Roads with Multi-lane Rural Highways: Selection of the Simulation Model." Rept. No. FHWA/ISHC/JHRP-79/8. U.S. Department of Transportation. Federal Highway

Administration. Washington, DC. July 1979.

Retting, R.A., H.B. Weinstein and M.G. Solomon. "Analysis of Motor Vehicle Crashes at Stop Signs in Four U.S. Cities." Insurance Institute for Highway Safety. Arlington, VA. July 2002.

Russell, E.R. and T. Mulinazzi. "Identification, Analysis and Correction of High-Accident Locations, 2nd ed." Kansas DOT, Topeka, KS. 1994.

Russell, E.R., B.L. Smith and W. Brondell. "Traffic Safety Assessment Guide." Contract No. DTFH61-94-C-00123. U.S. Department of Transportation. Federal Highway Administration. Washington, DC. April 1996.

Russell, E.R. "Commentary Driving: A Self-Taught Interactive Video/Workbook." Kansas State University, Department of Civil Engineering, 2118 Fiedler Hall, Manhattan, KS 66506. 1993.

Solomon, D. "Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle." U.S. Department of Transportation. Federal Highway Administration. Washington, DC. 1974.

South Dakota Department of Transportation. "Identification of Abnormal Accident Patterns at Intersections." Rept. No. SD98-12. South Dakota DOT, Office of Research, Pierre, SD. August 1999.

Stockton, W., Brackett, R. and Mounce, J. "Stop, Yield, and No Control at Intersections." Rept. No. FHWA/RD-81/084. U.S. Department of Transportation. Federal Highway Administration. Washington, DC. June 1981.

Stokes, R.W., et al. "Analysis of Rural Intersection Accidents Caused by Stop Sign Violation and Failure to Yield the Right-of-Way." Rept. No. K-TRAN KSU-98-6. Kansas DOT, Topeka, KS. September, 2000.

Stokes, R.W. and R.K. Robinson. "Assessment of Safety Benefits of Widened Median Intersections on Rural 4-Lane Divided Highways in Kansas." Rept. No. K-TRAN KSU-99-3 (Unpublished Technical Memorandum). Kansas DOT, Topeka, KS. December, 2000.

Stokes, R.W. "Expected Value Analysis for Kansas State Highway Intersections." Rept. No. K-TRAN KSU-94-4 (Unpublished Report). Kansas DOT, Topeka, KS. December, 1995.

U.S. Department of Transportation. "Traffic Safety Facts, 2000." Rept. No. DOT HS-809-337. Washington, DC. 2002.

Virkler, M.R. and K.L. Sanford Bernhardt. "Manual on Identification, Analysis and Correction of High-Crash Locations, 3rd ed." Missouri DOT Technology Transfer Assistance Program. 1999.

Zaidel, D., Hackert, A. and Barkan, R. "Rumble Strips and Paint Stripes at a Rural Intersection." Transportation Research Record 1069. Transportation Research Board. Washington, DC. 1986.

# Appendix A

## Expected Value Analysis

### A.1 Example Application

Data collected for 3 consecutive years at an intersection study site show that 14 rear-end collisions and 10 left-turn collisions occurred during the 3 year study period. Crash data from 10 other intersections with similar geometric and traffic characteristics are shown in the following table. Based on these data, determine whether rear-end and left-turn collisions at the study intersection are "higher than expected" for a 95 percent confidence level.

**TABLE A1: Three-Year Crash History at 10 Intersections**

| Intersection Number | Rear-End Crashes | Left-Turn Crashes |
|---|---|---|
| 1 | 8 | 11 |
| 2 | 5 | 12 |
| 3 | 7 | 4 |
| 4 | 8 | 5 |
| 5 | 6 | 8 |
| 6 | 8 | 3 |
| 7 | 9 | 4 |
| 8 | 10 | 9 |
| 9 | 6 | 7 |
| 10 | 7 | 6 |
| Average (A) | 7.40 | 6.90 |
| Standard Deviations (s) | 1.50 | 3.07 |

### A.2 Solution (Rear End Collisions)

Average rear-end crashes at the 10 other similar intersections = 7.4

Standard deviation of rear-end crashes at the 10 other similar intersections = 1.50

Maximum Expected Value (95%) = 7.4 + (1.96 x 1.50) = 10.3

Number of rear-end crashes at study intersection = 14 (greater than maximum expected).

Conclusion: rear-end crashes are higher than expected at the study intersection.

Therefore, the physical (geometric) and operating characteristics of the intersection should be studied to identify potential countermeasures to address the safety problem(s).

### A.3 Solution (Left-Turn Collisions)

Average left-turn crashes at the 10 other similar intersections = 6.9

Standard deviation of left-turn crashes at the 10 other similar intersections = 3.07

Maximum Expected Value (95%) = 6.9 + (1.96 x 3.07) = 12.9

Number of left-turn crashes at study intersection = 10 (less than maximum expected).

Conclusion: Left-turn crashes are within the expected range for intersections of this type.

### A.4 Examples of Expected Value Analysis Tables

The following pages present examples of *Expected Value Analysis Tables* that have been developed for rural intersections in Kansas, South Dakota and other states. The Kansas examples (Table A2) are from Stokes (1995). The South Dakota examples (Table A3) are from South Dakota DOT (1999). Table A4 is from Parker (1991) and represents data from unspecified locations.

The example tables are intended to illustrate the suggested format for Expected Value Analysis Tables and to show the range of values that have been developed for rural intersections. ***It is suggested that local agencies develop their own tables from local data, rather than simply "borrowing" values from the example tables.***

The following abbreviations are used in the Kansas Tables:

- N = total number of intersections,
- n = number of crashes (1992-94),
- S/S = intersection of two state highways,
- S/N = intersection of state and non-state highways
- Road Class = State Transportation Plan Road Class. The data in the example tables are for
- Road Classes D and E (ADT < 3000).

# TABLE A2: Expected Value Accident Analysis of Kansas State Highway Intersections

**RURAL INTERSECTIONS**

| ROAD CLASS: D | INTERSECTION CLASS: SS | TRAFFIC CONTROL: ALL |
|---|---|---|

**N = 126**

| Characteristic | n | Accidents per Year: Mean | Accidents per Year: 90th Percentile | Accidents per Year: 95th Percentile |
|---|---|---|---|---|
| **Severity:** | | | | |
| Fatal | 6 | 0.0159 | 0.2238 | 0.2628 |
| Injury | 128 | 0.3386 | 1.2988 | 1.4792 |
| Property Damage Only | 220 | 0.5820 | 1.8408 | 2.0773 |
| **Accident Type:** | | | | |
| Head on | 5 | 0.0132 | 0.2030 | 0.2386 |
| Rear End | 90 | 0.2381 | 1.0432 | 1.1945 |
| Angle | 151 | 0.3995 | 1.4423 | 1.6383 |
| Sideswipe-Opposing | 6 | 0.0159 | 0.2238 | 0.2628 |
| Sideswipe-Overtaking | 20 | 0.0529 | 0.4324 | 0.5038 |
| Left Turn with Through | 18 | 0.0476 | 0.4077 | 0.4753 |
| Overturned | 7 | 0.0185 | 0.2431 | 0.2852 |
| Pedestrian | 1 | 0.0026 | 0.0875 | 0.1035 |
| Parked Vehicle | 1 | 0.0026 | 0.0875 | 0.1035 |
| Pedalcycle | 0 | 0.0000 | 0.0000 | 0.0000 |
| Animal | 5 | 0.0132 | 0.2030 | 0.2386 |
| Fixed Object | 50 | 0.1323 | 0.7324 | 0.8451 |
| **Light Conditions:** | | | | |
| Daylight | 273 | 0.7222 | 2.1245 | 2.3879 |
| Dawn/Dusk | 11 | 0.0291 | 0.3106 | 0.3635 |
| Dark | 70 | 0.1852 | 0.8952 | 1.0286 |
| **Surface Conditions:** | | | | |
| Dry | 291 | 0.7698 | 2.2176 | 2.4896 |
| Wet | 47 | 0.1243 | 0.7062 | 0.8155 |
| Snow/Ice | 16 | 0.0423 | 0.3818 | 0.4456 |
| **Quarter of Year:** | | | | |
| January – March | 60 | 0.1587 | 0.8161 | 0.9396 |
| April – June | 92 | 0.2434 | 1.0574 | 1.2103 |
| July – September | 101 | 0.2672 | 1.1201 | 1.2803 |
| October – December | 101 | 0.2672 | 1.1201 | 1.2803 |
| **Hour of day:** | | | | |
| 00:00 - 06:00 | 21 | 0.0556 | 0.4445 | 0.5175 |
| 06:01 - 12:00 | 91 | 0.2460 | 1.0645 | 1.2182 |
| 12:01 - 18:00 | 171 | 0.4524 | 1.5622 | 1.7707 |
| 18:01 - 24:00 | 68 | 0.1799 | 0.8797 | 1.0112 |
| **Total:** | 354 | 0.9365 | 2.5333 | 2.8333 |

Traffic Control Type "ALL" includes signals, beacons, beacons w/stop, 4-way stop and all other types of control (2-way stop, yield, uncontrolled, etc.).

# TABLE A2: Expected Value Accident Analysis of Kansas State Highway Intersections (cont)

**RURAL INTERSECTIONS**

| ROAD CLASS: D | INTERSECTION CLASS: S/N | TRAFFIC CONTROL: ALL |
|---|---|---|

N = 2890

| Characteristic | n | Accidents per Year: Mean | 90th Percentile | 95th Percentile |
|---|---|---|---|---|
| **Severity:** | | | | |
| Fatal | 14 | 0.0016 | 0.0679 | 0.1380 |
| Injury | 322 | 0.0371 | 0.3551 | 0.6873 |
| Property Damage Only | 580 | 0.0669 | 0.4937 | 0.9351 |
| **Accident Type:** | | | | |
| Head on | 14 | 0.0016 | 0.0679 | 0.1380 |
| Rear End | 204 | 0.0235 | 0.2766 | 0.5422 |
| Angle | 456 | 0.0526 | 0.4310 | 0.8243 |
| Sideswipe-Opposing | 11 | 0.0013 | 0.0600 | 0.1222 |
| Sideswipe-Overtaking | 59 | 0.0068 | 0.1429 | 0.2865 |
| Left Turn with Through | 44 | 0.0051 | 0.1226 | 0.2467 |
| Overturned | 17 | 0.0020 | 0.0750 | 0.1522 |
| Pedestrian | 6 | 0.0007 | 0.0441 | 0.0900 |
| Parked Vehicle | 3 | 0.0003 | 0.0310 | 0.0635 |
| Pedalcycle | 12 | 0.0014 | 0.0628 | 0.1277 |
| Animal | 21 | 0.0024 | 0.0836 | 0.1694 |
| Fixed Object | 69 | 0.0080 | 0.1552 | 0.3104 |
| **Light Conditions:** | | | | |
| Daylight | 699 | 0.0806 | 0.5491 | 1.0315 |
| Dawn/Dusk | 37 | 0.0043 | 0.1121 | 0.2259 |
| Dark | 180 | 0.0208 | 0.2585 | 0.5082 |
| **Surface Conditions:** | | | | |
| Dry | 749 | 0.0864 | 0.5714 | 1.0697 |
| Wet | 133 | 0.0153 | 0.2197 | 0.4347 |
| Snow/Ice | 34 | 0.0039 | 0.1072 | 0.2164 |
| **Quarter of Year:** | | | | |
| January - March | 197 | 0.0227 | 0.2714 | 0.5325 |
| April - June | 215 | 0.0248 | 0.2846 | 0.5572 |
| July - September | 253 | 0.0292 | 0.3110 | 0.6063 |
| October - December | 251 | 0.0290 | 0.3097 | 0.6038 |
| **Hour of Day:** | | | | |
| 00:00 - 06:00 | 36 | 0.0042 | 0.1105 | 0.2228 |
| 06:01 - 12:00 | 258 | 0.0298 | 0.3144 | 0.6125 |
| 12:01 - 18:00 | 430 | 0.0496 | 0.4171 | 0.7994 |
| 18:01 -24:00 | 184 | 0.0212 | 0.2616 | 0.5140 |
| **Total:** | 916 | 0.1057 | 0.6420 | 1.1895 |

Traffic Control Type "ALL" includes signals, beacons, beacons w/stop, 4-way stop and all other types of control (2-way stop, yield, uncontrolled, etc.).

# TABLE A2: Expected Value Accident Analysis of Kansas State Highway Intersections (cont)

**RURAL INTERSECTIONS**

| ROAD CLASS: E | INTERSECTION CLASS: S/S | TRAFFIC CONTROL: ALL |
|---|---|---|

N = 25

| Characteristic | n | Accidents per Year: Mean | Accidents per Year: 90th Percentile | Accidents per Year: 95th Percentile |
|---|---|---|---|---|
| **Severity:** | | | | |
| Fatal | 2 | 0.0267 | 0.3059 | 0.3631 |
| Injury | 36 | 0.4800 | 1.6647 | 1.9072 |
| Property Damage Only | 83 | 1.1067 | 2.9056 | 3.2738 |
| **Accident Type:** | | | | |
| Head on | 3 | 0.0400 | 0.3820 | 0.4520 |
| Rear End | 33 | 0.4400 | 1.5743 | 1.8064 |
| Angle | 47 | 0.6267 | 1.9803 | 2.2574 |
| Sideswipe-Opposing | 2 | 0.0267 | 0.3059 | 0.3631 |
| Sideswipe-Overtaking | 6 | 0.0800 | 0.5637 | 0.6627 |
| Left Turn with Through | 7 | 0.0933 | 0.6157 | 0.7227 |
| Overturned | 7 | 0.0933 | 0.6157 | 0.7227 |
| Pedestrian | 1 | 0.0133 | 0.2108 | 0.2512 |
| Parked Vehicle | 0 | 0.0000 | 0.0000 | 0.0000 |
| Pedalcycle | 0 | 0.0000 | 0.0000 | 0.0000 |
| Animal | 1 | 0.0133 | 0.2108 | 0.2512 |
| Fixed Object | 14 | 0.1867 | 0.9255 | 1.0767 |
| **Light Conditions:** | | | | |
| Daylight | 83 | 1.1067 | 2.9056 | 3.2739 |
| Dawn/Dusk | 8 | 0.1067 | 0.6652 | 0.7795 |
| Dark | 30 | 0.4000 | 1.4815 | 1.7029 |
| **Surface Conditions:** | | | | |
| Dry | 97 | 1.2933 | 3.2380 | 3.6361 |
| Wet | 20 | 0.2667 | 1.1497 | 1.3304 |
| Snow/Ice | 4 | 0.0533 | 0.4482 | 0.5291 |
| **Quarter of Year:** | | | | |
| January - March | 25 | 0.3333 | 1.3206 | 1.5227 |
| April - June | 29 | 0.3867 | 1.4500 | 1.6676 |
| July - September | 39 | 0.5200 | 1.7531 | 2.0055 |
| October - December | 28 | 0.3733 | 1.4182 | 1.6320 |
| **Hour of day:** | | | | |
| 00:00 - 06:00 | 8 | 0.1067 | 0.6652 | 0.7795 |
| 06:01 - 12:00 | 39 | 0.5200 | 1.7531 | 2.0055 |
| 12:01 - 18:00 | 46 | 0.6133 | 1.9525 | 2.2266 |
| 18:01 - 24:00 | 28 | 0.3733 | 1.4182 | 1.6320 |
| **Total:** | 121 | 1.6133 | 3.7853 | 4.2299 |

Traffic Control Type "ALL" includes signals, beacons, beacons w/stop, 4-way stop and all other types of control (2-way stop, yield, uncontrolled, etc.).

## TABLE A2: Expected Value Accident Analysis of Kansas State Highway Intersections (cont)

**RURAL INTERSECTIONS**

| ROAD CLASS: E | INTERSECTION CLASS: S/N | TRAFFIC CONTROL: ALL |
|---|---|---|

N = 1769

| Characteristic | n | Mean | Accidents per Year 90th Percentile | 95th Percentile |
|---|---|---|---|---|
| **Severity:** | | | | |
| Fatal | 2 | 0.0004 | 0.0324 | 0.0384 |
| Injury | 69 | 0.0130 | 0.2011 | 0.2365 |
| Property Damage Only | 171 | 0.0322 | 0.3284 | 0.3840 |
| **Accident Type:** | | | | |
| Head on | 3 | 0.0006 | 0.0398 | 0.0472 |
| Rear End | 40 | 0.0075 | 0.1508 | 0.1777 |
| Angle | 122 | 0.0230 | 0.2732 | 0.3202 |
| Sideswipe-Opposing | 6 | 0.0011 | 0.0566 | 0.0670 |
| Sideswipe-Overtaking | 14 | 0.0026 | 0.0874 | 0.1033 |
| Left Turn with Through | 9 | 0.0017 | 0.0696 | 0.0824 |
| Overturned | 7 | 0.0013 | 0.0612 | 0.0725 |
| Pedestrian | 3 | 0.0006 | 0.0398 | 0.0472 |
| Parked Vehicle | 0 | 0.0000 | 0.0000 | 0.0000 |
| Pedalcycle | 2 | 0.0004 | 0.0324 | 0.0384 |
| Animal | 9 | 0.0017 | 0.0696 | 0.0824 |
| Fixed Object | 27 | 0.0051 | 0.1228 | 0.1449 |
| **Light Conditions:** | | | | |
| Daylight | 170 | 0.0320 | 0.3273 | 0.3828 |
| Dawn/Dusk | 18 | 0.0034 | 0.0995 | 0.1175 |
| Dark | 54 | 0.0102 | 0.1766 | 0.2079 |
| **Surface Conditions:** | | | | |
| Dry | 194 | 0.0366 | 0.3520 | 0.4113 |
| Wet | 35 | 0.0066 | 0.1406 | 0.1658 |
| Snow/Ice | 13 | 0.0024 | 0.0841 | 0.0995 |
| **Quarter of Year:** | | | | |
| January - March | 55 | 0.0104 | 0.1783 | 0.2099 |
| April - June | 69 | 0.0130 | 0.2011 | 0.2365 |
| July - September | 55 | 0.0104 | 0.1783 | 0.2099 |
| October - December | 63 | 0.0119 | 0.1916 | 0.2254 |
| **Hour of day:** | | | | |
| 00:00 - 06:00 | 14 | 0.0026 | 0.0874 | 0.1033 |
| 06:01 - 12:00 | 60 | 0.0113 | 0.1867 | 0.2197 |
| 12:01 - 18:00 | 111 | 0.0209 | 0.2595 | 0.3044 |
| 18:01 - 24:00 | 56 | 0.0106 | 0.1800 | 0.2119 |
| **Total:** | 242 | 0.0456 | 0.3979 | 0.4641 |

Traffic Control Type "ALL" includes signals, beacons, beacons w/stop, 4-way stop and all other types of control (2-way stop, yield, uncontrolled, etc.).

# TABLE A3: Expected Value Analysis Table for the State of South Dakota

**TYPE: RURAL, DIVIDED, 4 LANE TO 2 LANE, TWO WAY STOP**
**VOLUMES NOT A CONSIDERATION**

| | | Abnormally High Accidents/Year | |
|---|---|---|---|
| COLLISION TYPE | Mean Accidents Per Year | 90th Percentile | 95th Percentile |
| HEAD ON | 0.00 | 0.00 | 0.00 |
| ANGLE | 0.02 | 0.06 | 0.06 |
| REAR END | 0.02 | 0.04 | 0.05 |
| SS-OVTKIN | 0.00 | 0.00 | 0.00 |
| SS-OPSDIR | 0.00 | 0.00 | 0.00 |
| OVTKIN RD | 0.00 | 0.00 | 0.00 |
| RAN OFF RD | 0.00 | 0.00 | 0.00 |
| FIXED OBJECT | 0.02 | 0.04 | 0.05 |
| PARKED VEHICLE | 0.00 | 0.00 | 0.00 |
| PEDESTRIAN | 0.00 | 0.00 | 0.00 |
| ANIMAL | 0.09 | 0.14 | 0.15 |
| OTHER | 0.03 | 0.06 | 0.06 |
| LEFT TURN | 0.00 | 0.00 | 0.00 |
| SEVERITY | | | |
| FATAL | 0.00 | 0.00 | 0.00 |
| INJURY | 0.02 | 0.06 | 0.06 |
| PROP DMG ONLY | 0.15 | 0.23 | 0.25 |
| LIGHT CONDITION | | | |
| LIGHT | 0.06 | 0.12 | 0.14 |
| DAWN | 0.01 | 0.03 | 0.03 |
| DUSK | 0.01 | 0.03 | 0.03 |
| DARK | 0.10 | 0.16 | 0.18 |
| SURFACE CONDITION | | | |
| DRY | 0.14 | 0.22 | 0.24 |
| WET | 0.03 | 0.07 | 0.08 |
| ICE-FROST | 0.00 | 0.00 | 0.00 |
| SNOW-SLUSH | 0.01 | 0.03 | 0.03 |
| OTHER | 0.00 | 0.00 | 0.00 |
| SEASON OF YEAR | | | |
| DEC, JAN, FEB | 0.01 | 0.03 | 0.03 |
| MAR, APR, MAY | 0.04 | 0.08 | 0.09 |
| JUN, JUL, AUG | 0.06 | 0.12 | 0.14 |
| SEP, OCT, NOV | 0.07 | 0.11 | 0.12 |
| DAY OF WEEK | | | |
| SUNDAY | 0.05 | 0.10 | 0.11 |
| MONDAY | 0.01 | 0.03 | 0.03 |
| TUESDAY | 0.02 | 0.04 | 0.05 |
| WEDNESDAY | 0.01 | 0.03 | 0.03 |

| | | | |
|---|---|---|---|
| THURSDAY | 0.04 | 0.07 | 0.08 |
| FRIDAY | 0.02 | 0.04 | 0.05 |
| SATURDAY | 0.03 | 0.06 | 0.06 |
| HOUR OF DAY | | | |
| 00:00 - 06:00 | 0.01 | 0.03 | 0.03 |
| 06:01 - 09:00 | 0.03 | 0.06 | 0.06 |
| 09:01 - 11:00 | 0.01 | 0.03 | 0.03 |
| 11:01 - 13:00 | 0.03 | 0.07 | 0.08 |
| 13:01 - 15:00 | 0.00 | 0.00 | 0.00 |
| 15:01 - 18:00 | 0.01 | 0.03 | 0.03 |
| 18:01 - 24:00 | 0.09 | 0.14 | 0.15 |
| ALCOHOL/DRUGS* | | | |
| ALCOHOL | 0.00 | 0.00 | 0.00 |
| DRUGS | 0.00 | 0.00 | 0.00 |
| ALCH-DRUGS | 0.00 | 0.00 | 0.00 |
| OTHER-NONE | 0.23 | 0.37 | 0.40 |

NOTES: Data base contains 37 locations. However, 20 locations were sampled.
Accident data from 01-01-94 to 12-31-98.
Expected values are based on 5-year period.
* In this category, the numbers are total number of drivers/pedestrians/bicyclists involved, not total number of accidents.

## TABLE A3: Expected Value Analysis Table for the State of South Dakota (cont)

**TYPE: RURAL, 4 LANE, 1-WAY STOP, 3-LEG**
**VOLUMES NOT A CONSIDERATION**

| COLLISION TYPE | Mean Accidents Per Year | Abnormally High Accidents/Year 90th Percentile | 95th Percentile |
|---|---|---|---|
| HEAD ON | 0.00 | 0.00 | 0.00 |
| ANGLE | 0.11 | 0.24 | 0.27 |
| REAR END | 0.07 | 0.13 | 0.14 |
| SS-OVTKIN | 0.00 | 0.00 | 0.00 |
| SS-OPSDIR | 0.00 | 0.00 | 0.00 |
| OVTKIN RD | 0.00 | 0.00 | 0.00 |
| RAN OFF RD | 0.04 | 0.10 | 0.11 |
| FIXED OBJECT | 0.13 | 0.24 | 0.27 |
| PARKED VEHICLE | 0.00 | 0.00 | 0.00 |
| PEDESTRIAN | 0.00 | 0.00 | 0.00 |
| ANIMAL | 0.07 | 0.13 | 0.14 |
| OTHER | 0.07 | 0.15 | 0.18 |
| LEFT TURN | 0.11 | 0.20 | 0.22 |
| SEVERITY | | | |
| FATAL | 0.00 | 0.00 | 0.00 |
| INJURY | 0.20 | 0.34 | 0.37 |
| PROP DMG ONLY | 0.40 | 0.60 | 0.64 |

| | | | |
|---|---|---|---|
| LIGHT CONDITION | | | |
| LIGHT | 0.44 | 0.68 | 0.73 |
| DAWN | 0.00 | 0.00 | 0.00 |
| DUSK | 0.00 | 0.00 | 0.00 |
| DARK | 0.16 | 0.26 | 0.28 |
| SURFACE CONDITION | | | |
| DRY | 0.40 | 0.63 | 0.69 |
| WET | 0.07 | 0.15 | 0.18 |
| ICE-FROST | 0.09 | 0.22 | 0.25 |
| SNOW-SLUSH | 0.04 | 0.10 | 0.11 |
| OTHER | 0.00 | 0.00 | 0.00 |
| SEASON OF YEAR | | | |
| DEC, JAN, FEB | 0.11 | 0.20 | 0.22 |
| MAR, APR, MAY | 0.16 | 0.24 | 0.26 |
| JUN, JUL, AUG | 0.13 | 0.26 | 0.29 |
| SEP, OCT, NOV | 0.20 | 0.31 | 0.33 |
| DAY OF WEEK | | | |
| SUNDAY | 0.13 | 0.22 | 0.24 |
| MONDAY | 0.09 | 0.18 | 0.20 |
| TUESDAY | 0.09 | 0.18 | 0.20 |
| WEDNESDAY | 0.13 | 0.24 | 0.27 |
| THURSDAY | 0.04 | 0.10 | 0.11 |
| FRIDAY | 0.02 | 0.06 | 0.07 |
| SATURDAY | 0.09 | 0.15 | 0.17 |
| HOUR OF DAY | | | |
| 00:00 - 06:00 | 0.04 | 0.10 | 0.11 |
| 06:01 - 09:00 | 0.02 | 0.06 | 0.07 |
| 09:01 - 11:00 | 0.11 | 0.18 | 0.19 |
| 11:01 - 13:00 | 0.02 | 0.06 | 0.07 |
| 13:01 - 15:00 | 0.07 | 0.13 | 0.14 |
| 15:01 - 18:00 | 0.20 | 0.32 | 0.35 |
| 18:01 - 24:00 | 0.13 | 0.22 | 0.24 |
| ALCOHOL/DRUGS* | | | |
| ALCOHOL | 0.02 | 0.06 | 0.07 |
| DRUGS | 0.00 | 0.00 | 0.00 |
| ALCH-DRUGS | 0.00 | 0.00 | 0.00 |
| OTHER-NONE | 0.87 | 1.31 | 1.42 |

NOTES: Database contains 9 locations.
Accident data from 01-01-94 to 12-31-98.
Expected values are based on 5-year period.
* In this category, the numbers are total number of drivers/pedestrians/bicyclists involved, not total number of accidents.

# TABLE A3: Expected Value Analysis Table for the State of South Dakota (cont)

**TYPE: RURAL, 1-WAY STOP, THREE LEG INTERSECTION**
**VOLUMES NOT A CONSIDERATION**

| | | Abnormally High Accidents/Year | |
|---|---|---|---|
| COLLISION TYPE | Mean Accidents Per Year | 90th Percentile | 95th Percentile |
| HEAD ON | 0.00 | 0.00 | 0.00 |
| ANGLE | 0.11 | 0.23 | 0.25 |
| REAR END | 0.08 | 0.16 | 0.18 |
| SS-OVTKIN | 0.02 | 0.05 | 0.05 |
| SS-OPSDIR | 0.00 | 0.00 | 0.00 |
| OVTKIN RD | 0.03 | 0.05 | 0.06 |
| RAN OFF RD | 0.05 | 0.09 | 0.10 |
| FIXED OBJECT | 0.05 | 0.07 | 0.08 |
| PARKED VEHICLE | 0.00 | 0.00 | 0.00 |
| PEDESTRIAN | 0.00 | 0.00 | 0.00 |
| ANIMAL | 0.01 | 0.02 | 0.02 |
| OTHER | 0.06 | 0.13 | 0.14 |
| LEFT TURN | 0.06 | 0.13 | 0.14 |
| SEVERITY | | | |
| FATAL | 0.01 | 0.02 | 0.02 |
| INJURY | 0.16 | 0.28 | 0.31 |
| PROP DMG ONLY | 0.30 | 0.49 | 0.52 |
| LIGHT CONDITION | | | |
| LIGHT | 0.33 | 0.58 | 0.63 |
| DAWN | 0.00 | 0.00 | 0.00 |
| DUSK | 0.02 | 0.04 | 0.05 |
| DARK | 0.12 | 0.19 | 0.20 |
| SURFACE CONDITION | | | |
| DRY | 0.32 | 0.52 | 0.57 |
| WET | 0.05 | 0.09 | 0.10 |
| ICE-FROST | 0.05 | 0.09 | 0.09 |
| SNOW-SLUSH | 0.05 | 0.10 | 0.11 |
| OTHER | 0.01 | 0.02 | 0.02 |
| SEASON OF YEAR | | | |
| DEC, JAN, FEB | 0.12 | 0.20 | 0.22 |
| MAR, APR, MAY | 0.10 | 0.17 | 0.19 |
| JUN, JUL, AUG | 0.15 | 0.25 | 0.27 |
| SEP, OCT, NOV | 0.10 | 0.18 | 0.20 |
| DAY OF WEEK | | | |
| SUNDAY | 0.07 | 0.13 | 0.15 |
| MONDAY | 0.05 | 0.08 | 0.08 |
| TUESDAY | 0.09 | 0.15 | 0.17 |
| WEDNESDAY | 0.10 | 0.17 | 0.19 |

| | Mean Accidents Per Year | 90th Percentile | 95th Percentile |
|---|---|---|---|
| THURSDAY | 0.05 | 0.07 | 0.08 |
| FRIDAY | 0.07 | 0.12 | 0.13 |
| SATURDAY | 0.05 | 0.08 | 0.09 |
| HOUR OF DAY | | | |
| 00:00 - 06:00 | 0.06 | 0.10 | 0.10 |
| 06:01 - 09:00 | 0.06 | 0.12 | 0.13 |
| 09:01 - 11:00 | 0.06 | 0.13 | 0.14 |
| 11:01 - 13:00 | 0.04 | 0.08 | 0.09 |
| 13:01 - 15:00 | 0.05 | 0.09 | 0.10 |
| 15:01 - 18:00 | 0.12 | 0.21 | 0.23 |
| 18:01 - 24:00 | 0.09 | 0.13 | 0.14 |
| ALCOHOL/DRUGS* | | | |
| ALCOHOL | 0.05 | 0.09 | 0.10 |
| DRUGS | 0.00 | 0.00 | 0.00 |
| ALCH-DRUGS | 0.00 | 0.00 | 0.00 |
| OTHER-NONE | 0.75 | 1.32 | 1.43 |

NOTES: Datebase contains 100 locations. However, 35 locations were sampled.
Accident data from 01-01-94 to 12-31-98.
Expected values are based on 5-year period.
*In this category, the numbers are total number of drivers/pedestrians, bicyclists involved, not total number of accidents.

## TABLE A3: Expected Value Analysis Table for the State of South Dakota (cont)

**TYPE: RURAL, 2-WAY STOP, FOUR LEG INTERSECTION**
**VOLUMES NOT A CONSIDERATION**

| | | Abnormally High Accidents/Year | |
|---|---|---|---|
| COLLISION TYPE | Mean Accidents Per Year | 90th Percentile | 95th Percentile |
| HEAD ON | 0.00 | 0.00 | 0.00 |
| ANGLE | 0.10 | 0.14 | 0.15 |
| REAR END | 0.00 | 0.00 | 0.00 |
| SS-OVTKIN | 0.01 | 0.03 | 0.03 |
| SS-OPSDIR | 0.00 | 0.00 | 0.00 |
| OVTKIN RD | 0.02 | 0.03 | 0.04 |
| RAN OFF RD | 0.02 | 0.03 | 0.04 |
| FIXED OBJECT | 0.01 | 0.03 | 0.03 |
| PARKED VEHICLE | 0.00 | 0.00 | 0.00 |
| PEDESTRIAN | 0.00 | 0.00 | 0.00 |
| ANIMAL | 0.02 | 0.03 | 0.04 |
| OTHER | 0.02 | 0.04 | 0.04 |
| LEFT TURN | 0.04 | 0.07 | 0.08 |
| SEVERITY | | | |
| FATAL | 0.01 | 0.03 | 0.03 |
| INJURY | 0.10 | 0.15 | 0.16 |
| PROP DMG ONLY | 0.12 | 0.17 | 0.18 |

| | | | |
|---|---|---|---|
| LIGHT CONDITION | | | |
| LIGHT | 0.15 | 0.23 | 0.24 |
| DAWN | 0.01 | 0.02 | 0.02 |
| DUSK | 0.01 | 0.03 | 0.03 |
| DARK | 0.06 | 0.09 | 0.10 |
| SURFACE CONDITION | | | |
| DRY | 0.17 | 0.23 | 0.25 |
| WET | 0.01 | 0.02 | 0.02 |
| ICE-FROST | 0.05 | 0.07 | 0.08 |
| SNOW-SLUSH | 0.01 | 0.03 | 0.04 |
| OTHER | 0.00 | 0.00 | 0.00 |
| SEASON OF YEAR | | | |
| DEC, JAN, FEB | 0.06 | 0.10 | 0.11 |
| MAR, APR, MAY | 0.07 | 0.11 | 0.11 |
| JUN, JUL, AUG | 0.03 | 0.05 | 0.06 |
| SEP, OCT, NOV | 0.07 | 0.10 | 0.11 |
| DAY OF WEEK | | | |
| SUNDAY | 0.03 | 0.05 | 0.05 |
| MONDAY | 0.02 | 0.05 | 0.05 |
| TUESDAY | 0.03 | 0.06 | 0.06 |
| WEDNESDAY | 0.01 | 0.03 | 0.03 |
| THURSDAY | 0.05 | 0.08 | 0.09 |
| FRIDAY | 0.06 | 0.09 | 0.10 |
| SATURDAY | 0.03 | 0.05 | 0.05 |
| HOUR OF DAY | | | |
| 00:00 - 06:00 | 0.03 | 0.06 | 0.07 |
| 06:01 - 09:00 | 0.03 | 0.05 | 0.05 |
| 09:01 - 11:00 | 0.03 | 0.05 | 0.05 |
| 11:01 - 13:00 | 0.02 | 0.04 | 0.05 |
| 13:01 - 15:00 | 0.02 | 0.05 | 0.05 |
| 15:01 - 18:00 | 0.06 | 0.10 | 0.10 |
| 18:01 - 24:00 | 0.04 | 0.06 | 0.07 |
| ALCOHOL/DRUGS* | | | |
| ALCOHOL | 0.03 | 0.06 | 0.06 |
| DRUGS | 0.00 | 0.00 | 0.00 |
| ALCH-DRUGS | 0.00 | 0.00 | 0.00 |
| OTHER-NONE | 0.35 | 0.49 | 0.52 |

NOTES: Database contains 105 locations. However, 35 locations were sampled.
Accident data from 01-01-94 to 12-31-98.
Expected values are based on 5-year period.
* In this category, the numbers are total number of drivers/pedestrians/bicyclists involved, not total number of accidents.

# TABLE A3: Expected Value Analysis Table for the State of South Dakota (cont)

**TYPE: RURAL, 4-WAY STOP, FOUR LEG INTERSECTION**
**VOLUMES NOT A CONSIDERATION**

| | | Abnormally High Accidents/Year | |
|---|---|---|---|
| COLLISION TYPE | Mean Accidents Per Year | 90th Percentile | 95th Percentile |
| HEAD ON | 0.00 | 0.00 | 0.00 |
| ANGLE | 0.17 | 0.33 | 0.37 |
| REAR END | 0.03 | 0.08 | 0.10 |
| SS-OVTKIN | 0.00 | 0.00 | 0.00 |
| SS-OPSDIR | 0.00 | 0.00 | 0.00 |
| OVTKIN RD | 0.00 | 0.00 | 0.00 |
| RAN OFF RD | 0.00 | 0.00 | 0.00 |
| FIXED OBJECT | 0.03 | 0.08 | 0.10 |
| PARKED VEHICLE | 0.00 | 0.00 | 0.00 |
| PEDESTRIAN | 0.00 | 0.00 | 0.00 |
| ANIMAL | 0.00 | 0.00 | 0.00 |
| OTHER | 0.00 | 0.00 | 0.00 |
| LEFT TURN | 0.00 | 0.00 | 0.00 |
| SEVERITY | | | |
| FATAL | 0.06 | 0.17 | 0.20 |
| INJURY | 0.09 | 0.16 | 0.19 |
| PROP DMG ONLY | 0.09 | 0.20 | 0.23 |
| LIGHT CONDITION | | | |
| LIGHT | 0.20 | 0.37 | 0.41 |
| DAWN | 0.00 | 0.00 | 0.00 |
| DUSK | 0.00 | 0.00 | 0.00 |
| DARK | 0.03 | 0.08 | 0.10 |
| SURFACE CONDITION | | | |
| DRY | 0.14 | 0.31 | 0.35 |
| WET | 0.03 | 0.08 | 0.10 |
| ICE-FROST | 0.03 | 0.08 | 0.10 |
| SNOW-SLUSH | 0.03 | 0.08 | 0.10 |
| OTHER | 0.00 | 0.00 | 0.00 |
| SEASON OF YEAR | | | |
| DEC, JAN, FEB | 0.06 | 0.13 | 0.15 |
| MAR, APR, MAY | 0.09 | 0.16 | 0.19 |
| JUN, JUL, AUG | 0.03 | 0.08 | 0.10 |
| SEP, OCT, NOV | 0.06 | 0.13 | 0.15 |
| DAY OF WEEK | | | |
| SUNDAY | 0.03 | 0.08 | 0.10 |
| MONDAY | 0.03 | 0.08 | 0.10 |
| TUESDAY | 0.09 | 0.16 | 0.19 |
| WEDNESDAY | 0.03 | 0.08 | 0.10 |

| | | | |
|---|---|---|---|
| THURSDAY | 0.00 | 0.00 | 0.00 |
| FRIDAY | 0.03 | 0.08 | 0.10 |
| SATURDAY | 0.03 | 0.08 | 0.10 |
| HOUR OF DAY | | | |
| 00:00 - 06:00 | 0.00 | 0.00 | 0.00 |
| 06:01 - 09:00 | 0.00 | 0.00 | 0.00 |
| 09:01 - 11:00 | 0.03 | 0.08 | 0.10 |
| 11:01 - 13:00 | 0.06 | 0.13 | 0.15 |
| 13:01 - 15:00 | 0.00 | 0.00 | 0.00 |
| 15:01 - 18:00 | 0.09 | 0.20 | 0.23 |
| 18:01 - 24:00 | 0.06 | 0.13 | 0.15 |
| ALCOHOL/DRUGS* | | | |
| ALCOHOL | 0.03 | 0.08 | 0.10 |
| DRUGS | 0.00 | 0.00 | 0.00 |
| ALCH-DRUGS | 0.00 | 0.00 | 0.00 |
| OTHER-NONE | 0.40 | 0.73 | 0.81 |

NOTES: Database contains 7 locations.

Accident data from 01-01-94 to 12-31-98.

Expected values are based on 5-year period.

* In this category, the numbers are total number of drivers/pedestrians/ bicyclists involved, not total number of accidents.

# TABLE A4: Expected Value Analysis for All Districts

**TOTAL ENTERING ADT: 0-10,000**
**TYPE: 4-LEG, UNSIGNALIZED**

| | Mean Accidents Per Year | Abnormally High Accidents/Year 90th Percentile | 95th Percentile |
|---|---|---|---|
| COLLISION TYPE | | | |
| REAR END: | 0.16 | 0.66 | 0.76 |
| ANGLE : | 0.73 | 2.22 | 2.52 |
| HEAD ON : | 0.02 | 0.13 | 0.16 |
| SIDESWIPE SD: | 0.09 | 0.45 | 0.52 |
| SIDESWIPE OD: | 0.03 | 0.23 | 0.27 |
| PEDESTRIAN: | 0.01 | 0.10 | 0.12 |
| FIXED OBJECT: | 0.20 | 0.77 | 0.88 |
| SEVERITY | | | |
| FATAL: | 0.00 | 0.07 | 0.08 |
| INJURY: | 0.62 | 1.81 | 2.05 |
| PROP DAMAGE ONLY: | 0.72 | 2.02 | 2.28 |
| LIGHT CONDITION | | | |
| DAY: | 0.98 | 2.70 | 3.04 |
| NIGHT: | 0.28 | 0.94 | 1.07 |
| DAWN/DUSK: | 0.07 | 0.34 | 0.39 |
| SURFACE CONDITION | | | |
| DRY: | 1.04 | 2.78 | 3.12 |
| WET: | 0.26 | 0.84 | 0.96 |
| SNWY/ICY: | 0.04 | 0.24 | 0.28 |

| | | | |
|---|---|---|---|
| SEASON OF YEAR | | | |
| WINTER: . . . . . . . . . . | 0.28 . . . . . . . . . . | 0.90 . . . . . . . . . . | 1.02 |
| SPRING: . . . . . . . . . . | 0.33 . . . . . . . . . . | 1.03 . . . . . . . . . . | 1.17 |
| SUMMER: . . . . . . . . . . | 0.34 . . . . . . . . . . | 1.09 . . . . . . . . . . | 1.23 |
| FALL: . . . . . . . . . . | 0.40 . . . . . . . . . . | 1.21 . . . . . . . . . . | 1.37 |
| DAY OF WEEK | | | |
| MONDAY: . . . . . . . . . . | 0.14 . . . . . . . . . . | 0.52 . . . . . . . . . . | 0.60 |
| TUESDAY: . . . . . . . . . . | 0.19 . . . . . . . . . . | 0.67 . . . . . . . . . . | 0.77 |
| WEDNESDAY: . . . . . . . . . . | 0.19 . . . . . . . . . . | 0.71 . . . . . . . . . . | 0.81 |
| THURSDAY: . . . . . . . . . . | 0.19 . . . . . . . . . . | 0.65 . . . . . . . . . . | 0.75 |
| FRIDAY: . . . . . . . . . . | 0.21 . . . . . . . . . . | 0.70 . . . . . . . . . . | 0.80 |
| SATURDAY: . . . . . . . . . . | 0.26 . . . . . . . . . . | 0.92 . . . . . . . . . . | 1.05 |
| SUNDAY: . . . . . . . . . . | 0.18 . . . . . . . . . . | 0.68 . . . . . . . . . . | 0.78 |
| HOUR OF DAY | | | |
| 00:00 – 06:00: . . . . . . . . . . | 0.08 . . . . . . . . . . | 0.37 . . . . . . . . . . | 0.43 |
| 06:00 – 09:00: . . . . . . . . . . | 0.19 . . . . . . . . . . | 0.66 . . . . . . . . . . | 0.76 |
| 09:00 – 11:00: . . . . . . . . . . | 0.15 . . . . . . . . . . | 0.57 . . . . . . . . . . | 0.66 |
| 11:00 – 13:00: . . . . . . . . . . | 0.14 . . . . . . . . . . | 0.55 . . . . . . . . . . | 0.63 |
| 13:00 – 15:00: . . . . . . . . . . | 0.13 . . . . . . . . . . | 0.56 . . . . . . . . . . | 0.65 |
| 15:00 – 18:00: . . . . . . . . . . | 0.38 . . . . . . . . . . | 1.24 . . . . . . . . . . | 1.41 |
| 18:00 – 24:00: . . . . . . . . . . | 0.28 . . . . . . . . . . | 0.88 . . . . . . . . . . | 1.00 |

IF ACCIDENTS EXCEED THESE VALUES FURTHER STUDY IS WARRANTED.
NOTES: DATABASE CONTAINS 144 LOCATIONS
Accident data from 01-01-85 to 12-31-87.
Expected values are based on 3-year period.