Guidelines for Removal of Traffic Control Devices in Rural Areas

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16. Abstract

It is commonly regarded that the overuse of traffic control devices desensitizes drivers and leads to disrespect, especially for low-volume secondary roads with limited enforcement. The maintenance of traffic signs is also a tort liability concern, exacerbated by unnecessary signs. The Federal Highway Administration's (FHWA) *Manual on Uniform Traffic Control Devices* (*MUTCD*) and the Institute of Transportation Engineer's (ITE) *Traffic Control Devices Handbook* provide guidance for the implementation of STOP signs based on expected compliance with right-of-way rules, provision of through traffic flow, context (proximity to other controlled intersections), speed, sight distance, and crash history. The approach(es) to stop is left to engineering judgment and is usually dependent on traffic volume or functional class/continuity of system. Although presently being considered by the National Committee on Traffic Control Devices, traffic volume itself is not given as a criterion for implementation in the *MUTCD*. STOP signs have been installed at many locations for various reasons which no longer (or perhaps never) met engineering needs. If in fact the presence of STOP signs does not increase safety, removal should be considered. To date, however, no guidance exists for the removal of STOP signs at two-way stop-controlled intersections. The scope of this research is ultra-low-volume (< 150 daily entering vehicles) unpaved intersections in rural agricultural areas of Iowa, where each of the 99 counties may have as many as 300 or more STOP sign pairs. Overall safety performance is examined as a function of a county excessive use factor, developed specifically for this study and based on various volume ranges and terrain as a proxy for sight distance. Four conclusions are supported: (1) there is no statistical difference in the safety performance of ultra-low-volume stop-controlled and uncontrolled intersections for all drivers or for younger and older drivers (although interestingly, older drivers are underrepresented at both types of intersections); (2) compliance with stop control (as indicated by crash performance) does not appear to be affected by the use or excessive use of STOP signs, even when adjusted for volume and a sight distance proxy; (3) crash performance does not appear to be improved by the liberal use of stop control; (4) safety performance of uncontrolled intersections appears to decline relative to stop-controlled intersections above about 150 daily entering vehicles. Subject to adequate sight distance, traffic professionals may wish to consider removal of control below this threshold. The report concludes with a section on methods and legal considerations for safe removal of stop control.

GUIDELINES FOR REMOVAL OF TRAFFIC CONTROL DEVICES IN RURAL AREAS

Final Report
October 2005

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EXECUTIVE SUMMARY

Establishment of the proper level of traffic control on low-volume rural roads can be problematic for local agencies. Intersections in particular present challenges for engineers in selecting appropriate control for varying situations. The *Manual on Uniform Traffic Control Devices (MUTCD)* presents limited guidance for STOP and YIELD signs applications in Part 5—Traffic Control Devices for Low Volume Roads. Part 2 of the *MUTCD* discourages the overuse of regulatory signs and lists general applications for installation of STOP and YIELD signs. Excessive use of STOP signs in particular is thought to encourage disrespect and violations by drivers, add operational costs to agency budgets, and expose agencies to potential liability for deficient maintenance. However, no published guidelines for the removal of unneeded two-way stop control apparently exist, and local agencies are reluctant to undertake this action even at ultra-low-volume intersections (identified in this report as intersections with less than 150 daily entering vehicles [DEV]).

This study had two primary objectives. The first was to assess the safety performance of stop-controlled versus uncontrolled intersections at ultra-low-volume unpaved roads for a large data set (over 6000 intersections in Iowa and 10 years of data). The second objective was to develop criteria to assess the excessive use of stop control and analyze the effects of extensive versus lesser use of STOP signs. Legal implications were also studied, and guidance was developed for the safe removal of unneeded control.

Current literature reviewed with this study included the *Manual on Uniform Traffic Control Devices* and Institute of Transportation Engineers *Traffic Control Devices Handbook.* While providing basic guidance for intersection control, neither document includes definitive recommendations for ultra-low-volume roadways or any guidance for removal of unneeded control. Previous research reports indicated somewhat conflicting conclusions—some recommending more extensive use of yield control and others finding better crash histories through the use of stop control. However, none of the reviewed reports considered the effects of various control levels at ultra-low-volume rural intersections.

To determine the scope of practice in Iowa, a survey was sent to county engineers on practices and policies for the installation of traffic control at rural local road intersections. Information sought in the survey included type of control utilized, criteria employed for determining level of control, use of engineering studies, and adoption of formal policies for application of stop control. Twenty-nine of Iowa's ninety-nine counties responded to the survey.

In addition to the survey responses, nineteen counties furnished data describing the locations of STOP and YIELD signs in their jurisdictions. Following the selection of all unpaved study intersections, crash history was reviewed for a ten-year period. These data indicated that, in general, stop-controlled intersections exhibit lower totals for number of crashes, average crash rate, average severity, and average cost per crash than

uncontrolled intersections. However, crash rates at both stop and uncontrolled unpaved intersections in Iowa are very low.

Rural Analysis

To identify relationships within the data, a descriptive statistical analysis was conducted, considering 6,846 unpaved rural intersections. Fifty-six percent of these intersections were uncontrolled, and approximately ninety-two percent of all study intersections had not recorded a crash over a ten-year period (There was an insufficient number of yield-controlled intersections in the database to make any statistically significant conclusions regarding the use of YIELD signs; therefore, yield control was not studied in depth in this project.).

An initial analysis indicated that numbers and rates of crashes both increase as DEV increases. In addition, a difference in safety performance between stop-controlled and uncontrolled intersections was first noted around 70 DEV. At traffic volumes above this point, stop-controlled locations exhibit fewer crashes, while with lower DEV, little difference between types of control can be observed.

An approximate total cost analysis was completed for differing levels of control, assuming a delay of seven seconds per vehicle for stop control (verified in field trials), vehicle operating cost of $15 per hour, and annual sign maintenance/replacement cost of $50 per intersection. Factoring in total costs, the performance of stop-controlled and uncontrolled intersections was found to be essentially the same below 150 DEV.

Due to the small range of variance in the number of crashes recorded at these intersections, a logistic regression was completed to establish the relationship between type of control, DEV, and the probability of a crash occurrence over a ten-year period. In this analysis, safety performance of stop-controlled and uncontrolled intersections diverges at a point near 100 DEV. Above this traffic volume level, the probability of at least one crash in a ten-year period increases more dramatically for uncontrolled locations than for stop controlled. At lower volumes, little difference in safety performance was noted.

As part of this study, the suggestion that excessive use of STOP signs might indirectly contribute to an increased number of crashes in a jurisdiction was tested. In an initial attempt to investigate this phenomenon, the fraction of stop-controlled intersections for each county was determined and plotted against average crash rate. This plot indicated that crash rates declined as the level of control increased. Furthermore, it was found that this observation for unpaved intersection crashes was apparently unaffected by the overall crash rate in a specific county. When the average crash rate was adjusted for DEV, similar results were obtained.

A STOP sign placed in response to sight distance limitations would not be considered excessive or unneeded, but sight distance was not available for study area intersections. Therefore, a terrain factor was developed to act as a surrogate for the expected fraction of stop control required for sight distance. United States Geographical Services (USGS) maps were used to determine terrain factors for each study county considering topography and land cover. Combining minimum volume thresholds with various terrain factor formulations (provided for sensitivity analysis), estimated numbers of needed or "justified" stop-controlled intersections were calculated. When the fraction of excess STOP signs was plotted against crash rate, it was found again that adding STOP signs appeared to reduce crash rates. A field survey of three of the study area counties indicated that the terrain factor computed "justified fraction" matched two counties well (Adams and Boone), but failed to accurately estimate the fraction in the third county (Madison).

The effect of excessive use of STOP signs on safety performance was investigated further using an "average" county as the standard for the number of stop-controlled intersections per county. Cherokee County, with a relatively low number of stop-controlled intersections (93) and average topography, traffic volumes, and land cover, was selected as the "average" county. A ratio based on Cherokee County stop control was calculated for all study counties and plotted against average observed crash rates. This analysis method also indicated a general decrease in crashes with the increasing use of STOP signs.

Safety performance in counties with more than twice the number (this factor was subjectively determined to explore the potential explanatory power of the factor) of stop-controlled intersections of Cherokee County was compared to the performance in other counties. When plotted, trends for the two groups cross at approximately 125 DEV, indicating that above that volume, the excessive use of STOP signs may be detrimental to safety performance. This finding is contradictory to earlier findings.

A crash type examination revealed that most crashes at intersections on ultra-low-volume, unpaved rural roads are caused by driver's failure to yield the right-of-way. At stop-controlled locations, most of these crashes occurred after a driver had stopped but then proceeded to pull into the path of another vehicle. Ignoring or not seeing a STOP sign was not listed as a major crash cause. Broadside/right angle was the primary crash type at both control types.

Impacts of driver age on crash statistics were examined considering 65-year-old drivers and older, as well as those 19-year-old and younger. Regardless of control type, it was found that drivers in the younger group are slightly overrepresented in these intersection crashes. Older drivers, by contrast, are involved in crashes at these ultra-low-volume intersections at a much lower rate than the overall statewide average for all crashes for that age group. From this, it was concluded that older drivers either avoid these locations or use appropriate care when passing through the intersections.

Urban Study

To study the effects of intersection control in an urban area, an in-depth review of non-signalized intersections was undertaken in the City of Ames using video logging. Five levels of control were compared for a ten-year crash history. The best safety performance was observed at all-way stop control. Yield control exhibited the highest crash rate, followed by no control, traffic signal, and two-way stop (the rates for the latter three control types were very similar).

A hierarchical Poisson model was fitted to the Ames crash data. The model showed that signal-controlled intersections have significantly higher crash rates, two-way stop-controlled intersections have significantly lower crash rates, and there was no difference in crash rates between the all-way and the uncontrolled intersections.

To investigate the possible effect of excessive STOP sign use in an urban area, neighborhood crash rates were compared to city-wide averages. For this limited urban application, increased use of stop control would seem to have a positive impact on safety performance.

Conclusions and Recommendations

This research found that ultra-low-volume (< 150 DEV) unpaved rural intersections experience no adverse impact on safety performance due to type of control. Agencies that have erected STOP signs in these locations in the past may desire to remove perceived unneeded control.

Recommended procedures for removal or conversion of two-way stop control from ultra-low-volume rural locations include (1) establishment of a formal policy, (2) consultation with agency legal counsel and traffic control experts, (3) review of *MUTCD* applications for STOP and YIELD signs, (4) appropriate public notice, and (5) documentation and follow-up review.

A review of potential liability exposure concluded that agencies should not be exposed to tort claims for removal or conversion of unneeded stop control if adequate notice is provided and an adopted policy is followed.

If removal or conversion of unneeded STOP signs is desired, agencies may consider more extensive use of YIELD signs at locations where visibility is hampered for part of the year due to crops. Additional study of low-volume intersection control in urban areas is needed, and a long term (3–5 years) investigation of actual removal of two-way stop control and/or conversion to yield control would be beneficial.

Conclusions drawn from this research include:

- Ultra-low-volume (< 150 DEV) unpaved rural intersections exhibit much lower crash rates than experienced on local rural roads in general.
- Most prominent crash type at these locations is failure to yield right-of-way, regardless of control type.
- Above approximately 150 DEV, uncontrolled rural intersections exhibit increasingly higher crash rates when compared to stop controlled.
- For ultra-low-volume (< 150 DEV) rural unpaved intersections, type of control has negligible effect on safety performance.
- Overuse of stop control in low volume urban locations does not appear to adversely affect safety performance, but more study is needed to verify.
- For both STOP and uncontrolled ultra-low-volume rural intersections, older drivers exhibit a lower crash rate than on the general statewide system.
- Additional STOP sign use at these intersections does not appear to adversely affect safety performance.
- Several references were found for conversion of all-way to two-way stop control, but guidelines for removal of two-way STOP signs have not been published.
- If proper techniques and criteria are followed, it appears that rural agencies could remove or convert stop-controlled ultra-low-volume intersections without exposure to liability.

INTRODUCTION

Local agencies have been struggling with the increasing liability and the constant pressure to improve the efficiency of their stop-controlled intersections in order to lower not only agency costs, but user costs as well. Many of these rural two-way STOP signs are installed based on policy or general procedure, or an engineering study of geometric and operational factors. Others may have been installed in response to citizen complaints or studies that were conducted when traffic volumes may have been greater or sight distances less than they are today. These locations may no longer warrant the use of a STOP sign. For the purpose of this report, excessive stop control is defined as stop control beyond that required by sight distance or volume. An ultra-low-volume intersection is defined in this study as any intersection with a daily entering volume less than or equal to 150 vehicles. If the excessive use of stop control is negatively (or not) correlated with intersection performance, removal or change to less restrictive control (YIELD signs) may present an opportunity for improved operations, reduced maintenance costs and liability, and safety through increased respect for remaining control.

Problem statement

In Iowa, from 2001 to 2003, the major cause of about 20 percent of all fatal crashes on secondary roads was "ran STOP sign" and "FTYROW from STOP sign." However, excessive stop control is expensive to maintain, a potential liability, and may cause a reduction of respect for all signs. The expense of maintenance and enforcement in rural areas is particularly challenging. With an estimated 50,000 or more STOP signs on county roads in the State of Iowa, unnecessary signs also cost local governments thousands of dollars per year in maintenance and can represent a potential legal liability if inadequate maintenance or placement of signage is found to be a contributing factor in a crash. One city in Illinois spends up to $50 per year per STOP sign on maintenance and inspection *(46)*. This cost does not represent the tort liability potential caused by signs that are not properly maintained. Pocahontas County estimates there may be more than 50 STOP signs that might safely be removed, mainly because sight distances have been improved sometime after their installation (e.g., a grove of trees has been removed). “A 1988 field survey of traffic signs in a major metropolitan area found that 60 percent of the locations surveyed needed to have some form of sign maintenance—either replacement of a sign, re-erection of a sign that was missing, removal of a sign that was unnecessary, or installation of a sign that was needed” *(47)*. A different study of tort claims in which a fatality or serious injury occurred found that signing deficiencies were cited as the factor in 41 percent of the claims *(47)*.

It is generally held that unnecessary STOP signs lead to disregard by motorists, potentially creating hazardous conditions at locations where the control is actually warranted. In fact, the *Manual on Uniform Traffic Control Devices* (*MUTCD*) (*32*) states that regulatory and warning signs should be used conservatively, as unnecessary signs do

not command attention. However, while commonly regarded as an important factor, the effect of excessive use of stop control on disrespect has not been quantified.
The *MUTCD* presents specific guidance to assist agencies in selecting an appropriate level of traffic control at intersections, including stop, yield, and signal control. Although, the *MUTCD* presents specific criteria for the removal of traffic signals, no criteria are listed for the removal of STOP signs or change to less restrictive control. Further, no studies to date compare the performance of ultra-low-volume stop-controlled and uncontrolled intersections.

As budgets are constrained and traffic conditions change, especially in rural jurisdictions, local agencies wish to optimize available resources and maintain or increase safety and level of service, while limiting or reducing exposure to tort liability claims. Changing low-volume rural intersections to less restrictive forms of control may be one way in which to respond efficiently to increasingly scarce resources, as well as reduced traffic flow or improved sight distance in some areas. This study investigated the effectiveness of rural stop control with the goal of developing warrants that can be used to support engineering decisions made by county and small city street superintendents to reduce or eliminate unnecessary control. The safety performance of intersections with and without STOP signs was compared using statistical techniques to adjust for volume differences. Results are intended to serve as a first step in the development of guidance and procedures for elimination of unnecessary control.

Objectives

The objectives of this study are framed by the following questions:

1. What documentation, guidelines, and current research address removal or change to less restrictive control?

2. Adjusted for volumes, is there any difference in crash performance of uncontrolled versus stop-controlled ultra-low-volume intersections? Do certain driver groups (older or younger) have particular problems at rural stop-controlled or uncontrolled intersections, and are certain types of crashes more or less prevalent at those locations?

3. Can a factor to represent the excessive use of STOP signs be developed to quantify the effect of STOP sign disrespect? Is compliance affected by the excessive use of STOP signs? Can a combination of volume, excessive use, and terrain be used to improve models of the effectiveness of stop control at low-volume intersections?

4. As data collection for sight distance of thousands of intersections is cost prohibitive, is it possible to develop a surrogate for the relative number of

intersections that would be expected to have sight distance limitations, based on county land cover and topography?

5. Is there a defensible volume threshold for removal of stop control at ultra-low-volume intersections? (Iowa specific "warrant")

6. What are the legal issues and operational procedures for removal of unnecessary stop control?

Background/literature review

Much research has been conducted on the safety effectiveness of all-way and two-way stop control. The Institute of Transportation Engineers (ITE) and the Federal Highway Administration (FHWA) recommend applications (through the *MUTCD*) for the installation of stop control. Intended for urban settings, these applications may be questionable for rural use. Several studies are available that address rural and low-volume areas, as discussed below.

Rural intersections

Installation warrants

There are two key references used for warrants regarding the installation of stop control: the *MUTCD* (*32*) and the ITE *Traffic Control Devices Handbook* (*13*). However, neither of these documents provides warrants for the removal of STOP signs (The National Committee for Uniform Traffic Control Devices is currently considering proposed language for the *MUTCD* that would base the application of two-way stops on combined vehicular, pedestrian, and bicycle volume [*43*]). The *MUTCD* calls for multi-way STOP signs at intersections with high speeds, sight distance issues, or a crash problem (indicated by five or more reported crashes in a twelve-month period that are susceptible to correction by a multi-way STOP installation), but does not include a volume warrant. Instead, it includes a warrant based upon the average volume for both the major and minor roadway over an eight-hour period during the day. This warrant states that a STOP sign should be considered at a location where the vehicular volume entering the intersection from the major street (total of both approaches) averages at least 300 vehicles per hour for any eight hours of an average day, and the combined vehicular, pedestrian, and bicycle volume entering the intersection from the minor street (total of both approaches) averages at least 200 units per hour for the same eight hours, with an average delay to minor street vehicular traffic of at least thirty seconds per vehicle during the highest hour.

The FHWA conducted a study in 1981 in an attempt to establish definitive criteria for the application of two-way stop or yield control at low-volume intersections (*27*). After completing an analysis of variance, the researchers observed a significant increase in crash experience when the volume on the major roadway reached 2,000 vehicles per day.

Lum and Stockton (*20*) agreed and concluded that, up to a volume of 6,000 vehicles on the major roadway, a YIELD or STOP sign may be used to assign the right-of-way at an intersection. They also stated that it was not clear that the 6,000-vehicle volume level was the upper boundary of the region for which no relationship was evident between crashes and volume.

The ITE *Traffic Control Devices Handbook (TCDH)* discourages the use of multi-way STOP signs unless the volumes on the major and minor roadways are approximately equal. The handbook also states that the *MUTCD* warrants should be the main criteria used to determine the locations for STOP signs.

In several studies, Stokes (*28, 29*) advocates STOP sign warrants based on available sight distance and crash history. He contends that the majority of crashes associated with rural stop-controlled intersections are not caused by STOP sign violations, rather, the driver's inability to judge distances adequately. Preston and Storm completed a study in which they also observed that the most common type (60%) of right angle crash at rural thru-stop-controlled intersections in the state of Minnesota involved a vehicle stopping and then pulling out into an unsafe gap (*36*). Stokes concludes that effective solutions to the failure to yield problem should focus on the intersection as a whole rather than simply improving the sight distance or other characteristics of one leg of the intersection. He suggests the use of speed zones and advanced warning signs where drivers on the side road may have difficulty judging the speeds of approaching vehicles. Table 1 presents Stokes' recommendation for control based on available sight distance, crash history (three years worth of data), and the major roadway volume. A note attached to the chart indicates that the values should be used in conjunction with *MUTCD* criteria when assessing the need for stop or yield control. It should be noted that while many intersections are stop controlled, volumes at Iowa rural unpaved intersections are typically an order of magnitude lower than the cutoff values recommended by Stokes.

Table 1. Stokes' method for determining control type

<table>
<tr><th rowspan="2">Sight Distance</th><th rowspan="2">Crash History
(Last three 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 rowspan="2">YIELD</td></tr>
<tr><td><= 2</td><td>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 four crashes in three years. Note: The material in this table is intended to be used in conjunction with appropriate MUTCD criteria in assessing the need for STOP or YIELD control.

Several studies have been completed on the impact of sight distance on the safety of stop-controlled intersections. Stockton (*27*) concluded that region, location, and geometry have an essentially negligible effect on safety and operations at low-volume intersections.

The report recommended that major roadway volume should be the principal factor in the determination of control type and that sight distance has no significant impact on the number of crashes that occur at an intersection. Mounce (*22*) completed a study in which he agrees with Stockton indicating that the choice of control should be strictly based upon the volume of the major roadway only, as long as the available sight distance is greater than the minimum required. Mounce recommended that no control be used on an intersection with a major roadway volume between zero and 2,000 vehicles, yield control be used with a major roadway volume between 2,000 and 5,000 vehicles, and stop control be used with a major roadway volume greater than 5,000 vehicles.

Although Stockton and Mounce do not advocate use of sight distance to determine control type, it should be noted that there are at least two sight distance methods commonly used in the traffic engineering industry. One was included in the *Traffic Control Devices Handbook (TCDH*) published by the U. S. Department of Transportation (USDOT) Federal Highway Administration in 1983 (*40*). However, this method was not included in the handbook when it was updated in 2001 (*13*). The second can be found in *A Policy on Geometric Design of Highways and Streets* 2001 Fourth Edition, published by the American Association of State Highway and Transportation Officials (AASHTO) (*38*). As stated in the *TCDH* method, "the decision as to whether to use a STOP sign or a YIELD sign is primarily based upon sight distance at the intersection" (*13*). The method uses a "critical approach speed" which is defined as the lowest speed that a motorist would be able to travel and still not be able to avoid a collision with an approaching vehicle on the cross street.

"Critical approach speeds" are determined through the use of available sight distance, the allowance of parking, and a nomograph. An intersection with a critical approach speed of less than 10 miles per hour (mph) is controlled by a STOP sign. An intersection where the critical approach speed is between 10 mph and 15 mph may be controlled with a YIELD sign. If the critical approach speed on all approaches is above 15 mph, then the intersection can be uncontrolled.

The *TCDH* assumes that motorists approaching uncontrolled intersections reduce their speed to account for prevailing conditions at the intersection. Consequently, the use of this method can result in a number of intersections remaining uncontrolled. Therefore, this method can be useful in urban areas. When Mounce refers to sight distance, he is using the *TCDH* method.

The AASHTO method assumes that motorists approaching uncontrolled intersections reduce their speed by 50% based on observations. The method uses this assumption to determine the length of sight distance that is necessary along each leg of the intersecting roadway resulting in a desirable sight distance triangle. If this sight distance triangle exists, then no control is needed. If it does not exist, then control is needed. This method can also be adjusted for grades and tends to be more suited for rural areas. Use of this method almost always results in control being installed.

Mounce and Stockton (*41*) stated that "one of the major criteria for the application of intersection control on low-volume rural roads is the economic justifiability of such control." They considered the probability that any two vehicles would enter an intersection within three seconds of each other resulting in a conflict. As a result of their calculations, they prepared the following table.

Table 2. Expected number of crashes based on ADT

		ADT–Facility A							
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**
ADT - Facility B	**50**	0.022	0.043	0.065	0.087	0.109	0.13	0.151	0.172
	100	0.043	0.087	0.13	0.174	0.216	0.259	0.301	0.345
	150	0.065	0.13	0.195	0.259	0.324	0.388	0.452	0.516
	200	0.087	0.174	0.259	0.345	0.432	0.516	0.602	0.686
	250	0.109	0.216	0.324	0.432	0.538	0.644	0.751	0.856
	300	0.13	0.259	0.388	0.516	0.644	0.772	0.899	1.026
	350	0.151	0.301	0.452	0.602	0.751	0.899	1.048	1.194
	400	0.172	0.345	0.516	0.686	0.856	1.026	1.194	1.363

As can be seen from Table 2, intersections with less than 700 entering vehicles per day are expected to have less than one crash per year. This table was made using the following assumptions:

- "Conflict" is defined as that maneuver of vehicle B such that the driver of vehicle A must change speed or direction to avoid collision
- Average speed is 40 mph
- Any two vehicles approaching the intersection from conflicting directions such that the second vehicle would enter the intersection within three seconds after the first vehicle enters the intersection are said to be in "conflict"
- Effects of sight distance are not considered
- All vehicles arrive during a twelve-hour period from 7:00 a.m. to 7:00 p.m.
- All arrivals follow a Poisson distribution
- The possibility of vehicles arriving on three approaches within a three-second interval is negated
- The probability of an accident occurring is thirty-three in one hundred thousand conflicts (*42*), or 0.00033

Effectiveness of stop and yield control

Lum and Stockton (*20*) conducted a study in which they investigated the relative effectiveness of STOP and YIELD signs at low-volume intersections (less than 500 vehicles/day on minor roadway) in rural and urban environments. One of the major hypotheses that Lum and Stockton tested was that, at the 140 intersections involved in the study, STOP signs were used at intersections where sight distance was poor. This hypothesis was not supported by data, and the researchers concluded that stop control at low-volume intersections is used in spite of adequate sight distance, and uncontrolled intersections are as likely to have poor sight distance. Lum and Stockton also tested the hypothesis that stop compliance increased as sight distance decreased. The researchers observed more than 3,000 movements and concluded that drivers would slow to whatever speed required to evaluate the safety of entering the intersection before choosing a course of action. This led Lum and Stockton to conclude that the current use of STOP signs is unrelated to sight distance availability. This behavior was consistent across all levels of sight distance and control type.

Dyar (9) completed a similar study in which he researched drivers' compliance with STOP signs at rural and urban intersections in South Carolina. Dyar noticed a compliance rate of 11% and that there was no significant difference in drivers' observance of STOP signs with or without special control measures (larger STOP signs, STOP signs placed on both the right and left sides of the road, combination of red flashers and STOP signs used for traffic control, etc.) at rural intersections with inadequate sight distance. Lum and Stockton commented that these low compliance rates indicate STOP signs are being used indiscriminately; hence, the sign's purpose of providing for orderly and predictable movement of traffic is defeated. Further, Lum and Stockton stated that it is evident that STOP signs have lost their meaning because drivers treat it as a YIELD sign instead: drivers slow and proceed through the intersection with caution. The study also concluded that many STOP signs at low-volume intersections are unjustified (although warranted by the *MUTCD*) and could be replaced by YIELD signs without increasing crash experience. The authors feel that this use of YIELD signs would restore the respect and effectiveness of STOP signs and improve operating efficiency.

The Minnesota Department of Transportation (MNDOT) completed a study in 1998 in which the crash experiences at low-volume intersections in the state of Minnesota were examined to determine conclusions concerning the application of stop-controlled, yield-controlled, and uncontrolled intersections (*5*). Out of the three types of intersections studied, the intersections with stop control had the fewest number of crashes over the study period. Because of this finding, MNDOT suggested that crash experience is an important aspect in the determination of type of control to be used at an intersection. Specifically, the report concluded that uncontrolled intersections with more than three crashes in three years (associated with right-of-way) be studied to determine whether more control was needed. However, Lum and Stockton (*20*) concluded that the conversion to stop control at low-volume intersections does not categorically help to reduce crashes because crashes at those locations are rare events.

McGee and Blankenship (*21*) studied 765 urban intersections to determine effects of stop and yield controls. They concluded that crashes can increase when stop control is converted to yield control, but severity remains unaffected. Operating cost reductions will offset increased crash effects at lower volumes. The researchers recommended that adequate sight distance requirements should be met when establishing yield control.

Urban intersections

Many cities have installed all-way stop-controlled intersections in residential areas in an attempt to reduce speed or provide extra safety for children in the area (*10*). These installations do not meet the warrants of the *MUTCD* (*32*), which states that STOP signs should not be installed for speed control. It is this misuse of traffic control devices that may promote a lack of respect for all traffic control devices and, therefore, decrease driver compliance with all such devices (*10*). There are studies that condemn the use of all-way stop control to reduce speeds in residential areas (*16*, *24*, and *33*). These studies demonstrate the ineffectiveness of STOP signs for speed control, and one of these studies (*33*) states that mid-block speeds actually increase between signs.

Comparison of two-way and four-way stop control

Eck and Biega (*10*) completed a study that assists in resolving the conflicting opinions and research results existing about two-way versus four-way stop control at low-volume intersections in residential areas. The researchers found three low-volume intersections in a residential area in Star City, West Virginia, that were controlled by two-way STOP signs during the winter months and converted to four-way control during the summer months. This had been common practice in this community for many years to provide extra safety for children in the summer. Since the site conditions and traffic volumes at the intersections remained constant, the differences in the data obtained during the winter months (two-way stop control) and summer months (all-way stop control) could be directly attributed to the type of control used at that time.

The mean speeds at mid-block were measured for all four directions in both conditions. After the conversion to all-way stop control, the mean speed on the north-south streets decreased from 23.0 to 21.9 miles per hour and on the east-west streets from 18.6 to 18.3 miles per hour. These differences were not statistically significant; therefore, the mean speeds on the major and minor approaches were relatively unaffected by the use of two-way and four-way stop controls.

The fraction of non-stopping drivers increased from 14.1 percent during the two-way stop control to 25.1 percent after the conversion to an all-way stop control. The fraction of drivers who practically stopped (zero to three mph) decreased from 65.7 percent to 55.8 percent after the conversion.

The total user cost for each type of control was calculated as well using the default values from AASHTO Red Book (*39*). The installation of all-way stop control resulted in an average annual road user cost increase of $2,400 per intersection. The analysis led to the conclusion that the use of two-way stop control was three and a half times more efficient economically than the use of all-way stop control.

Effectiveness of multi-way stop control

Bretherton (37) completed a study in which he reviewed over seventy technical documents concerning all-way stops (or multi-way stops) and their successes and failures as traffic control devices in residential areas. He studied twenty-three hypotheses using multi-way stops as speed control, and the research found additional nine hypotheses that tested the effect multi-way stops have on other traffic engineering problems.

After the research had been completed, Bretherton concluded that multi-way STOP signs do not control speed except under very limited conditions. The research determined that the concerns about unwarranted STOP signs are well founded. Below are some of the conclusions of Bretherton's research:

1. Multi-way stops do not control speeds. (23 references)
2. Stop compliance is poor at unwarranted multi-way STOP signs. An unwarranted STOP is defined as a STOP sign which does not meet the warrants of the *MUTCD*. Drivers do not stop because they feel that the signs have no traffic control purpose. Drivers believe there is little reason to yield the right-of-way when there are usually no vehicles on the minor street. (19 references)
3. Before and after studies show multi-way STOP signs do not reduce speeds on residential streets. (4 references)
4. Unwarranted multi-way stops increased speed some distance from intersections. These studies hypothesize that motorists are making up the time they lost at the "unnecessary" STOP sign. (17 references)
5. Multi-way STOP signs have high operating costs based on vehicle operating costs, vehicular travel times, fuel consumption, and increased vehicle emissions. (15 references)
6. Safety of pedestrians, especially small children, is decreased at unwarranted multi-way stops. It seems that pedestrians expect vehicles to stop at the STOP signs, but many vehicles have gotten in the habit of running the "unnecessary" STOP sign. (13 references)
7. Citizens feel safer in communities that are "positively controlled" by STOP signs. Positively controlled is meant to infer that the streets are controlled by unwarranted (possibly unnecessary) STOP signs. Homeowners on the residential collector feel safer on a "calmed" street. (7 references) Hypothesis eleven (below) lists five references that dispute the results of these studies.
8. Speeding problems on residential streets are not associated with "through" traffic. Homeowners feel the problem is created by "outsiders." Frequently, the driver who is speeding through the neighborhood is the person complaining. (5 references)
9. Unwarranted multi-way stops may present potential liability problems for undocumented exceptions to accepted warrants. Local jurisdictions feel they may be incurring higher liability exposure by "violating" the *MUTCD*. Many times, the unwarranted STOP signs are installed without a warrant study or some documentation. (6 references)

10. The costs of installing multi-way stops are low, but enforcement costs are prohibitive. Many communities do not have the resources to effectively enforce compliance with the STOP signs. (5 references)
11. STOP signs do not significantly change the safety of an intersection. STOP signs are installed with the hope that they will make the intersection and neighborhood safer. (5 references) Hypothesis seven (above) lists seven references that dispute the results of these studies.
12. Unwarranted multi-way stops have been successfully removed with public support and result in improved compliance at justified STOP signs. (3 references)
13. Unwarranted multi-way stops reduce crashes in cities with intersection sight distance problems and at intersections where parked cars restrict sight distance. The STOP signs are unwarranted based on volume and do not meet the crash threshold. (3 references)
14. Citizens feel STOP signs should be installed at locations based on traffic engineering studies. Some homeowners realize the importance of installing "needed" STOP signs. (2 references)
15. Multi-way stops can reduce cut-through traffic volume if many intersections along the road are controlled by STOP signs. If enough STOP signs are installed on a residential or collector street, motorists may use a different route because of the inconvenience of having to start and stop at so many intersections. This includes many drivers who will not stop but slowly "cruise" through the STOP signs. This driving behavior has been nicknamed the "California cruise." (2 references)
16. Special police enforcement of multi-way STOP signs has limited effectiveness. This has been called the "halo" effect. Drivers will obey the "unreasonable" laws as long as a policeman is visible. (2 references)
17. District judges order the removal of STOP signs not installed in compliance with city ordinance. Judges have ordered the conversion of "unnecessary" all-way stop-controlled intersections to two-way stop-controlled intersections. The problem begins when the traffic engineer and/or elected officials are asked to consider their intersection a "special case". This creates a precedent and results in a proliferation of "special case" all-way STOP signs. (2 references)
18. Some jurisdictions have created warrants for multi-way stops that are easier to meet than those outlined in the *MUTCD*. These jurisdictions feel that the *MUTCD* warrants are too difficult to meet in residential areas. The reduced warrants are usually created to please elected officials. (2 references)
19. Citizens perceive STOP signs as effective methods of speed control because traffic "slows" at a STOP sign. If everybody obeyed the traffic laws, STOP signs would reduce speeds on residential streets. (1 reference)
20. Removal of multi-way STOP signs does not change speeds, but speeds are slightly lower without the STOP signs. These findings support the drivers' behavior referenced in item four (above) which stated that speed increases when unwarranted STOP signs are installed. Speed decreases when the STOP signs were removed. (1 reference)

Urban stop warrants

Many civil engineers use basic traffic engineering principles to argue against the policies of the *MUTCD* (32). As vehicles at all-way stops alternate the right-of-way, all-way stops function better at locations where vehicle conflicts occur frequently and the traffic volumes on the major and minor roads are approximately equal. All-way stops also function well at locations where there have been many correctable right-angle-type crashes or where unusual circumstances exist. However, all-way stops should only be placed where necessary since drivers may disregard STOP signs that they deem to be "unnecessary" due to traffic, pedestrian volume, or limited visibility. The installation of unwarranted STOP signs can create excessive delay and fuel use as well.

The City of San Diego was an innovator in the creation of an all-way stop policy. The City created its first alternative to the national policy in 1962. The City's newest policy consists of five warrants and a point system. All-way stops may be justified at intersections with twenty-five or more points. The point system can be waived and all-way stops can be justified under any of the following special provisions:

1. Five or more crashes susceptible to correction by all-way stops have occurred in a twelve-month period.
2. Traffic signals are warranted and not yet installed.
3. The intersection has an extreme combination of unusual conditions, and engineering judgment determines that the location would be best served by all-way stops.

The five warrants and corresponding point values are as follows:

1. Crash experience—maximum fifteen points. Three points are assigned for each correctable crash that occurred in the preceding twelve-month period.
2. Unusual conditions (parking in the vicinity, sight distance issues, etc.)—maximum five points. Points are assigned for unusual conditions based on engineering judgment. The point value assigned to each condition should be correlated to the improvement that all-way stops would provide. When awarding points in this warrant, it is important to consider only the actual benefits that all-way stops provide, not the perceived benefits attributed to all-way stops by many non-professionals. Speed control should never be a basis for awarding points.
3. Traffic volumes—maximum fifteen points. Two tables, one for the minor street and one for the major street, are used to assign points based on volume. For the minor street, the number of points awarded increases as the volume increases up to a maximum of ten points. For the major street, the maximum of five points is assigned to a range of volumes at which all-way stops function best.
4. Traffic volume difference—maximum ten points. This warrant differs from the "traffic volumes" warrant in that it considers only the difference between the four-hour volumes of the two streets. All-way stops function best when the difference between the volumes is small.

5. Pedestrian volumes—maximum five points. The volume of pedestrians crossing the major street is of concern when evaluating for all-way stops. One point is assigned for each set of fifty pedestrians in four hours.

The City of San Diego used twenty-three all-way stop intersections to evaluate the capability of this new policy to select intersections that perform well with all-way stops. All twenty-three of these intersections had all-way stops installed despite not meeting the criteria of the old policy. These intersections were then re-evaluated using the criteria of the new policy with data from the original evaluation. If the new policy had been in effect at the time these intersections were originally evaluated, only fourteen of the twenty-three intersections would have had an all-way stop installed. The fourteen intersections that met the criteria were placed in Group A and the remaining nine that did not meet the criteria were placed in Group B for evaluation.

An analysis of all the crashes that occurred twelve months before and after the installation was completed. Group A experienced a significant reduction, whereas Group B experienced a slight increase in crashes. However, the increase of Group B was not statistically significant.

Group A had an average volume ratio (major roadway volume to minor roadway volume) of 1.8, whereas Group B had an average of 4.0. These data support the idea that all-way stops function better with volumes that are approximately equal. Group A also had a lower fraction of motorists on the major street who failed to stop than Group B (6.8 percent to 13.0 percent). The difference between these two figures is statistically significant at the five percent level.

After the completion of the analysis, the research team determined that the new policy was effective at selecting the intersections where an all-way stop is warranted and will earn the respect of the motorists so that it will have a better rate of STOP sign compliance.

The *MUTCD* and the ITE *Traffic Control Devices Handbook* are the major references for the installation of all-way and two-way stops. Several researchers have found reasons for the modification of these warrants, but each researcher comes to a different conclusion on how the warrants should be modified. There remains no list of volume warrants for the installation or removal of stop control in the rural or urban setting.

SURVEY AND DATA COLLECTION

A survey was conducted to investigate county policy or practice in Iowa related to the installation and removal of STOP signs at rural ultra-low-volume intersections. Data was then collected to support analyses comparing the safety performance of controlled and uncontrolled intersections and county safety performance based on the prevalence of stop control.

Survey

The survey was sent to all ninety-nine Iowa county engineers. (The survey can be seen in the Appendix.) Respondents were asked about the following:

- The number of uncontrolled intersections, all-way stops, and yield-controlled intersections on county roads
- Criteria used for installation of STOP signs
- The use of engineering studies prior to installation
- The existence of formal or general policy for STOP sign usage (e.g., place a STOP sign at all intersections, only intersections with sight distance issues, only intersections with paved roadways).

Twenty-nine counties responded to the survey. Below is a summary of responses.

1. Five counties have no rural uncontrolled intersections, while eleven counties have more than 200 uncontrolled intersections. No county has paved or paved/unpaved uncontrolled intersections.
2. Three counties have no all-way rural stop intersections. Three counties have more than fifty all-way stop intersections and two of these have more than 100 all-way stop intersections. Twenty-three of the twenty-six counties with all-way rural stop intersections stated that at least one of these intersections is a paved or paved/unpaved intersection.
3. Twelve counties have no yield-controlled rural intersections. Four of them indicated that they will not consider the use of YIELD signs.
4. The most common major criteria considered by county engineers before installing stop control at an intersection is crash experience (twenty-five counties), followed by sight distance (twenty-three counties) (See Figure 1).
5. Fourteen counties have no formal policy or procedure for installing stop control at intersections. Eleven counties have an informal policy which generally consists of an investigation of crash history and available sight distance, public input, or the completion of an engineering study. The other four counties did not respond.
6. Eighteen counties always perform an engineering study prior to installing STOP signs, while one county never performs an engineering study prior to installation.
7. The two most popular references used in support of engineering studies are the *MUTCD* (twenty-eight counties) and the Iowa Department of Transportation

(Iowa DOT) guidelines (twelve counties). No county indicated the use of ITE procedures to perform an engineering study.

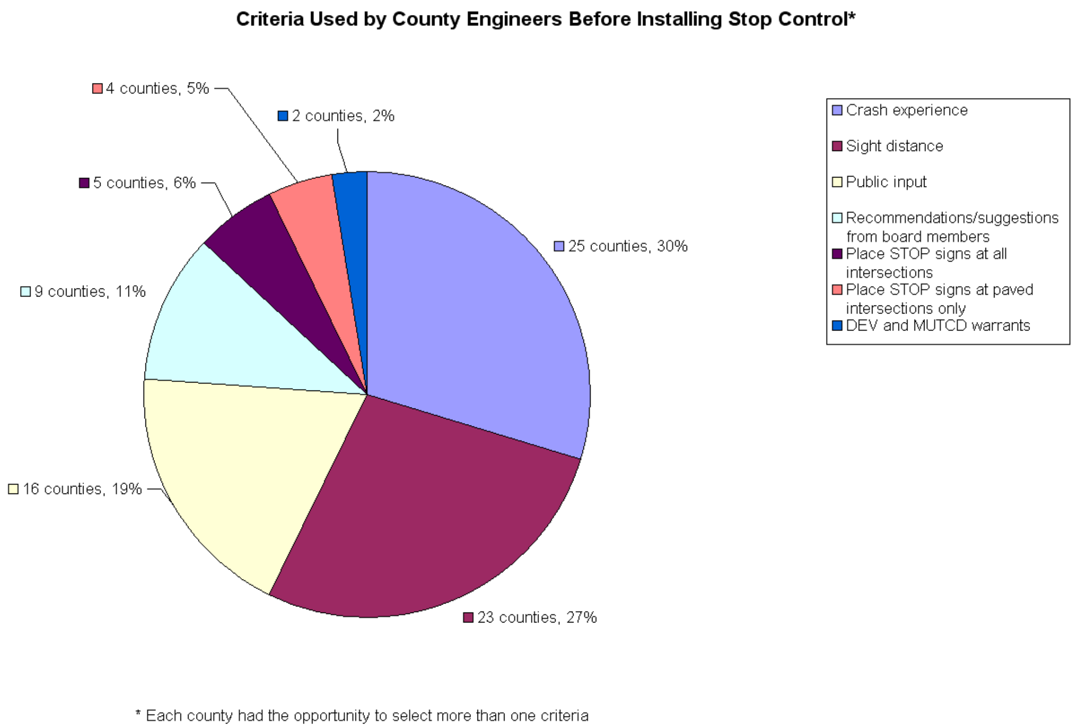

Figure 1. Criteria used by county engineers before installing stop control

The survey indicated that the two most popular criteria considered by county engineers before the installation of a STOP sign were available sight distance and crash history. There were no counties that specified the use of volume as an indicator for STOP sign usage and that had a formal policy for the installation of a STOP sign. Instead, counties followed the guidelines outlined in the *MUTCD* and those used by the Iowa DOT.

Data collection

Along with the responses to the survey, nineteen counties sent either a map or a database identifying the locations of their rural STOP signs. Several of the databases that were sent contained several thousand records of every sign (regulatory, warning, and guide signs) in the county. These databases were assembled to determine the locations of all stop- and yield-controlled intersections for each county. Next, each stop- or yield-controlled intersection was manually selected from a GIS layer of all intersections in the state of Iowa. After the intersections for a county had been selected, a map of the county was created identifying the control type of each intersection.

After the study intersections had been selected, a crash analysis was conducted using ten years of crash data (1994-2003). Intersection-related crashes were selected using a GIS program. Only multi-vehicle crashes were identified as intersection crashes. Further, crashes more than 150 feet from the intersections were excluded from consideration (150 feet is the standard distance used by the Iowa DOT for rural and urban intersection crash identification). A spatial "join" was then completed to assign each crash to the nearest intersection. After the daily entering vehicles (DEV) for each intersection had been calculated, the average number of crashes, crash rate, average severity loss, and cost per intersection was computed and summarized for each county and stratified by number of intersection legs as well as by type of control. All costs were determined using standard values for crash severity used by the Iowa DOT.

An example county summary is shown in Table 3. The table shows that stop-controlled intersections had a much higher average crash rate per million entering vehicles than uncontrolled intersections in Story County. Stop-controlled intersections also had a higher average number of crashes per intersection, as well as a lower average severity cost per intersection. However, there were only twelve stop-controlled intersections as compared to nearly 320 uncontrolled intersections in this county.

Table 3. Summary for Story County

Unpaved – Unpaved Intersections – Story County (values per intersection)				
	3 leg intersections		4 leg intersections	
	Uncontrolled	Stop-controlled	Uncontrolled	Stop-controlled
Avg MEV rate	0.30	0.30	1.06	1.94
Avg DEV	86	93	88	115
Avg crashes	0.09	0.20	0.33	0.57
Avg sev	0.15	0.40	0.73	1.14
Avg sev cost	$1,270	$500	$20,344	$3,571
Number of int	156	5	160	7
Max rate	24.35	1.52	9.13	7.83
Max DEV	395	180	435	255
Min DEV	18	25	25	35
Max crashes	4	1	4	1
Max sev cost	$150,000	$2,500	$1,000,000	$10,000
Total crashes	14	1	52	4
Pooled Data				
	Uncontrolled	Stop-controlled	All data	
Avg MEV rate	0.68	1.26	0.71	
Avg DEV	87	106	88	
Avg crashes	0.21	0.42	0.22	
Avg sev	0.44	0.83	0.45	
Avg sev cost	$10,926	$2,292	$10,489	
Number of int	316	12	332	
Max rate	24.35	7.83	24.35	
Max DEV	435	255	435	
Min DEV	18	25	18	
Max crashes	4	1	4	
Max sev cost	$1,000,000	$10,000	$1,000,000	
Total crashes	66	5	72	

As shown in Table 4, statewide stop-controlled intersections have a lower average crash rate, average severity cost, total number of crashes, and an average cost per crash than uncontrolled intersections. The average number of crashes per intersection is approximately equal for stop-controlled and uncontrolled intersections.

Table 4. Unpaved Intersection Crash Performance, Nineteen Counties

	3 leg intersections		4 leg intersections	
	Uncontrolled	**Stop-controlled**	**Uncontrolled**	**Stop-controlled**
Avg. rate (MEV)	0.17	0.14	0.50	0.36
Avg. DEV	67	80	69	94
Avg. crashes	0.04	0.05	0.13	0.14
Avg. severity	0.08	0.07	0.33	0.29
Avg. sev. cost	$836	$291	$12,470	$8,370
Number of int.	2268	1373	1561	1607
Max rate	24.35	13.70	18.26	10.96
Max DEV	465	440	443	455
Min DEV	8	8	15	10
Max crashes	4	2	4	4
Max sev. cost	$150,000	$150,000	$1,150,000	$1,020,000
Total crashes	99	62	205	217

	Pooled data for all 3 & 4 leg intersections		All data
	Uncontrolled	**Stop-controlled**	**Pooled**
Avg. rate (MEV)	0.31	0.26	0.28
Avg. DEV	68	88	77
Avg. crashes	0.08	0.09	0.09
Avg. severity	0.18	0.19	0.18
Avg. sev. cost	$5,578	$4,648	$5,171
Number of int.	3829	2980	6809
Max rate	24.35	13.70	24.35
Max DEV	465	455	465
Min DEV	8	8	8
Max crashes	4	4	4
Avg. cost/crash	$70,265	$49,645	
Total crashes	304	279	583

ANALYSIS

The following sections discuss the analyses completed in this study. An analysis of safety performance (stop versus uncontrolled) and a cost analysis were completed. A regression analysis was conducted to determine whether a crash was more likely to occur at a specific intersection based on type of control and DEV. However, none of these analyses attempted to quantify the relationship between the widespread use of stop control and intersection safety performance. In order to quantify this relationship, three different analyses were completed: (1) the determination of “excess” control based only on a volume threshold, (2) the determination of “excess” control based on a volume threshold and the fraction of intersections that should be controlled due to sight distance limitations (approximated by a “terrain factor”), and (3) determination of a use factor based on the ratio of stop control used in a typical Iowa county (Cherokee County). These analyses led to the identification of a potential volume threshold for the use of stop control. Analyses were completed to determine older or younger drivers crash experiences at ultra-low-volume rural unpaved intersections and whether specific types of crashes were more prevalent at study intersections. The analysis chapter concludes with a section outlining an urban application that was completed in the City of Ames, Iowa.

Controlled versus uncontrolled intersections

A descriptive statistical analysis was first conducted on 6,846 unpaved rural intersections. Fifty-six percent of the study intersections were uncontrolled (There was an insufficient number of rural yield-controlled intersections in the database to make any statistically significant conclusions regarding the use of YIELD signs. Therefore, yield control was not studied in depth in this project.). Ninety-two percent of the intersections had no crashes in ten years (approximately the same for both stop-controlled and uncontrolled intersections). The probability of one or more crashes at an intersection during the ten-year period was then modeled as a function of DEV and type of control.

Figure 2 shows all the intersections involved in the study with a DEV less than or equal to 100 vehicles. The vast majority of these intersections had no crashes during the ten-year analysis period. Nearly 5,500 intersections had a DEV of less than 100 vehicles and over 5,000 of these intersections had no crashes.

Figure 3 shows the same information for all the study intersections. The intersections were then classified into volume categories (see Table 5) and graphed in subsequent figures.

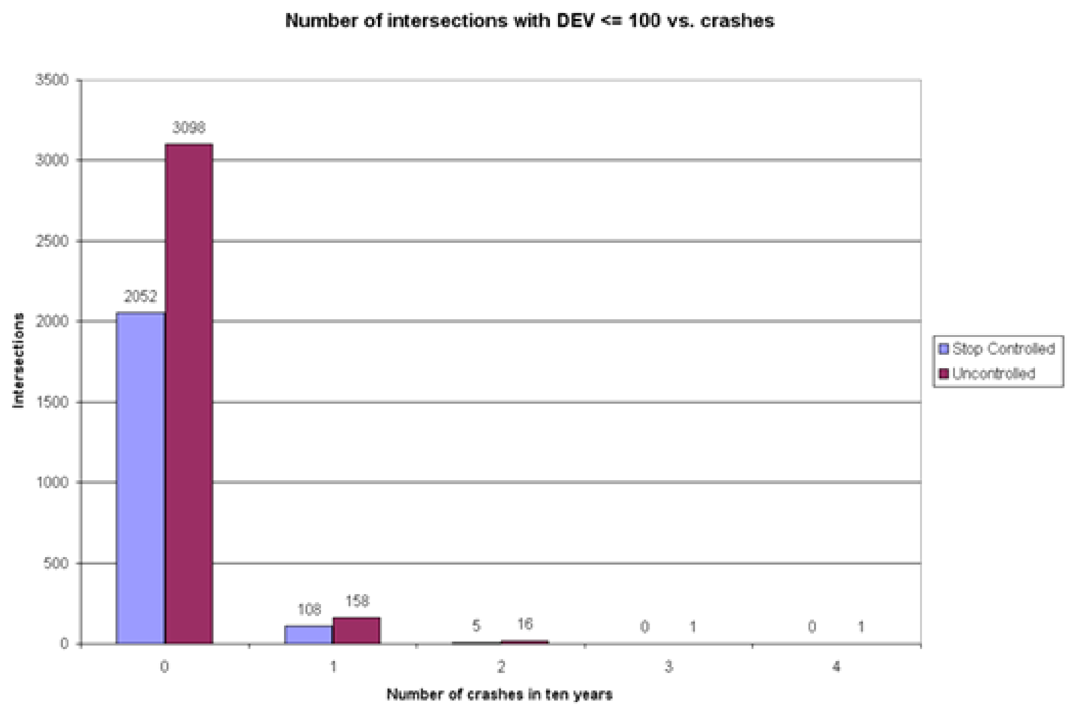

Figure 2. Intersections with DEV less than 100 vehicles

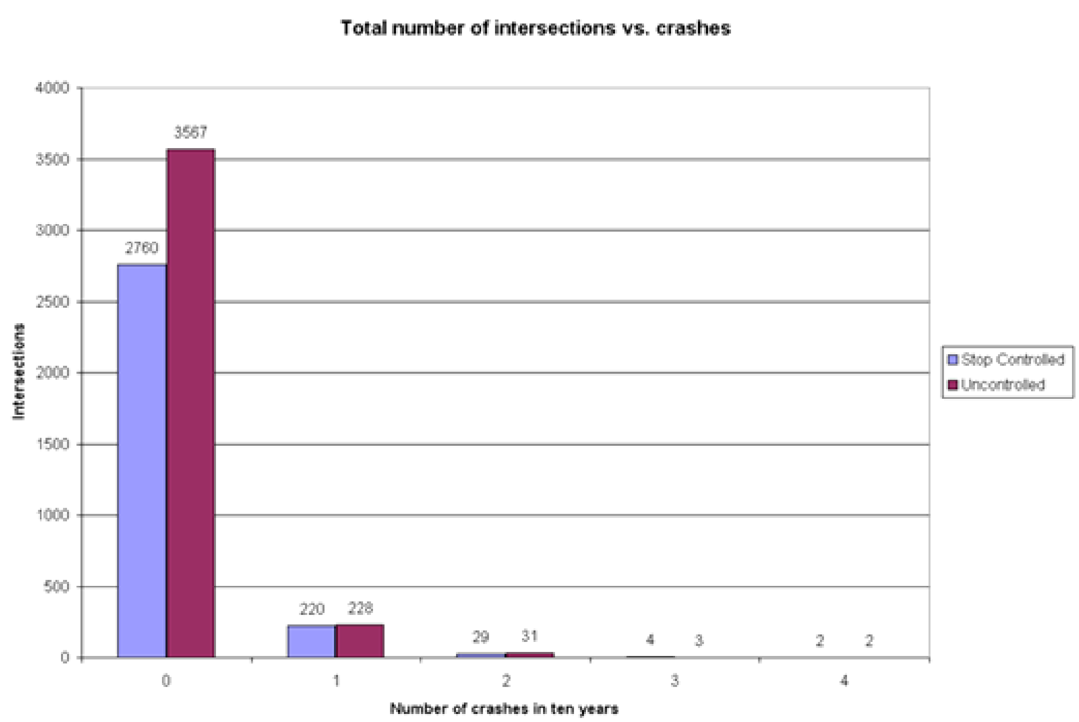

Figure 3. All unpaved intersections

Table 5. Crash comparison by DEV range

Stop-controlled Intersections						
Category	**DEV**	**# of int**	**Crashes**	**Avg crashes/int**	**Avg rate/int**	**Avg sev/crash**
20	0-20	97	1	0.01	0.14	4.00
40	21-40	452	8	0.02	0.14	2.88
60	41-60	646	32	0.05	0.25	1.63
80	61-80	581	39	0.07	0.26	2.23
100	81-100	389	38	0.10	0.29	2.16
120	101-120	250	30	0.12	0.29	1.93
140	121-140	167	18	0.11	0.22	2.06
160	141-160	109	24	0.22	0.40	1.79
180	161-180	74	17	0.23	0.36	1.82
200	181-200	51	15	0.29	0.42	1.67
Uncontrolled Intersections						
Category	**DEV**	**# of int**	**Crashes**	**Avg crashes/int**	**Avg rate/int**	**Avg sev/crash**
20	0-20	190	4	0.02	0.33	1.75
40	21-40	872	29	0.03	0.27	2.28
60	41-60	1091	51	0.05	0.25	2.24
80	61-80	748	66	0.09	0.34	2.61
100	81-100	373	47	0.13	0.38	2.15
120	101-120	198	36	0.18	0.45	2.67
140	121-140	122	21	0.17	0.36	2.10
160	141-160	76	13	0.17	0.32	2.38
180	161-180	49	11	0.22	0.36	1.91
200	181-200	26	3	0.12	0.17	2.67

Figure 4 shows that, as expected, as DEV increases, the average number of crashes per intersection increases. (Numbers above each bar in the figure indicate the number of intersections in that DEV category.) Generally speaking, uncontrolled intersections have more crashes per intersection below 160 DEV.

Figure 5 indicates that as DEV increases for stop-controlled intersections, the average crash rate per intersection tends to increase as well. (Numbers above each bar in the figure indicate the number of intersections in that DEV category.) However, it appears as though no observable trend exists for the uncontrolled intersections. Here, again, the average crash rate for uncontrolled intersections tends to be higher below 160 DEV.

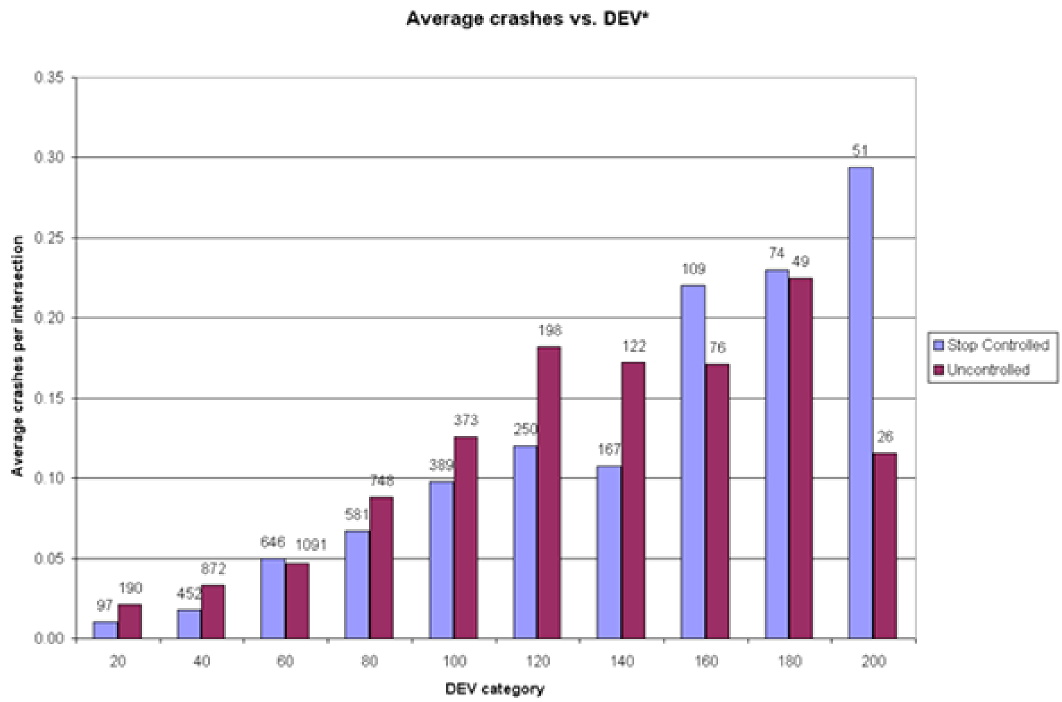

Figure 4. Average crashes vs. DEV

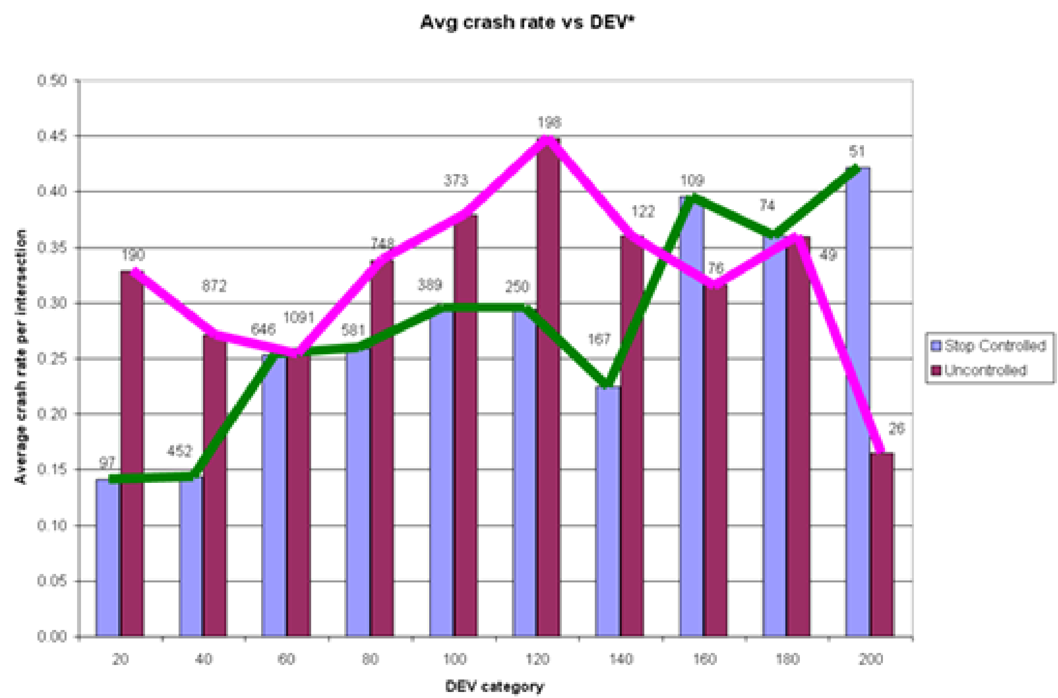

Figure 5. Average crash rate per intersection vs. DEV category

Figure 6 shows that, generally, the average severities per crash for both stop-controlled and uncontrolled intersections are comparable. Uncontrolled intersections tend to have a somewhat higher average severity across all DEV categories, with the exception of the lowest DEV categories where sample size is very small. (Numbers above each bar in the figure indicate the number of crashes in that DEV category.)

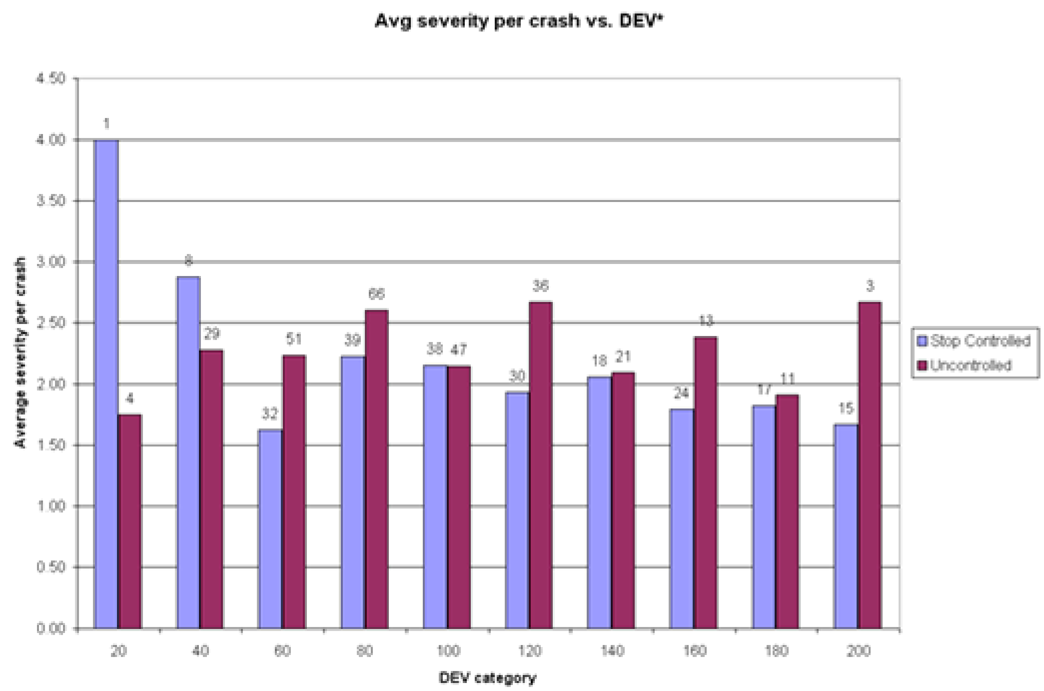

Figure 6. Average severity per crash vs. DEV category

Figures 7 and 8 present the data points for each of the nineteen study area counties (one for stop-controlled intersections and one for uncontrolled intersections). The figures portray the average number of crashes and crash rate versus average DEV per intersection. Again, as expected, as DEV increases, the average number of crashes per intersection tends to increase as well for both control types. Above a DEV value of about 60 vehicles per day, uncontrolled intersections have more crashes than their stop-controlled counterparts. Figure 7 also appears to indicate that at DEV lower than the divergent point, the two types of control are approximately equal with respect to the average number of crashes per intersection.

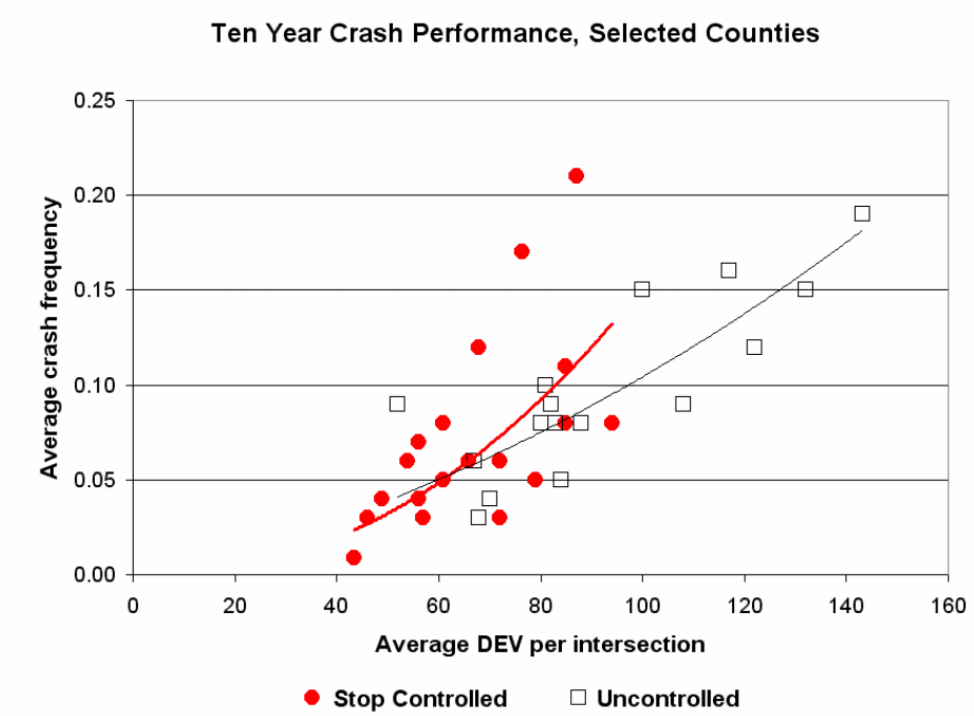

Figure 7. Average number of crashes per intersection on a countywide basis

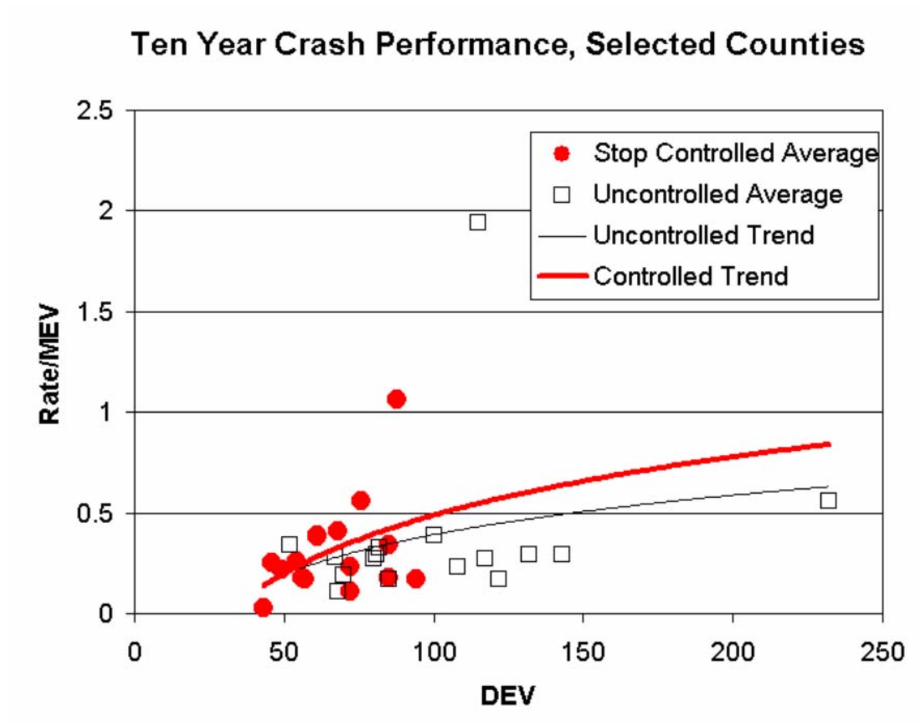

Figure 8. Comparison of intersection performance

As shown in the previous figures, stop-controlled intersections tend to have a lower crash rate except at very ultra-low-volume locations (less than sixty DEV), where it appears as though the crash rates of both stop-controlled and uncontrolled intersections are approximately equal. This may indicate that statistically there is no significant difference between the two types of control at any DEV less than this threshold value.

Cost analysis

Statewide, stop-controlled intersections have a slightly lower average crash rate per million entering vehicles as well as a lower average cost per crash. For these reasons, it would appear that there is a savings (excluding delay cost) which could be realized by switching all uncontrolled intersections to stop-controlled intersections. (The following calculation is made using numbers taken from Table 4.)

Crashes saved by changing uncontrolled to stop-controlled intersections = (0.05 (difference in crash rate) x 68 (average DEV) x 365 days x 10 years x 3,829 intersections) / 1,000,000 = 47.5 crashes

To calculate the expected savings, the cost of the crashes after the conversion (256 crashes multiplied by the average cost per crash for stop-controlled intersections, $50,000) can be subtracted from the cost of the crashes before the conversion (304 crashes multiplied by average cost per crash for uncontrolled intersections, $70,000). The savings would be approximately $8.5 million, not including the cost of installing and maintaining STOP signs. However, this analysis assumes that none of the stop-controlled intersections is warranted based on sight distance. A more realistic analysis would include crash, maintenance, and delay costs. Therefore, the following assumptions were made:

- Vehicles slowed from fifty-five miles per hour to forty miles per hour at uncontrolled intersections and then accelerated to fifty-five miles per hour (delay of thirty seconds per vehicle from field tests completed by author)
- Vehicles slowed from fifty-five miles per hour to a complete stop at stop-controlled intersections and then accelerated to fifty-five miles per hour (delay of forty-five seconds per vehicle from field tests completed by author)
- The cost per driver hour was fifteen dollars
- All stop-controlled intersections are two-way stop intersections
- Maintenance/replacement cost per year per intersection was fifty dollars

The equations representing the regression curves on Figure 7 were used to calculate the number of crashes used in the cost analysis, resulting in the cost estimates presented in Figure 9.

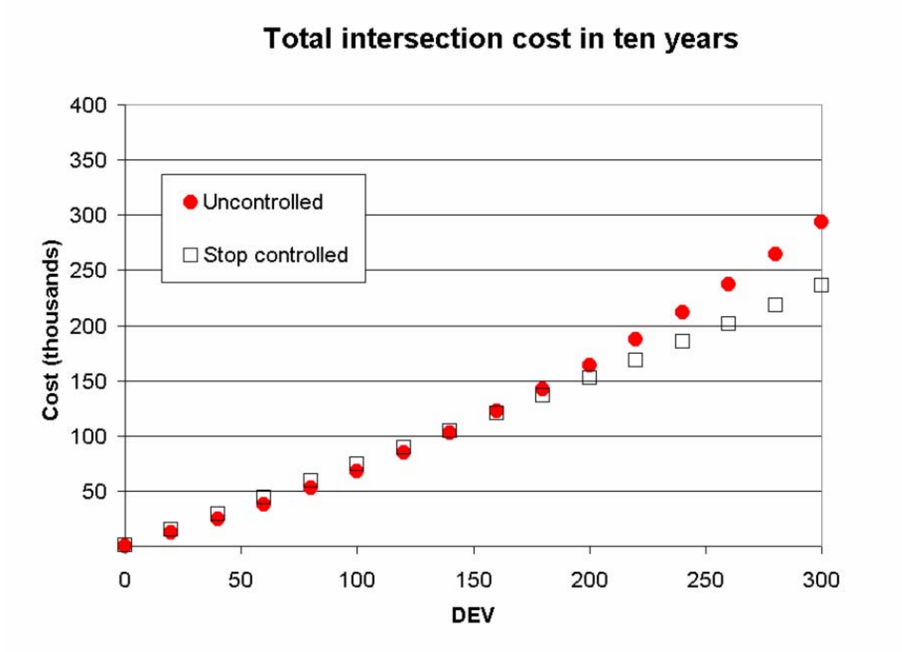

Figure 9. Total cost in ten years based on control type

This figure indicates another divergent point near 250 entering vehicles. The inclusion of all costs in this analysis caused the divergent point to shift from a DEV near 70 vehicles (based solely on crashes) to a value of 250 vehicles. Presuming all of the above assumptions to be accurate, this graph indicates that stop-controlled intersections should not be used at intersections with a DEV lower than 250 vehicles based on total cost (crashes, maintenance, and delay). However, this analysis may overstate the benefits of the use of an uncontrolled intersection. Turning vehicles have to decelerate at an intersection regardless of control type, and turning movements may be prominent at study intersections due to the lack of thoroughfare at ultra-low-volume rural intersections. Therefore, this analysis may overstate the benefits of an uncontrolled intersection with respect to turning movements.

Logistic regression

A logistic regression was completed to quantify the relationship between type of control, DEV, and the probability of having at least one crash occur at an intersection over ten years (however, this analysis did not include sight distance). As the number of crashes was nearly always equal to zero or one, logistic regression was used to determine the probability that one or more crashes would occur at a specific intersection during the ten-year period based on type of control and DEV (Sight distance is not included as a variable in this analysis. The DEV used in this analysis were collected by IDOT between 1960 and 2003.). For a binary variable, the appropriate model is the binomial which is fitted using logistic regression.

Figure 10 shows the regression equation and resulting probabilities for all study intersections. Type of control was treated as a dummy variable (-1 for stop-controlled and +1 for uncontrolled intersections). A divergent point exists near a DEV equal to 100 vehicles. It is at this point that uncontrolled intersections begin to have a higher probability of having at least one crash in a ten-year period. Below this point, however, it appears as though the probabilities for stop-controlled and uncontrolled intersections are approximately equal. This may indicate a threshold value, below which the type of control is not statistically significant and may not matter because the intersection performance of stop-controlled and uncontrolled intersections is approximately the same.

A ninety-five percent confidence interval was determined for the location of the divergent point. The interval determined that this point lies between 66 and 140 daily entering vehicles. The correct interpretation of this interval is as follows: the interval from 66 to 140 DEV covers the true DEV value at which there is no difference in the probability of a crash between intersections with and without stop control with ninety-five percent confidence.

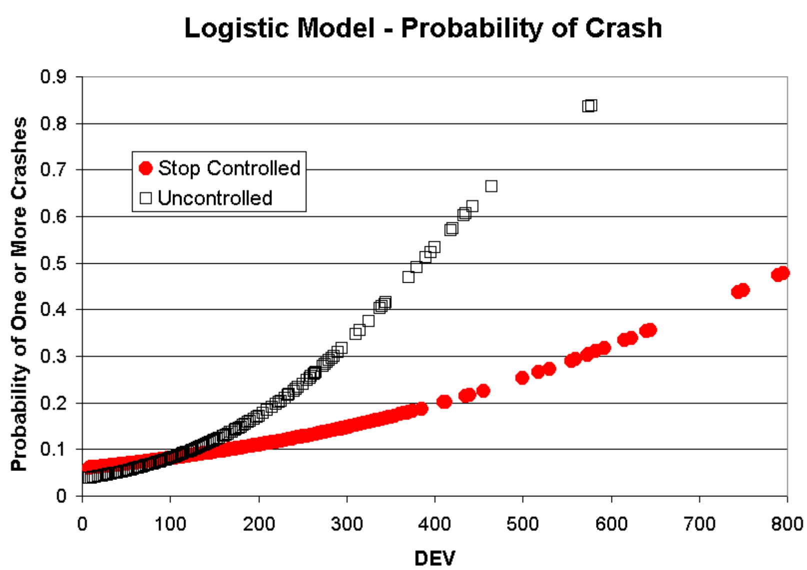

Figure 10. Probability of a crash occurring in ten years

Effect of "positive" control

Although statewide crash rates at stop-controlled intersections are lower than at uncontrolled intersections, it is overly simplistic to say that conversion of all intersections to stop control would result in a reduction of crashes. The procedure completed previously does not account for the potential of any underlying factors that may make the previously uncontrolled intersections different from their controlled counterparts. Therefore, an analysis was completed in which the use of excess stop control was investigated. The fraction of stop-controlled intersections for each county was determined as shown in Table 6.

Table 6. Fraction of stop-controlled intersections per county

County	100	150	Total # of int	# of stop-controlled int	% controlled
	# of int meeting threshold				
Adams	17	4	361	252	70%
Boone	60	18	379	94	25%
Bremer	77	39	268	113	42%
Calhoun	50	16	379	140	37%
Carroll	144	46	401	245	61%
Cedar	142	58	396	167	42%
Cerro Gordo	89	23	359	208	58%
Cherokee	33	9	350	93	27%
Clay	40	10	332	49	15%
Emmet	10	4	183	92	50%
Henry	130	51	346	181	52%
Madison	166	101	496	143	29%
Montgomery	54	8	349	208	60%
Osceola	19	4	219	98	45%
Pocahontas	26	3	325	66	20%
Sac	54	16	379	88	23%
Story	98	33	328	12	4%
Washington	151	61	483	398	82%
Woodbury	125	81	489	368	75%

This data was plotted against the average crash rate at all stop-controlled intersections for each county to determine the effect that positive control had on intersection performance (See Figure 11).

It has been hypothesized that as the use of stop control at intersections increases, the crash rate (on a countywide basis) would increase as well (This hypothesis was used to validate the potential removal of several stop-controlled intersections.). Figure 11 shows that this phenomenon does not exist. It appears that the average crash rate would slightly decrease as the use of STOP signs increased. Because of the downward trend in these data, the fraction controlled was used to determine the existence of any correlations elsewhere within the data.

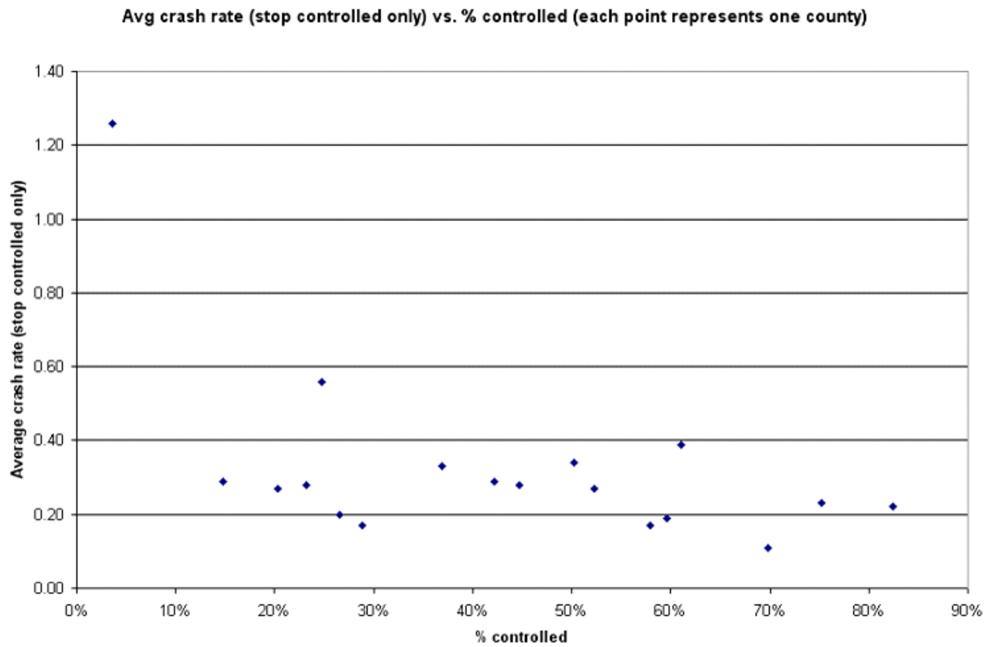

Figure 11. Effect of positive control on stop-controlled intersections crash rate

Figure 12 shows the average crash rate for all intersections in each county versus the fraction of stop-controlled intersections. This figure also shows a slightly downward trend. It was hypothesized that this trend occurred because counties that had a low crash rate for all the unpaved intersections in the county also had a low crash rate for the entire county (all crashes along all unpaved roads in the county). The green points represent the crash rate for all the crashes that occurred along unpaved roads in the county (not just intersection crashes). As Figure 12 shows, these rates do not tend to decrease as fractional control increases. Therefore, the relationship between average crash rate (all unpaved intersections) and fraction controlled is not correlated with countywide crash rate.

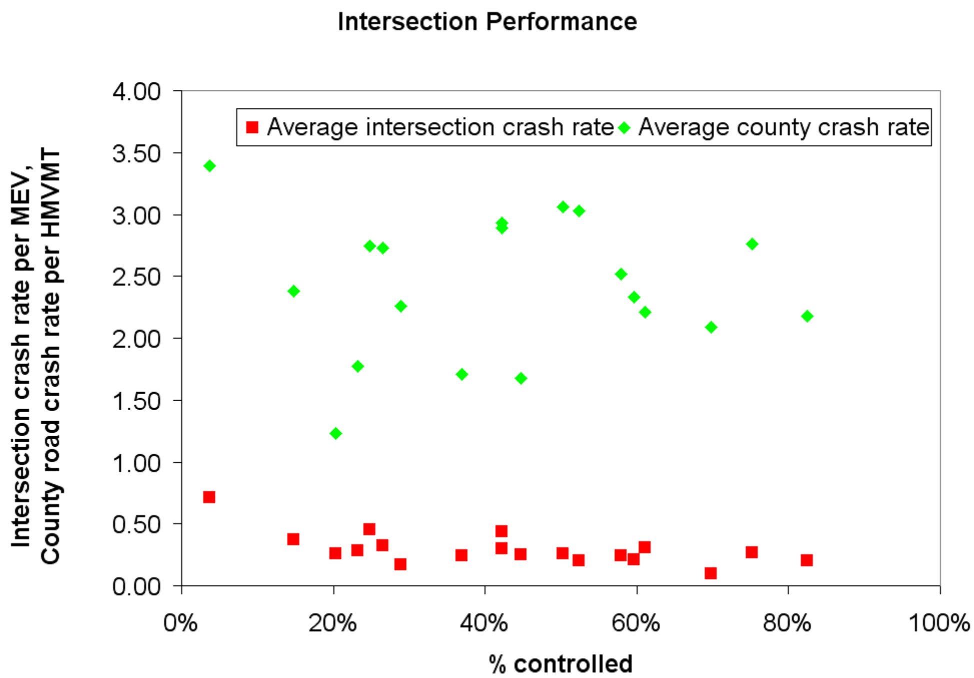

Figure 12. Effect of positive control on countywide crash rate

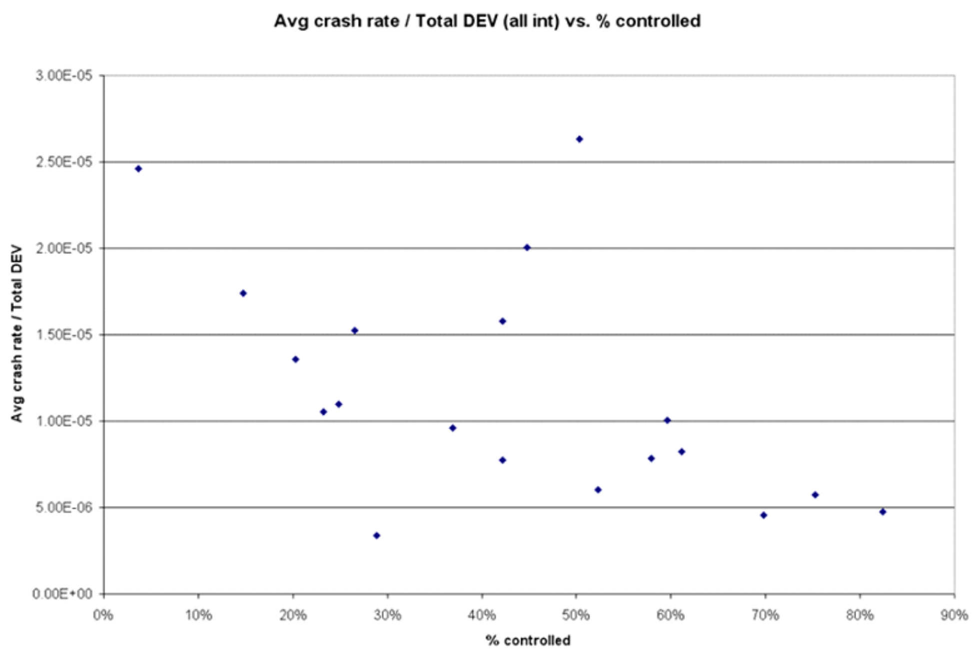

Figure 13. Non-linear effect of DEV and control on crash rate

Figure 13 shows the average crash rate divided by the total DEV for all the unpaved intersections versus percent controlled. This figure was created to determine the nonlinear effect of DEV on the relationship between average crash rate and fraction controlled. Again, a downward trend appears to exist.

As shown in Table 7, a new variable, "percent excess" was calculated. This variable indicates fraction of additional intersections that each county has based on the assumption that all intersections that have at least 100 DEV should be controlled by use of a STOP sign. A DEV equal to 100 was selected based upon the logistic regression discussed previously. That regression showed that at a DEV near 100 vehicles, stop-controlled and uncontrolled intersections appeared to have the same value. Equation 1 shows the calculation of the "percent excess" variable. The trends shown in Figures 11 through 13 do not support the hypothesis that crash rate increases as the use of stop control increases. For this reason, the effect of "excessive" use was studied next.

Excessive control (based on volume threshold only)

After determining that there was little apparent relationship between the stop control representation of a county and intersection crash performance, the next step was to determine if the use of excessive control (based on a volume threshold only) had an effect on intersection performance. To determine the amount of excessive use that each county had, a volume threshold was created to determine the number of intersections where stop control was valid based on volume alone. Again, this analysis did not take into account the number of intersections that were valid based on sight distance. This analysis focused strictly on volume validation. As shown in Figure 11, a DEV level of 100 vehicles appeared to be the point where uncontrolled intersection safety performance began to decline in comparison to that of its stop-controlled counterpart. For this reason, a validation volume of 100 DEV was chosen to determine the effect of excessive control.

The following equation was used to calculate the percentage of excess stop-controlled intersections each county had based on a DEV threshold of 100 vehicles:

Equation 1: Calculation of percent excess

percent excess = (the number of stop-controlled intersections that exist minus the number of stop-controlled intersections that the county should have based on a DEV of 100) / the number of stop-controlled intersections that the county should have based on a DEV of 100

Table 7 shows the "percent excess" calculated for each county based on a threshold value of 100 DEV. There are two counties with negative percentages: Madison and Story County. These numbers are negative because the number of intersections with at least 100 DEV in these counties is greater than the number of stop-controlled intersections which exist in these counties.

Table 7. Percent excess calculated for each county

County	% "excess" assuming volume threshold = 100	Total crashes	Average crashes	Avg rate	Avg DEV	Total DEV (1000s)	Rate (crashes/MEV)
Adams	1382%	9	0.02	0.10	61	22	4.5
Boone	57%	58	0.15	0.45	108	41	11.1
Bremer	47%	50	0.19	0.44	104	28	15.8
Calhoun	180%	21	0.06	0.24	66	25	9.6
Carroll	70%	49	0.12	0.31	94	38	8.2
Cedar	18%	48	0.12	0.30	98	39	7.7
Cerro Gordo	134%	27	0.08	0.24	85	31	7.9
Cherokee	182%	21	0.06	0.32	60	21	15.2
Clay	23%	29	0.09	0.37	64	21	17.4
Emmet	820%	11	0.06	0.26	54	10	26.3
Henry	39%	34	0.10	0.20	96	33	6.0
Madison	-14%	57	0.11	0.17	102	51	3.4
Montgomery	285%	13	0.04	0.21	60	21	10.2
Osceola	416%	11	0.05	0.25	57	12	20.0
Pocahontas	154%	19	0.06	0.26	59	19	13.6
Sac	63%	25	0.07	0.28	70	27	10.6
Story	-88%	72	0.22	0.71	88	29	24.6
Washington	164%	34	0.07	0.20	87	42	4.8
Woodbury	194%	40	0.08	0.27	96	47	5.8

Figure 14 shows the relationship between the average crash rate for all study intersections in each county versus the fraction of excess stop-controlled intersections. It appears that as the fraction of excess stop-controlled intersections increases, the average crash rate per intersection (on a countywide basis) decreases. A correlation was completed to determine if there was an actual relationship between these two variables.

The test statistic for a correlation is the p-value. A p-value less than or equal to 0.05 indicates a strong relationship between two variables (at the ninety-five percent significance level). The correlation completed for these two variables indicated a p-value of 0.48. This value means that the fraction of excess stop-controlled intersections is not a strong indication of the average crash rate on a countywide basis. Since there was no strong relationship between these two variables, a factor to indicate the effect of excess use had to be calculated. This factor would not only include a volume threshold, but also a surrogate for sight distance on a countywide basis.

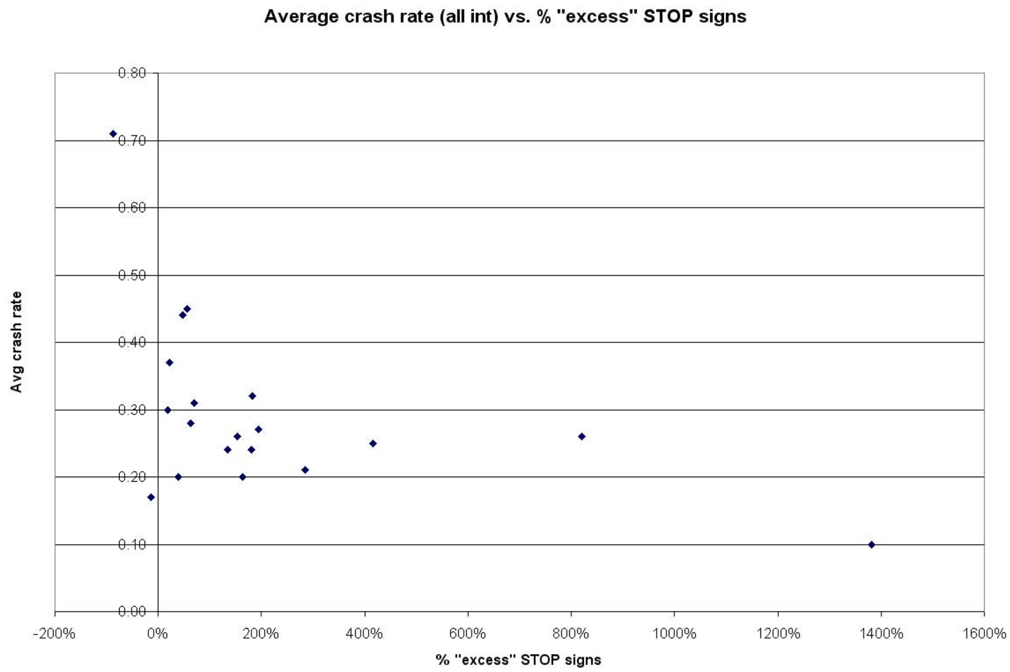

Figure 14. "Percent excess" STOP signs based on a volume threshold of 100 DEV

Terrain factor

Clearly, STOP sign overuse is not indicated at sites with sight distance limitations. However, as sight distance is not available in the Iowa DOT database and this project scoped to more than 6,000 locations, it was not feasible to collect sight distance for each intersection. In an attempt to account for the fraction of intersections that should be controlled due to sight distance, a terrain factor was developed. This factor was a surrogate for sight distance (It was assumed that counties with rougher terrain would have more sight distance limitations than a flat, crop-covered county.). The "percent excess" calculated previously (based on volume alone) was adjusted by this terrain factor in an attempt to more appropriately represent the effect of excess STOP sign use. The terrain factor was created based on topography and land cover on a county by county basis, based on United States Geological Survey (USGS) land cover and shaded relief maps. Each county was given a value of one to three (one = low, flat land, agriculture cover, three = high, river land, forest cover) based on topography and land cover. See Figures 15 through 17 below.

Figure 15. USGS land cover map

Figure 16. USGS shaded relief map

Figure 17. Terrain values for each county

"Justified" stop-controlled intersections based on volume and terrain

To determine the number of "justified" stop-controlled intersections, two separate fractions were estimated. The first was the fraction of intersections that met the threshold value of 100 DEV (as outlined previously). The second was the fraction of intersections that would be warranted on sight distance limitations. As the terrain factor was somewhat subjectively determined, a sensitivity analysis was conducted to examine the effect of a range of terrain values.

Table 8. Terrain factor values

County	Terrain values - Low Range			Terrain values - Medium Range			Terrain values - High Range		
	Landcover	Topography	Terrain factor	Landcover	Topography	Terrain factor	Landcover	Topography	Terrain factor
	% justified on terrain alone			% justified on terrain alone			% justified on terrain alone		
Adams	60%	60%	36%	60%	60%	36%	70%	70%	49%
Boone	30%	30%	9%	40%	40%	16%	50%	50%	25%
Bremer	30%	30%	9%	40%	40%	16%	50%	50%	25%
Calhoun	30%	30%	9%	40%	40%	16%	50%	50%	25%
Carroll	30%	30%	9%	40%	40%	16%	50%	50%	25%
Cedar	60%	60%	36%	60%	60%	36%	70%	70%	49%
Cerro Gordo	30%	30%	9%	40%	40%	16%	50%	50%	25%
Cherokee	30%	30%	9%	40%	40%	16%	50%	50%	25%
Clay	30%	30%	9%	40%	40%	16%	50%	50%	25%
Emmet	30%	30%	9%	40%	40%	16%	50%	50%	25%
Henry	60%	60%	36%	60%	60%	36%	70%	70%	49%
Madison	90%	60%	54%	80%	60%	48%	90%	70%	63%
Montgomery	30%	60%	18%	40%	60%	24%	50%	70%	35%
Osceola	30%	30%	9%	40%	40%	16%	50%	50%	25%
Pocahontas	30%	30%	9%	40%	40%	16%	50%	50%	25%
Sac	30%	30%	9%	40%	40%	16%	50%	50%	25%
Story	30%	30%	9%	40%	40%	16%	50%	50%	25%
Washington	60%	60%	36%	60%	60%	36%	70%	70%	49%
Woodbury	30%	60%	18%	40%	60%	24%	50%	70%	35%

After the terrain factor values were created, the number of "justified" stop-controlled intersections (based on terrain and volume threshold) was calculated using the following equation:

Equation 2: Number of "justified" stop-controlled intersections based on volume and terrain

Number of "justified" stop-controlled intersections = Total number of intersections multiplied by (1 – (1 – % justified based on a volume threshold of 100 DEV) x (1 – % justified based on terrain))

After the number of "justified" stop-controlled intersections was calculated, the fraction of excess stop-controlled intersections was recalculated.

Table 9. "Justified" stop-controlled intersections based on volume threshold of 100 DEV and terrain

County	Set 1	Set 2	Set 3
Adams	186	141	141
Boone	140	89	111
Bremer	125	94	108
Calhoun	132	80	103
Carroll	208	167	185
Cedar	266	233	233
Cerro Gordo	157	113	132
Cherokee	112	62	84
Clay	113	66	87
Emmet	53	26	38
Henry	236	208	208
Madison	374	344	324
Montgomery	157	107	125
Osceola	69	37	51
Pocahontas	101	53	74
Sac	135	83	106
Story	156	119	135
Washington	314	271	271
Woodbury	252	191	212

Table 10. Excess recalculated based on a volume threshold of 100 DEV and terrain

County	Set 1	Set 2	Set 3
Adams	36%	79%	79%
Boone	-33%	6%	-15%
Bremer	-9%	20%	5%
Calhoun	6%	76%	36%
Carroll	18%	47%	32%
Cedar	-37%	-28%	-28%
Cerro Gordo	33%	84%	57%
Cherokee	-17%	51%	11%
Clay	-57%	-26%	-43%
Emmet	73%	260%	144%
Henry	-23%	-13%	-13%
Madison	-62%	-58%	-56%
Montgomery	32%	94%	67%
Osceola	42%	165%	92%
Pocahontas	-34%	25%	-11%
Sac	-35%	6%	-17%
Story	-92%	-90%	-91%
Washington	27%	47%	47%
Woodbury	46%	93%	73%

To determine if there was a relationship between this "percent excess" variable and the countywide intersection crash rates, the data was graphed as can be seen below.

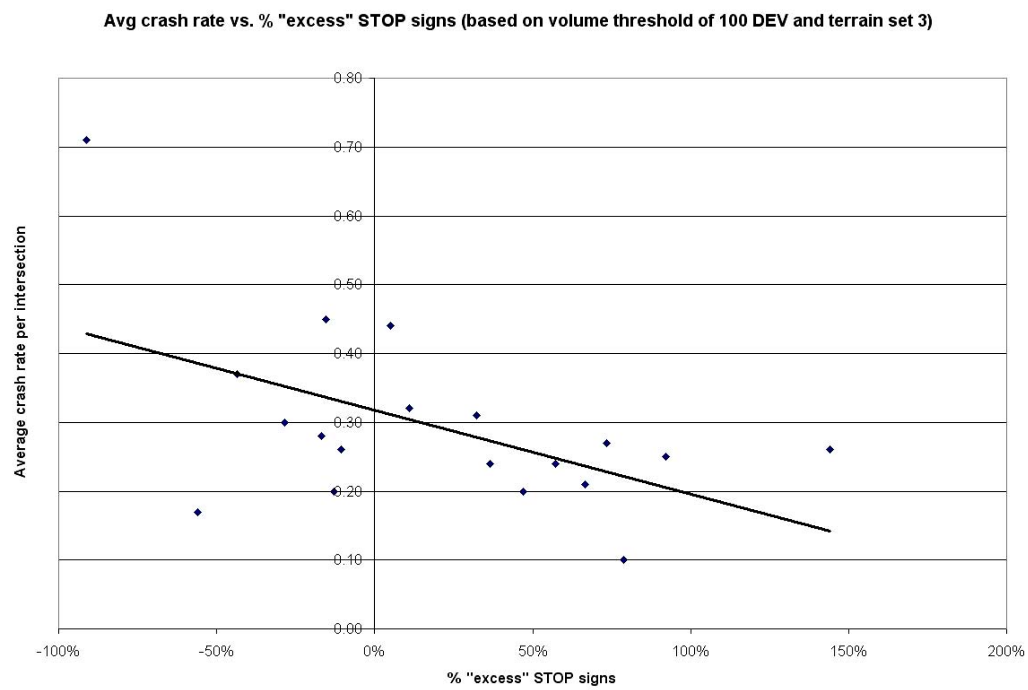

Figure 18. "Percent excess" STOP signs recalculated based on volume threshold and terrain

Figure 18 shows that as the fraction of excess stop-controlled intersections increases, the average crash rate per intersection tends to decrease. To determine the strength of this relationship, a correlation was completed between "percent excess" and average crash rate. The correlation resulted in an insignificant p-value of 0.54. This indicates a weaker relationship between crash rate and excess based on volume and terrain than based on volume alone. The poor fit may be caused partly because of assumptions used in the estimation of intersections that should have sight distance limitations. To validate the assumptions used as proxies for sight distance, a field survey of three of the study area counties was completed. This field survey indicated that the terrain factor-predicted number of sites with sight distance limitations matched two counties well (Adams and Boone), but failed to accurately estimate the fraction in the third county (Madison).

To try to determine the relationship between the use of STOP signs and crash rate, another method was used. This method used fewer assumptions and did not base its calculation on subjectively created data.

Development of an excessive use factor based on Cherokee County

The “percent excess” calculation was developed using topography and land cover in an attempt to represent the fraction of intersections that may have sight distance restrictions in a county. An alternative formulation of this calculation assumed that most study area counties would be similar and have some minimum number of stop-controlled intersections based on available sight distance. The study area county selected was Cherokee County. It was assumed that due to the low number of stop-controlled intersections (ninety-three), Cherokee County would have stop control where required by sight distance and few others controlled in excess. Cherokee County also represents a county with average rural terrain, land cover, and traffic volumes.

To determine a factor based on Cherokee County practice, the number of stop-controlled intersections in each county was divided by the number of stop-controlled intersections in Cherokee County. The average crash rate per intersection was plotted against this new excessive use factor. Figure 19 shows the relationship between the two variables.

Again, Figure 19 shows a downward trend, i.e., as the Cherokee County factor increases, the average crash rate per intersection on a countywide basis tends to decrease. In an attempt to quantify the relationship between excessive use of stop-controlled intersections and average crash rate, excessive use was defined, for the purpose of this report, as any county with more than twice the number of stop-controlled intersections of Cherokee County (see Figure 20).

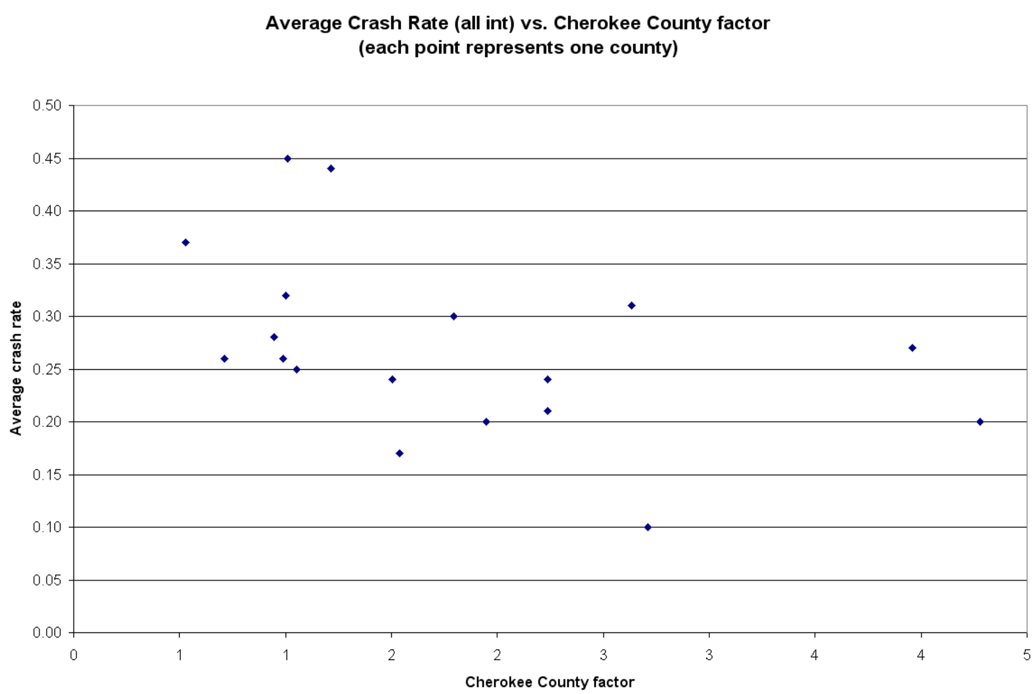

Figure 19. Relationship between average crash rate and the Cherokee County factor

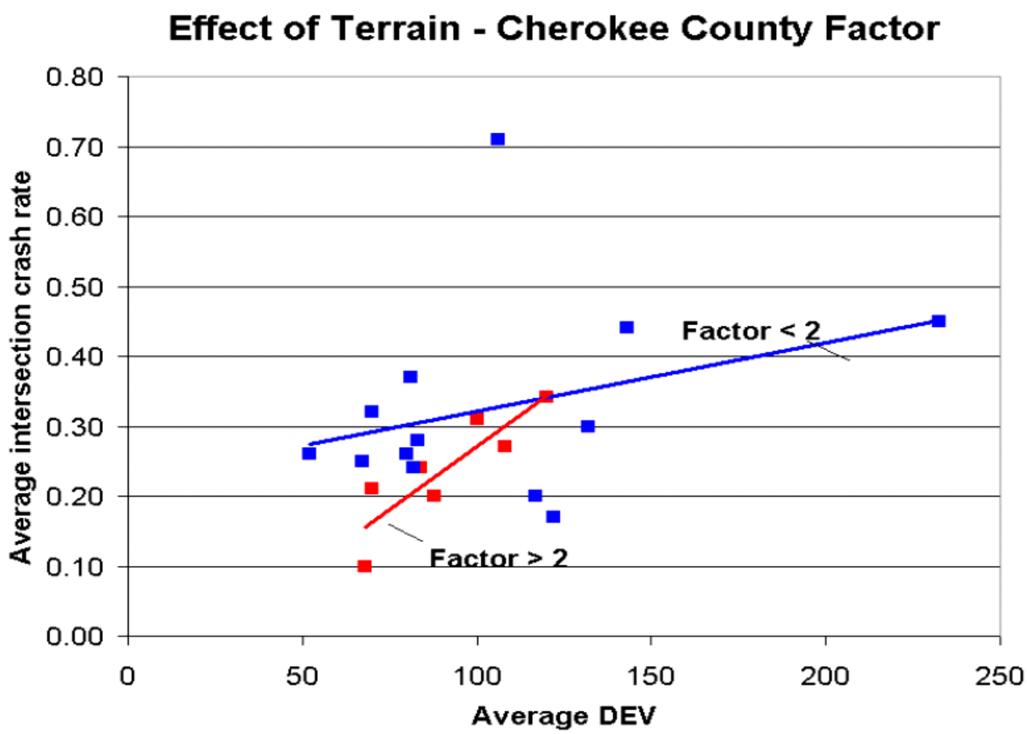

Figure 20. Intersection performance with Cherokee County factor

Using the excessive use definition, two regression lines (one for counties with excessive use and one for the others) were created, as seen in Figure 20. It appears that these two lines may intersect near a DEV of about 125 vehicles. Above this point, it appears that excessive use of stop control has a detrimental effect on intersection performance. It is interesting to note that this intersection point is close to the point (~100 DEV) where crash probabilities for controlled and uncontrolled intersections intersected based on the logistic regression.

To determine if the relationship between the Cherokee County factor and average crash rate was significant, another correlation was completed. The p-value calculated for this correlation was 0.53. Again, this p-value indicated no strong relationship between these two variables.

Even though there is no strong correlation indicated between the excessive use of stop control and intersection performance, several graphs indicate the existence of a volume threshold, below which there appears to be no statistically significant difference between the use of a stop-controlled or an uncontrolled intersection in safety performance.

Determination of volume threshold

There appears to be a volume range, below which there is no statistically significant difference in crashes between stop-controlled and uncontrolled intersections. Figure 21 compiles four previous supporting graphs that suggest this volume ranges from about 60 to 200 DEV. Figure 21a, crashes vs. volume for stop-controlled and uncontrolled intersections, indicates a threshold around 60 DEV. Figure 21b uses rate and again indicates a threshold around 60 or 70 DEV. The two regression lines in Figure 21c, probability of crash, cross at 100 DEV (95% confidence interval 66–140). Above 150-200, there is clearly a difference. Figure 21d, which incorporates a proxy for sight distance (Cherokee factor), suggests a threshold around 125 DEV.

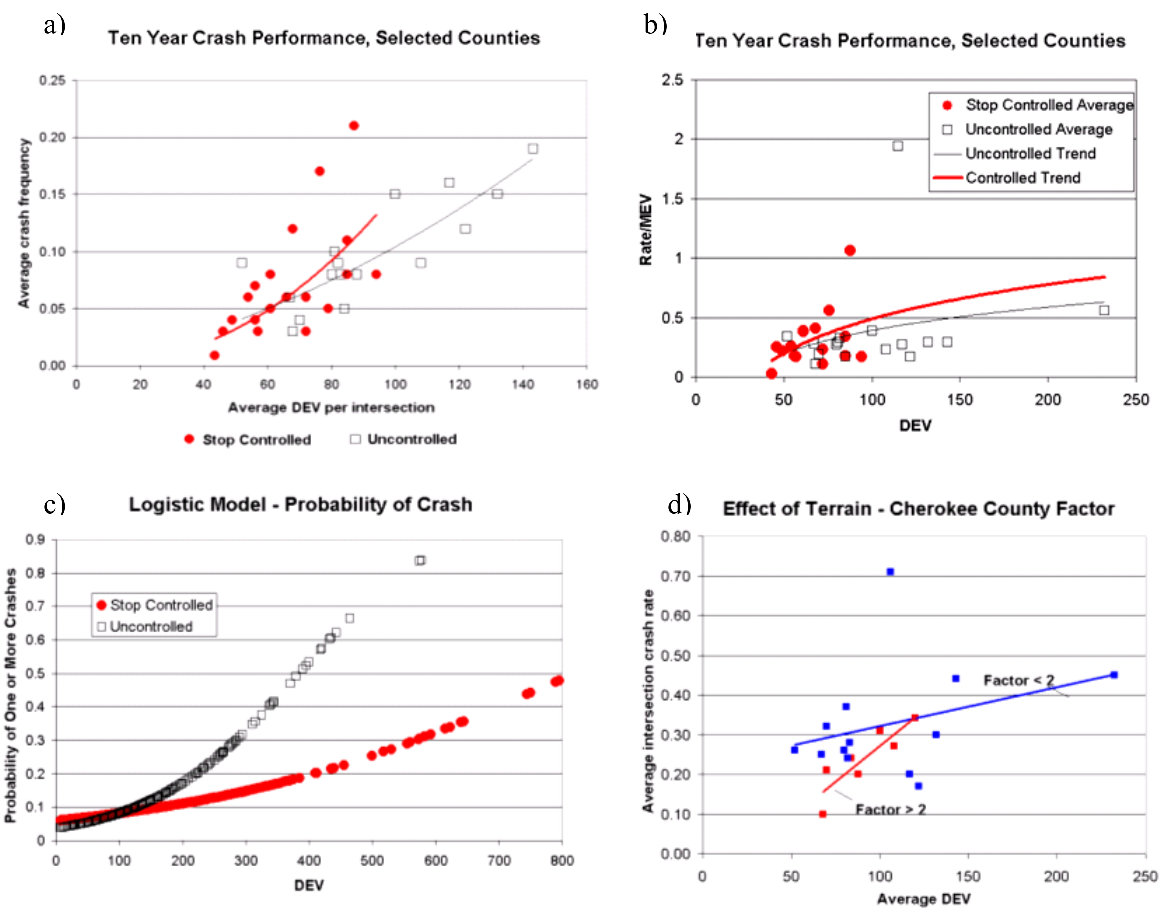

Figure 21. Comparison of four methods

Age group analysis

As the Iowa driving population ages and younger drivers also enter the mix, an age group analysis was completed to determine whether older or younger drivers have more safety problems at ultra-low-volume unpaved stop-controlled and uncontrolled intersections. An older driver is defined as 65-year-old or older and a younger driver is defined as 19-year-old or younger.

Table 11. Statewide crash analysis

	All age groups		Younger drivers		Older drivers	
	Crashes	**Drivers**	**Crashes**	**Drivers**	**Crashes**	**Drivers**
Statewide (all crashes)	59472	101987	15259 (26%)	16828 (17%)	14476 (24%)	17035 (17%)
Statewide (multi-vehicle crashes)	38593	81108	11331 (29%)	12900 (16%)	12479 (32%)	15038 (19%)

Table 11 shows an analysis completed on a statewide basis. This figure shows that older and younger driver representations at the statewide (multi-vehicle crashes) level are approximately equal in both crashes and driver involvement categories.

Table 12 shows the crash analysis that was completed on the stop-controlled intersections in this study. The top boldfaced number in each column should be compared to the bottom boldfaced number in each column to determine if there is a difference in overall statewide multi-vehicle crashes and those at stop-controlled intersections. The table shows that older drivers are underrepresented and younger drivers are slightly overrepresented at rural unpaved ultra-low-volume stop-controlled intersections.

Table 13 shows the crash analysis that was completed on the uncontrolled intersections involved in this study. Again, the top boldfaced number in each column should be compared to the bottom boldfaced number in each column to determine if there is a difference in overall statewide multi-vehicle crashes and those at uncontrolled intersections. These data appear to be similar to the stop-controlled intersections data. The table shows that older drivers are underrepresented and younger drivers are overrepresented at rural unpaved ultra-low-volume uncontrolled intersections.

Table 12. Crash analysis completed at study stop-controlled intersections

	All age groups		Younger drivers		Older drivers	
	Crashes	**Drivers**	**Crashes**	**Drivers**	**Crashes**	**Drivers**
Statewide (all crashes)	59472	101987	15259 (26%)	16828 (17%)	14476 (24%)	17035 (17%)
Statewide (multi-vehicle crashes)	38593	81108	**11331 (29%)**	**12900 (16%)**	**12479 (32%)**	**15038 (19%)**
Stop-controlled Intersections						
Adams*	8	16	1 (13%)	1 (6%)	5 (63%)	6 (38%)
Boone	29	60	12 (41%)	12 (20%)	3 (10%)	3 (5%)
Bremer	24	48	11 (46%)	12 (25%)	1 (4%)	1 (2%)
Calhoun*	13	26	3 (23%)	3 (12%)	2 (15%)	3 (12%)
Carroll	37	75	12 (32%)	14 (19%)	3 (8%)	3 (4%)
Cedar	28	57	14 (50%)	15 (26%)	4 (14%)	4 (7%)
Cerro Gordo*	11	22	1 (9%)	2 (9%)	1 (9%)	1 (5%)
Cherokee*	5	10	1 (20%)	1 (10%)	0 (0%)	0 (0%)
Clay*	5	10	3 (60%)	3 (30%)	3 (60%)	4 (40%)
Emmet*	8	16	2 (25%)	2 (13%)	0 (0%)	0 (0%)
Henry	32	66	9 (28%)	13 (20%)	5 (16%)	5 (8%)
Madison	17	34	9 (53%)	10 (29%)	1 (6%)	1 (3%)
Montgomery*	11	22	4 (36%)	5 (23%)	2 (18%)	2 (9%)
Osceola*	6	12	1 (17%)	1 (8%)	0 (0%)	0 (0%)
Pocahontas*	6	12	1 (17%)	1 (8%)	2 (33%)	2 (17%)
Sac*	8	16	1 (13%)	1 (6%)	0 (0%)	0 (0%)
Story*	6	13	1 (17%)	2 (15%)	2 (33%)	2 (15%)
Washington	30	61	11 (37%)	15 (25%)	2 (7%)	3 (5%)
Woodbury	37	75	15 (41%)	17 (23%)	8 (22%)	8 (11%)
Totals	321	651	**112 (35%)**	**130 (20%)**	**44 (14%)**	**48 (7%)**

* Indicates a county with low crash count (statistically unreliable).

Table 13. Crash analysis completed at study uncontrolled intersections

	All age groups		Younger drivers		Older drivers	
	Crashes	**Drivers**	**Crashes**	**Drivers**	**Crashes**	**Drivers**
Statewide (all crashes)	59472	101987	15259 (26%)	16828 (17%)	14476 (24%)	17035 (17%)
Statewide (multi-vehicle crashes)	38593	81108	**11331 (29%)**	**12900 (16%)**	**12479 (32%)**	**15038 (19%)**
Uncontrolled Intersections						
Adams*	1	2	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Boone	40	81	7 (18%)	7 (9%)	4 (10%)	4 (5%)
Bremer	32	65	13 (41%)	17 (26%)	9 (28%)	9 (14%)
Calhoun*	9	18	5 (56%)	5 (28%)	1 (11%)	1 (6%)
Carroll*	12	26	4 (33%)	5 (19%)	3 (25%)	3 (12%)
Cedar	16	34	4 (25%)	4 (12%)	4 (25%)	4 (12%)
Cerro Gordo	16	32	6 (38%)	6 (19%)	4 (25%)	4 (13%)
Cherokee	20	40	6 (30%)	9 (23%)	4 (20%)	4 (10%)
Clay	25	50	6 (24%)	7 (14%)	3 (12%)	3 (6%)
Emmet*	3	6	2 (67%)	2 (33%)	0 (0%)	0 (0%)
Henry*	6	12	5 (83%)	6 (50%)	0 (0%)	0 (0%)
Madison	27	56	11 (41%)	16 (29%)	2 (7%)	2 (4%)
Montgomery*	4	8	2 (50%)	2 (25%)	0 (0%)	0 (0%)
Osceola*	5	10	2 (40%)	2 (20%)	2 (40%)	2 (20%)
Pocahontas	15	30	6 (40%)	7 (23%)	2 (13%)	2 (7%)
Sac	19	38	5 (26%)	5 (13%)	5 (26%)	5 (13%)
Story	76	152	17 (22%)	19 (13%)	14 (18%)	16 (11%)
Washington*	13	28	3 (23%)	4 (14%)	3 (23%)	3 (11%)
Woodbury*	7	14	1 (14%)	1 (7%)	1 (14%)	1 (7%)
Totals	346	702	**105 (30%)**	**124 (18%)**	**61 (18%)**	**63 (9%)**

* Indicates a county with low crash count (statistically unreliable).

There are two possible reasons for the considerable underrepresentation of older drivers at all unpaved ultra-low-volume study intersections. This may indicate that older drivers either use appropriate caution and have no difficulty negotiating these intersections or they avoid these locations.

Crash type analysis

An analysis of thirty intersections (fifteen stop-controlled and fifteen uncontrolled) that had at least two multi-vehicle crashes over the ten-year period was completed to determine if any specific crash type or contributing circumstance was more or less prevalent for either type of control. This analysis was also completed to determine if the crash reports available at the Iowa DOT could add any value to the information already included in the crash database.

Table 14. Comparison of crash types for thirty study intersections

Uncontrolled intersections		Stop-controlled intersections	
Crash type from crash data	**Number of crashes**	**Crash type from crash data**	**Number of crashes**
Broadside/Right angle	21	Broadside/Right angle	27
NA	6	Head on	1
Sideswipe	4	Sideswipe	1
Rear end	2	Angle	1
Head on	2	Other	1
Other	1	NA	1
Non-collision	1		

Table 14 shows a comparison of crash types for the thirty intersections involved in the analysis. As expected, the most prominent crash type for both stop-controlled and uncontrolled intersections was broadside/right angle.

Table 15 shows the contributing circumstances determined from both the crash database and the crash reports for stop-controlled intersection crashes. The most prominent contributing circumstance for stop-controlled intersections was failure to yield the right-of-way. However, the most prominent type of failure to yield the right-of-way was not caused by the failure to stop at a STOP sign, but rather drivers judging gaps ineffectively.

Table 16 shows the contributing circumstances determined from both the crash database and the crash reports for uncontrolled intersection crashes. The most prominent contributing circumstance for uncontrolled intersections was failure to yield the right-of-way as well.

It is also interesting to note that sight distance and vision obscured issues are not major crash contributing factors.

Table 15. Contributing circumstances from stop-controlled intersection crashes

Contributing circumstances from crash reports	Number of crashes	Contributing circumstances from crash data	Number of crashes
FTYROW - made full stop but pulled out in front of another vehicle	17	NA	25
Failed to stop at STOP sign and pulled out in front of another vehicle	10	FTYROW	14
Attempted to stop at STOP sign but slid through intersection colliding with another vehicle	3	No improper action	11
Sight distance related	3	Ran STOP sign	9
Passing another vehicle	1	Speed too fast for conditions	3
Rear end - not paying attention	1	Other improper action	2
Alcohol involvement	1	Vision obscured	2
		Crossed centerline	1
		Failure to have control	1
		Passing where prohibited	1
		Improper signal	1
		Inattentive/distracted	1
		Passed stopped school bus	1

Table 16. Contributing circumstances from uncontrolled intersection crashes

Contributing circumstances from crash reports	Number of crashes	Contributing circumstances from crash data	Number of crashes
FTYROW - pulled out in front of another vehicle	28	NA	28
Rear end - not paying attention	4	FTYROW	21
Sight distance related	4	Failure to have control	5
Passing another vehicle	3	No improper action	4
Corn crop causing sight distance issues	2	Vision obscured	4
		Too fast for conditions	3
		Crossed Centerline	2
		Other improper action	2
		Following too close	1
		Illegal/improper parking	1
		Improper signal	1
		Improper turn	1
		Inattentive/distracted	1
		Passing where prohibited	1
		Wrong way/side of road	1

Urban applications

The excessive use of stop control may be a problem in urban areas. A study similar to that for the county rural intersections was also completed in the City of Ames, Iowa. As a sign inventory was unavailable, a video log of many intersections in the City of Ames was created as part of this project. This video log was used to create a traffic control database for the City of Ames. This database facilitated the comparison of safety at controlled and uncontrolled intersections.

The methodology for the urban study was similar to that of the rural part of this project with only a few minor differences. Rather than using a 150-foot tolerance, 75-foot tolerance was used to identify crashes (the standard distance used by the Iowa DOT for the identification of urban intersection crashes). The City of Ames was divided into twelve neighborhoods, and control type characteristics (crashes, crash rate, etc.) were summarized by neighborhood. This aggregation was completed to attempt to quantify a relationship between excessive use and crashes or crash rate for urban areas. A map showing the neighborhoods involved in the study can be seen in Figure 22 and an example summary table can be seen in Table 17.

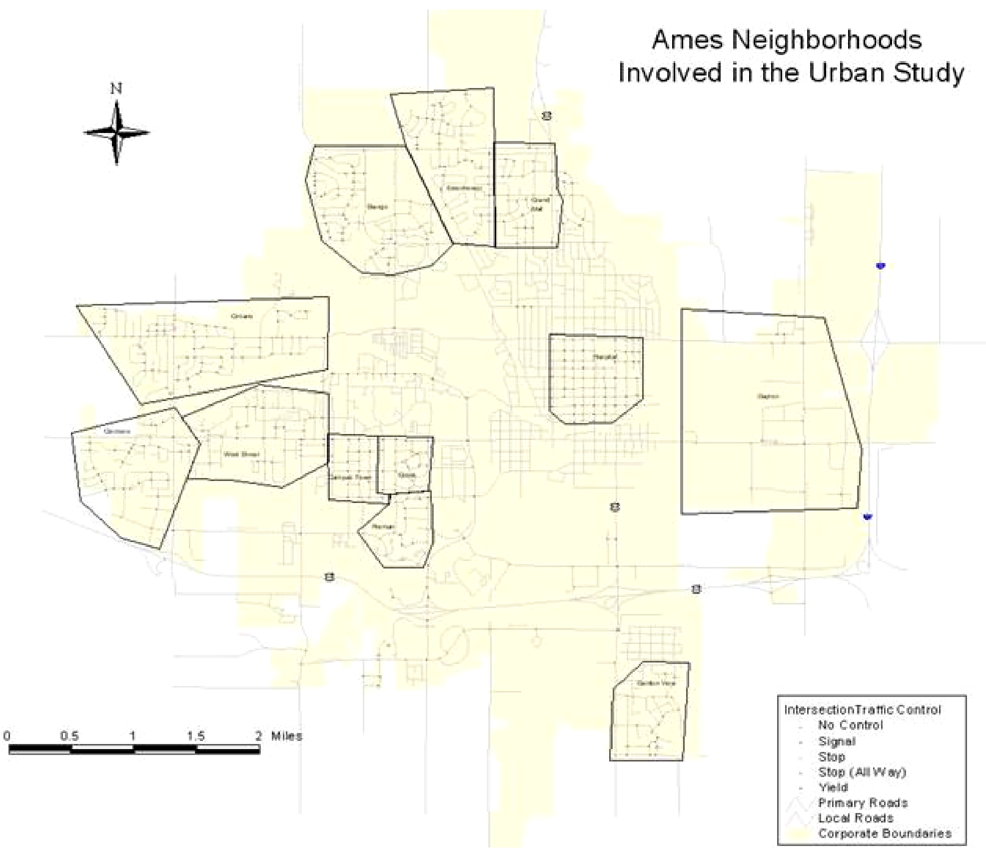

Figure 22. Map of City of Ames neighborhoods

Table 17. Neighborhood summary

Ontario Neighborhood	Control Type					
	No Control	Yield	Stop	Stop (All-way)	Signal	Total
Avg rate per MEV	1.33	1.56	2.41	0.70		1.83
Avg DEV	690	1060	1260	1580		1010
Avg crashes	1.50	6	3.18	4		2.61
Number of intersections	10	1	11	1	0	23
% total intersections	43.5	4.4	47.8	4.4		
Max rate	5.48	1.56	7.89	0.70		7.89
Min rate	0.23	1.56	0.10	0.70		0.10
Max DEV	1208	1057	8300	1575		8300
Min DEV	50	1057	129	1575		50
Max crashes	3	6	8	4		8
Min crashes	1	6	1	4		1
Total crashes	15	6	35	4		60

The neighborhood summaries were combined to create a summary for the City of Ames (see Table 18).

Nearly 60% of the intersections involved in this urban study are two-way stop-controlled intersections, whereas only 10% are all-way stop controlled. Uncontrolled intersections have a slightly higher average crash rate than two-way stop-controlled intersections (1.0 to 0.9), and all-way stop-controlled intersections have the lowest crash rate of any control type in the study (0.57). Yield-controlled intersections have a high average crash rate, although the sample size is quite limited. Figure 23 shows the relationship between average crash rate and average DEV per intersection based on control type for the intersections involved in the urban study.

Table 18. Summary of Ames intersections

	Control Type					
	No Control	Yield	Stop	Stop (All-way)	Signal	Total
Avg rate per MEV	1.00	1.50	0.90	0.57	0.95	0.91
Avg DEV	790	900	5100	6130	17600	5900
Avg crashes	1.58	3.56	5.92	10.90	61.54	12.25
Number of intersections	33	9	130	21	26	219
% total intersections	15.1	4.1	59.4	9.6	11.9	
Max rate	5.48	6.39	13.70	2.19	3.45	13.70
Min rate	0.08	0.41	0.04	0.05	0.09	0.04
Max DEV	3546	1351	21803	10685	24350	24350
Min DEV	50	300	50	1206	8900	50
Max crashes	5	7	40	29	123	123
Min crashes	1	2	1	1	3	1
Total crashes	52	32	769	229	1600	2682

Figure 23 shows that majority of uncontrolled intersections are low volume. This figure also shows that all-way stop-controlled intersections have a lower average crash rate than uncontrolled and two-way stop-controlled intersections. Figure 24 illustrates the crash performance of each type of control.

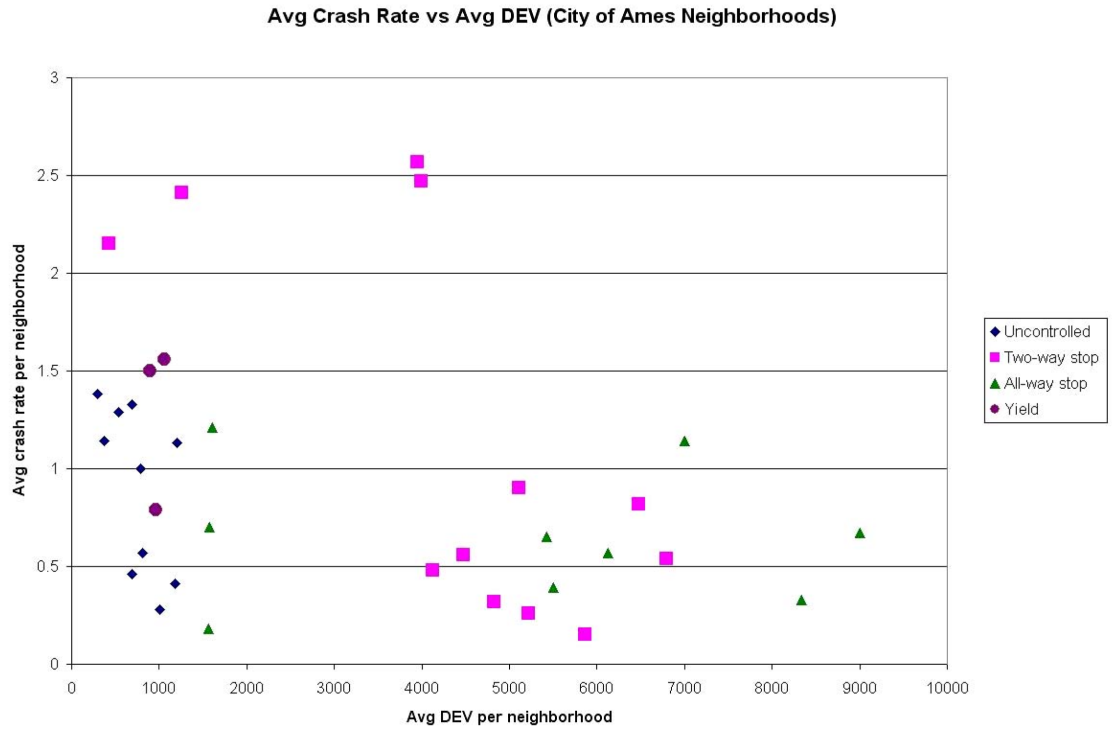

Figure 23. Intersection performance for the City of Ames neighborhoods

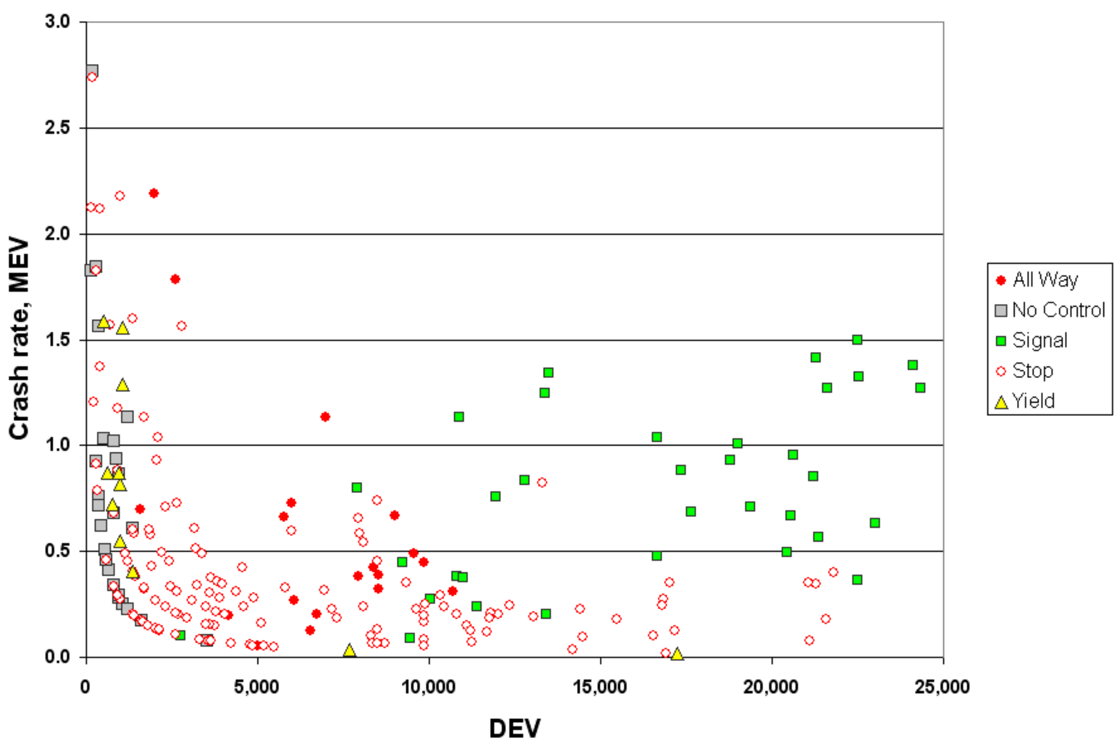

Figure 24. Intersection performance of Ames intersections

Statistical Assessment

A hierarchical Poisson model was fitted to the Ames crash data. The model indicates that crash frequencies at an intersection are distributed as Poisson variables with mean λ * DEV, where here λ is defined as crash frequency divided by DEV. The log of lambda is then modeled as a function of the type of control and a random error. Because very few yield-controlled intersections were available in this data set, the yield-controlled and the uncontrolled intersections were grouped together. Dummy variables were defined for the four types of control, and the no control group was used as the reference. The error in the second level of the model was assumed to be normal (implying that log (λ) is also normal).

Estimates of model parameters were obtained using a Bayesian approach (*45*). The regression coefficients associated to control types were assigned non-informative normal prior distributions with zero mean and very large variance. This indicates that, a priori, we do not assume any differences in crash rates due to control type. The prior distribution for the variance of the error was an inverted gamma distribution with mean equal to one and a very large variance, again to reflect prior ignorance about the distribution of the error. A priori, the regression coefficients and the variance component were assumed to be independent, and the joint prior distribution was semi-conjugate to the sampling distribution.

The model using WinBUGS and Markov chain Monte Carlo methods were fitted. Obtained were posterior distributions of expected crash frequency at each intersection (where frequency is defined as the expected number of crashes at the intersection given its DEV), expected crash rate at each intersection (defined here as the number of crashes per million entering vehicles [MEV]), and expected average crash rate at intersections of each of the different types.

Posterior distributions are summarized by their mean, standard deviation, and 2.5th, 50th, and 97.5th percentile. A central 95% posterior credible set is given by the set bounded by the 2.5th and the 97.5th posterior percentiles. Table 19 shows the posterior distributions of expected crash rates (number of crashes per MEV) at intersections with each of the four control types. For example, the likely values of crash rate for intersections with a two-way STOP sign are 0.27 to 0.30.

If the credible sets for two types of intersections do not overlap, it is concluded that there are significant differences between them. For example, signal-controlled intersections have significantly higher crash rates than all others. Two-way stop-controlled intersections have significantly lower crash rates than all others. There is no difference in crash rates between the all-way and the uncontrolled intersections. The plots in Figure 25 show the posterior distributions of crash rates for the various intersection types.

Table 19. Expected crash rates

Type	Mean	Std	2.5th percentile	Median	97.5th percentile
Signal	0.90	0.02	0.87	0.91	0.95
Two-way	0.28	0.01	0.27	0.29	0.30
All-way	0.46	0.03	0.40	0.46	0.52
No control	0.41	0.04	0.33	0.41	0.50

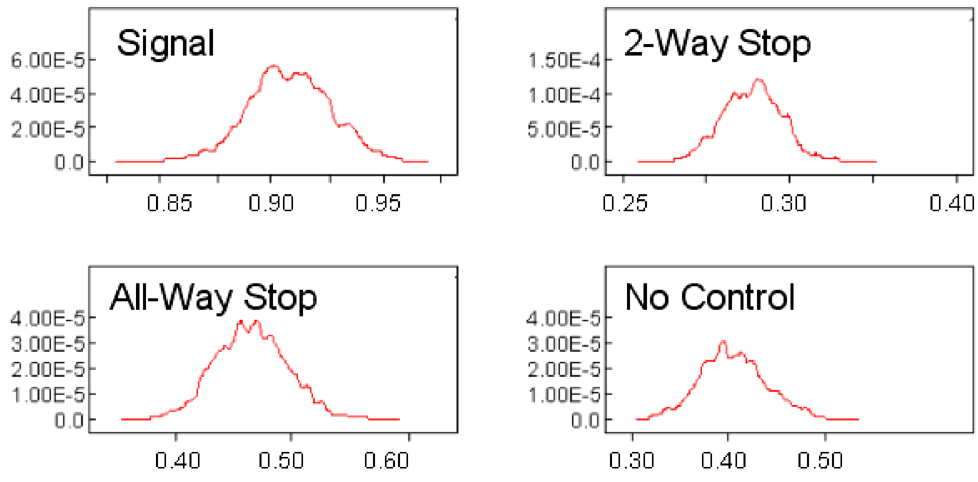

Figure 25. Crash rate distributions based on control type

Effect of excessive use

To attempt to quantify a relationship between excessive use and crash rate/number of crashes for urban areas, a simple excessive use factor was created. The number of two-way stop-controlled intersections was divided by the total number of intersections in each neighborhood to determine the fraction of total intersections that were two-way stop controlled. Anything above average is termed “excessive;” though, clearly, other factors for use may be involved. This same procedure was then completed for all-way stop-controlled intersections. Figure 26 shows the relationship between average number of crashes per intersection in ten years and DEV stratified by this excessive use calculation. The figure indicates that neighborhoods which have a higher fraction of two-way stop-controlled intersections than the citywide average tend to have more crashes over ten years for any given level of DEV, indicating a negative effect of possible excessive use, contrary to the rural findings.

Figure 27 shows overall and stop-controlled crash rates for each neighborhood versus fractional control. Contradictory to the findings shown in Figure 26, this analysis indicates a slight positive impact on safety performance of excessive STOP sign use.

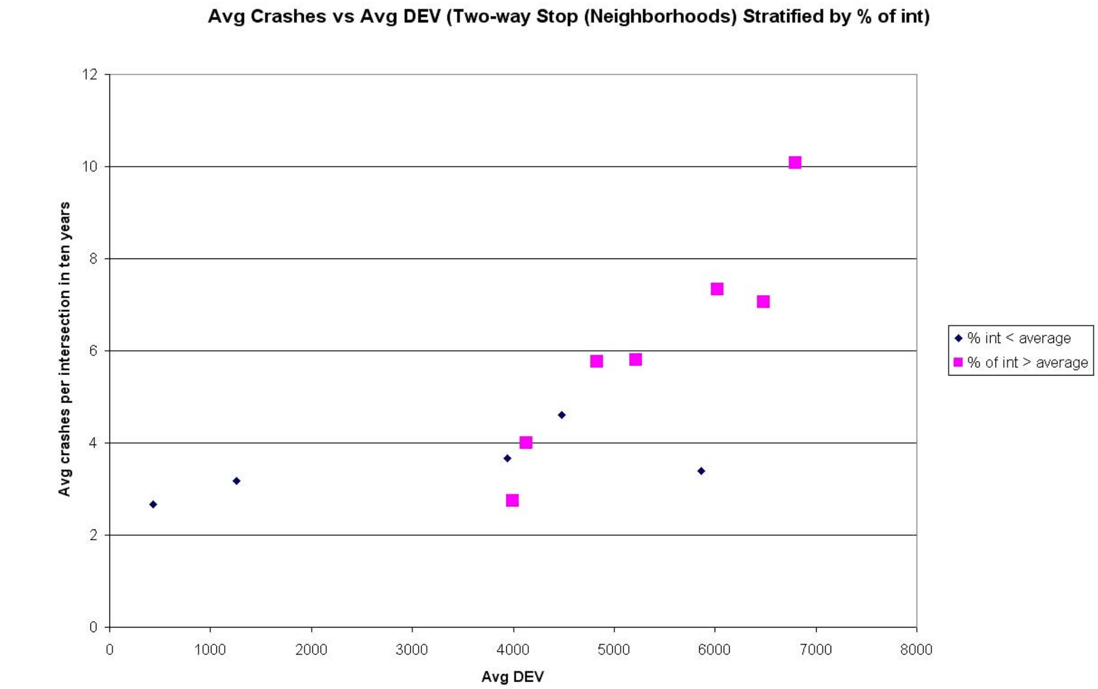

Figure 26. Effect of excessive stop control on urban crash frequency

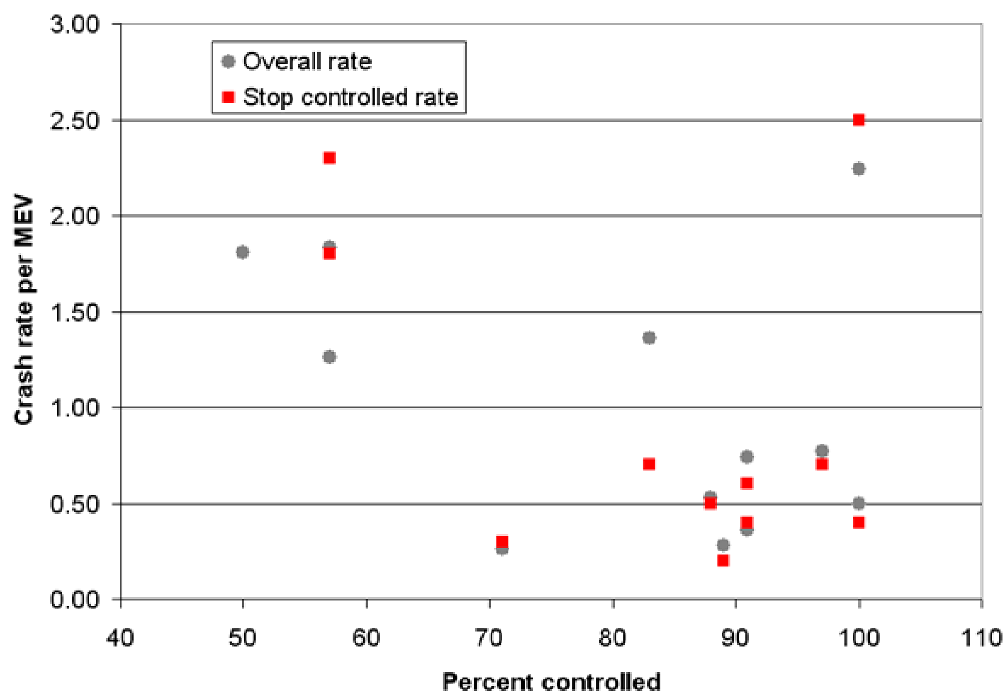

Figure 27. Effect of stop control on urban crash rate

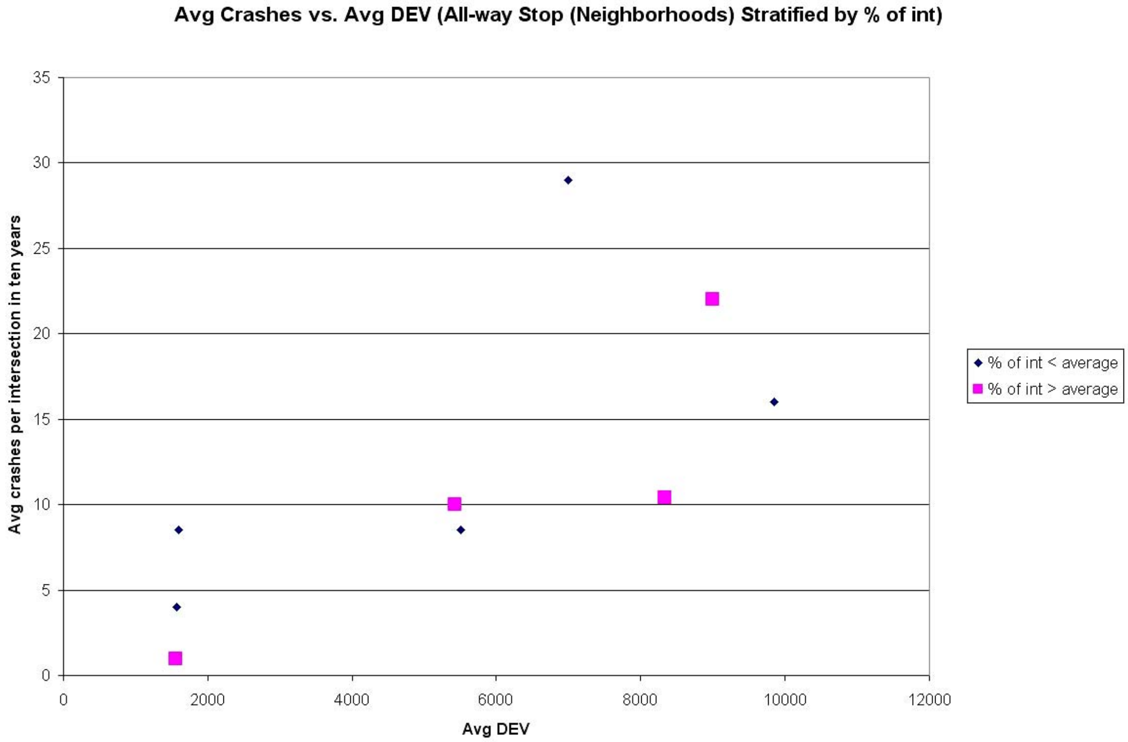

Figure 28. Effect of excessive all-way stop control on urban crash frequency

Figure 28 shows the same relationship for all-way stops. Possibly due to small sample size, there is no discernable difference in safety performance of intersections in neighborhoods with more or less all-way stop control.

IMPLEMENTATION

Removal or reduction techniques for unneeded stop control

The following sections of this report present suggested procedures (legal and operational) for the removal or reduction in the level of intersection traffic control. Various resources (*14, 18, 27, 43*, and *44*) were used as references in the development of these recommendations, summarized as follows:

- Develop and adopt a formal policy
- Undertake a thorough engineering study
- Provide appropriate public notice
- Perform follow-up assessment

Preliminary activities

According to the MUTCD, traffic control devices can only be established as authorized by the public authority or official having jurisdiction. Removal or reduction of these devices must also be properly authorized. Before any action is contemplated, a formal policy should be adopted by the governing board or council. This policy should outline criteria for selection of locations and public notice to be provided at a minimum. Advice from the agency attorney should be sought in advance.

Judgment should be exercised in selecting possible locations for reduction or removal of existing traffic control, including STOP signs. After sites have been identified, a thorough engineering study of each location should be conducted, considering minimum traffic volumes, sight distance restrictions, and crash history. Study information should be properly documented.

Following approval of removal/reduction proposals by the governing authority, public notice must be provided. Local news media should be utilized to publicize the proposals and consideration given to provide specific notice to residents in the immediate area of the modifications.

Prior to actual modification of traffic control, appropriate temporary advisory signing should be installed. The following signing and process is suggested for removal of STOP signs.

Approximately 30 days preceding the date of change, install an advisory sign below or in advance of the signs to be removed, "THIS STOP SIGN WILL BE REMOVED ON ____/____/____." Beneath or in advance of signs to remain, install "CROSS STREET (ROAD) STOP WILL BE REMOVED ON ____/____/____." On the date selected for removal, selected STOP signs, advance STOP AHEAD signs, and advisory signs should be removed and special warning signs, "WATCH FOR CROSS TRAFFIC," erected at an appropriated distance in advance of the intersection. These signs should remain in place for a minimum of three months after removal of the STOP signs. In urban locations, any inappropriate stop bars should also be removed. For the STOP signs remaining in place, the “CROSS STREET (ROAD) STOP WILL BE REMOVED ON ___/___/___” should be removed and special signs stating “WATCH FOR CROSS TRAFFIC” installed at the appropriate location in advance of the subject intersection. Consideration should be given to mounting a red flag above the remaining STOP signs for at least 30 days.

Post conversion activities

It may be advisable to conduct an engineering study before removing the “WATCH FOR CROSS TRAFFIC” signs. Driver behavior on the date of the removal should be monitored to identify any potential concerns. Consideration should be given to repeating the process one week and one month later. Appropriate action should be taken if improper behavior, near misses, or increasing crash experience is observed.

It may also be desirable to conduct additional studies following any reduction in the level of traffic control, such as speed and volume analyses. It should be noted that very low traffic volume locations may require several years to provide sufficient data for a meaningful analysis.

Legal liability resulting from the removal of STOP signs

The issue of legal liability of a city or county (hereafter called agencies or agency) that remove unwarranted and unneeded STOP signs is a matter of Tort Law and, in the case of Iowa, the Iowa Code (Iowa Law). There are two parts to the potential for governmental liability for removal of a STOP sign. One part is related to whether the agency removing the sign has exposed motorists to undue hazard as a result of removing a STOP sign and, therefore, had a duty to maintain an unwarranted sign. The other part deals with statutory immunity provided to the agency through the Iowa Code.

Statutory immunity

Chapter 668 of the Iowa Code covers comparative fault—more commonly called comparative negligence. Comparative negligence assigns fault for damages suffered by a damaged party. A motorist may be partly responsible for her/his own damages, and thus assigned part of the fault for their own damages. So long as the motorist is not responsible for more than half of the negligence that resulted in damages, the plaintiff has a reasonable claim. For example, if a motorist is damaged by an obvious defect (e.g., a traffic signal shows green for two conflicting movements) and a crash results, there is clearly negligence associated with the operation of the traffic signal. However, if that motorist was also speeding at the time and the high speed was partly to blame for the damages, the plaintiff might be assigned part of the fault.

Chapter 668, section 10, defines the situations in which the government is exempt in the assignment of fault. Part 1 of 668.10 deals specifically with STOP signs and provides statutory immunity for not erecting a sign that is not warranted by the *Manual on Uniform Traffic Control Devices* (*MUTCD*). The Iowa Code § 668.10 (*1*) states the following:

> 668.10 GOVERNMENTAL EXEMPTIONS.
> In any action brought pursuant to this chapter, the state or a municipality shall not be assigned a percentage of fault for any of the following:
> 1. The failure to place, erect, or install a STOP sign, traffic control device, or other regulatory sign as defined in the uniform manual for traffic control devices adopted pursuant to section 321.252. However, once a regulatory device has been placed, created or installed, the state or municipality may be assigned a percentage of fault for its failure to maintain the device. (*1*)

It appears that the roadway agency is provided statutory immunity from negligence related to failure to erect a sign. Thus, if a sign is not warranted, a claimant cannot claim negligence for a sign which does not exist. When a sign is removed, even if it is not warranted, a plaintiff may argue that the agency failed to maintain the sign and the roadway agency can be assigned fault.

In a related Iowa negligence case, the plaintiff argued negligence due to failure to maintain the sign when a sign was not erected (*30*). In this case, the county had recently paved an unpaved roadway. The roadway approached a small community from the south and made two slight curves—first to the left, followed by a 700-foot tangent section, and then to the right. When the roadway was unpaved, a reverse curve sign was located before the first curve to provide warning for both curves. After the roadway was paved, the plaintiff was injured while riding as a passenger on a motorcycle. While traveling north on the roadway, the driver successfully navigated through the first curve (where the warning sign existed), but veered off the road into a ditch after taking the second curve at a high speed. The plaintiff argued that the county was at fault because the county had clearly seen the need for a warning sign, and one sign was not a sufficient warning for both curves when the curves are separated by 700 feet. Therefore, it had erected a sign and failed to maintain it, thus causing the crash.

Ultimately, the case (Saunders versus Dallas County) was appealed to the Iowa Supreme court and the court found for Dallas County and stated the following:

> The county clearly would have been immune from liability if it had erected no signs at the scene. For immunity to be lost it must appear as a minimum that the signs were erected in such a manner as to mislead or endanger the driver. We think the allegations here all come down to decisions about whether or where to place traffic signs. Negligent decisions of this kind are precisely the ones which section 668.10 (*1*) immunizes from liability (*30*).

In the case of the removal of an unwarranted STOP sign, a plaintiff would make a similar argument suggesting that the responsible agency was negligent due to a failure to maintain the sign. However, based on the Supreme Court's interpretation in Saunders versus Dallas County case, it seems unlikely that the plaintiff would be successful. If the STOP sign is unwarranted and sight distances are adequate, there is no hazard. There should be no liability for removing a sign where the agency would have not been liable had it not erected a sign in the first place.

Is this a valid tort action?

The agency maintaining the roadway has the duty to motorists to maintain the roadway in a safe condition, so as to not expose motorists to undue hazard. In cases where a hazard exists, the operating agency has the duty to eliminate or warn the motorist of that hazard. Therefore, if an agency fails to perform its duty through either commission or omission of action which results in unsafe condition, the agency is negligent (tort law concepts are taken from Glennon [*12*]).

To have a valid tort action, the following need to occur:

1. The plaintiff has to have suffered damages.
2. The defendant has to have a legal duty to the plaintiff (keeping roadways safe).
3. The defendant was negligent because its duty was breached.
4. The negligence has to be the cause of the damages.

Tort law is based on precedent from prior cases, and the only way to determine whether the removal of an unwarranted STOP sign increases the legal liability of an agency is for an injury to occur at the location of a STOP sign removal. Then, the damaged party must claim the agency was negligent for removing the sign.

A court case was found where the conditions were similar to the conditions considered when removing an unwarranted STOP sign. This case was heard before the Court of Appeals of the State of California, Third Appellate District (*2*). The case, "City of South Lake Tahoe v. Markham, 62 Cal.App. 4th 971, 73 Cal.Rptr.2d 146 (1998)," involved a local resident on a local street in the City of South Lake Tahoe. Earlier that day, a STOP sign at the intersection of Third and Eloise (a two-way stop-controlled intersection) was knocked down in a crash. Since Markham frequently drove through the intersection in the direction without the stop control, he was accustomed to having the right-of-way at this intersection.

After the STOP sign was knocked down in the opposite direction, Markham drove through the intersection and collided with the car of a second driver, Huff. Huff was from out of town and did not see the downed STOP sign. The plaintiffs were consolidated to one action by the court, and claimed that the cause of the damages was the City's failure to maintain the STOP sign. There have been similar cases where a STOP sign is knocked down and the roadway agency failed to re-erect the STOP sign expeditiously and a crash resulted. The issue in these cases often becomes whether the roadway agency had constructive notice. In other words, was the roadway agency aware of the situation but failed to react in a timely fashion. The difference in this case was that the STOP signs were not warranted at this intersection due to low volume, and the operation of the intersection without two-way stop control did not present a hazard.

California legal code contains a statutory exemption, similar to that of the Iowa code, where an agency has immunity from legal liability for injuries caused by not erecting a sign. However, once a sign is erected, no immunity exists for failure to maintain the traffic control device (Section 830.8 of the "California Government Code") (*3*). When the case was first heard in the Superior Court of El Dorado County, the court found that "Section 830.4 did not immunize the defendant, and that there was a triable issue of fact as to whether the failure to replace the STOP sign gave rise to a dangerous condition" (*2*).

Later, when heard in the Appellate court, the lower court's finding was overturned. The Appellate court found the following:

> The basic premise of defendant's summary judgment motion is that since it has no duty to provide a STOP sign in the first place, and by virtue of section 830.4, could not be held liable if no sign had ever existed at the corner of Third and Eloise, it cannot become liable if the sign is removed, whatever the reason for the removal may be. We find this logic persuasive. To conclude otherwise would require us to accept the proposition that once the STOP sign on Eloise was in place it could never be removed with impunity, and that motorists, particularly those on Third Street, could forever after rely on its presence. This reasoning, which is implicit in the plaintiffs' arguments, finds no support in statute or case law.

In California case law, an agency can remove a STOP sign, as long as an uncontrolled intersection does not present a hazard and can still be covered under statutory immunity. Although this California case does provide an interesting example of how California courts manage the removal of a STOP sign, it does not necessarily imply that a similarly argued case in an Iowa courtroom would result in the same interpretation. However, it seems unlikely that a different result would occur.

What else can be done to offer protection?

In addition to the protections offered by statutory immunity, the agency can protect itself by exercising the doctrine of discretionary immunity. Iowa Code §670.4 identifies claims against a municipality (city or county) that are exempt from action (Part 3 provides employees with discretionary immunity). An employee cannot be held liable for omission or commission of action that is within the scope of his/her job and where the act required discretion and he/she exercised due care in executing the job. The Iowa State Association of Counties, in their legal briefing on this section in Iowa Code, interprets this section as follows:

> Basically, Iowa Code §670.4 says that government officials (including county officials) are not liable where the challenged conduct involved a matter of choice or an element of judgment. In other words, there can be no "Monday morning quarterbacking" of policy decisions county officials make. (*7*)

To test whether a function is a discretionary function and hence deserves immunity, Iowa courts have applied the Berkovitz test (*34*). This test involves "first considering whether the action involved a matter of choice on the part of those acting for the government. If so, it must also appear that the challenged judgment call is of the kind the discretionary function was designed to shield."

Iowa Code §670.4 Part 4 states:

> Discretionary function immunity is based upon the design to prevent judicial second-guessing of legislative and administrative decisions grounded in social, economic, and political policy through the medium of an action of tort. (1)

Thus, to be discretionary, first, the activity must involve a matter of choice, and second, the activity must involve legislative and administrative decisions ground in social, economic, and political policy. A recent Iowa court case involving a crash at a traffic signal illustrates how Iowa courts more strictly define what a discretionary action is (*35*). The plaintiff argued that a crash was caused by the City of Ankeny providing a too short yellow interval at the intersection of State Street and Oralabor Road. When the plaintiff entered the intersection immediately after the signal turned green in her direction, a car coming in the conflicting direction collided with her. The second motorist claimed she could not stop during the allotted yellow interval. The plaintiff claimed that the City was negligent by not properly setting the signal timings. The City claimed the act of timing a traffic signal required independent judgment and, therefore, the City should be immune.

Initially, the trial court found in favor of the City. The plaintiff then appealed the judgment to the District Court of Polk County, which also found in favor of the City. In the second appeal to Iowa's Supreme Court, the decisions of the lower courts were reversed. The Supreme Court found that traffic signal timing was not the type of discretionary activity that the Iowa Statute was designed to hold immune. The Supreme Court found that many government employees must make choices and use discretion in numerous activities, but that does not make them immune from tort action. The Court stated that the "city did not have discretionary function immunity because its judgment in setting the timing of the traffic light was based on nothing more than a generic safety consideration and did not involve legitimate policy-based considerations."

Three other Iowa cases bear on the discretionary function exception and traffic control device immunity: Davison v. State, 671 N.W.2d 519 (Iowa App. 2030); Schmitz v. City of Dubuque, 682 N.W.2d 70 (Iowa 2004); and Hunt v. State, 538 N.W.2d 659 (Iowa App. 1995).

Although case law does not provide a clear example of a specific situation where an agency has removed a STOP sign, there are steps that an engineer or road manager can do to increase the probability that they and their agency will be successful in invoking discretionary immunity. This can be done by developing a policy that spells out the steps to be taken before a STOP sign is removed, which might include the following:

1. A site visit to the intersection to review sight distance and other potential hazards
2. A review of crash records for the intersection to identify a pattern of crashes that might be exacerbated if the sign is removed
3. A check of traffic volumes and planned development around the intersection to make sure that current volume or future volume will not make an uncontrolled intersection hazardous
4. A plan for informing the local residents when the STOP sign will be removed
5. A plan for any interim steps such as the use of YIELD signs for a period (e.g., one year) after removing the STOP signs
6. Monitor the operation of the intersection following the removal of the STOP sign

The city or county policy board needs to adopt the plan and then document the completion of each step when considering an intersection for the removal of stop control. Having a plan that is adopted by the policy board, following the plan, and documenting the results of the steps once they are completed will provide the roadway manager or engineer and his/her agency with a greater likelihood of receiving discretionary immunity.

CONCLUSIONS

This report investigated the effect of stop control on the operation and safety performance of ultra-low-volume (<150 DEV) unpaved, rural intersections. Several conclusions can be drawn from this research.

Survey results indicated that Iowa counties do not utilize consistent procedures for establishing stop control at low-volume rural intersections. Most use available sight distance and crash history as criteria for stop control.

The intersections involved in this study not only had very low volumes but also exhibited very low crash rates (crashes were very rare events for all types of control involved in this study). Crash rates observed at ultra-low volume intersections were much lower than rates for local rural roads in general.

Intersections with two-way stop control tended to have lower crash rates than uncontrolled above a certain threshold DEV value. Below this threshold, there appeared to be no statistically significant difference between the safety performance of a stop-controlled or uncontrolled intersection.

The fraction of stop-controlled intersections in a rural area did not appear to affect the general crash rate for that jurisdiction.

Several references with guidelines for conversion of all-way to two-way stop control or two-way stop control to yield control are available, but no guidance for *removal* of stop control could be found.

Older driver crash rates are underrepresented at ultra-low-volume rural unpaved intersections (both stop-controlled and uncontrolled). This may mean that either older drivers use more caution at these intersections or they avoid these types of intersections altogether. Younger drivers however, experienced crashes at rates somewhat higher at these locations than for rural roads in general.

As expected, broadside/right angle crashes are the most prominent multi-vehicle crash types for both stop-controlled and uncontrolled ultra-low-volume unpaved intersections. The most prominent contributing circumstance at these intersections is failure to yield the right-of-way. However, at stop-controlled intersections, that failure to yield the right-of-way cannot be attributed to ignoring the STOP sign. Instead, drivers tended to insufficiently judge gaps and proceeded into the path of oncoming vehicles. In addition, restricted sight distance was not listed as a major contributor to crashes at uncontrolled intersections.

The amount of possible excess stop-controlled intersections for each county was calculated several different ways. It was not possible in this study to develop a surrogate for the relative number of intersections that would be expected to have sight distance limitations based on county land cover and topography. Therefore, none of these calculations proved to be significant indicators of the countywide crash rate. Instead of the creation of an excessive use factor for an entire county, a smaller area could be used. This may make the creation of the factor more driver-specific and accurate.

Even though a surrogate for sight distance could not be created, it appeared as though there is a threshold DEV value of about 150 vehicles, below which there is no statistically significant difference between the use of a stop-controlled or uncontrolled intersection.

If accomplished in accord with a formal policy and supported by an engineering study and judgment, significant liability exposure should not result from modification of intersection traffic control.

Results of an urban area study are inconclusive regarding the effect of additional stop control on overall intersection crash rates. However, more research in urban areas is needed.

RECOMMENDATIONS

1) Agencies should consider the adoption of formal policies for establishment of control levels at intersections and for modification of that control when perceived beneficial.

2) Local rural agencies could consider removal or conversion of two-way stop control at selected ultra-low-volume unpaved intersections, if certain criteria are met.

3) Urban agencies may also benefit from removal of unwarranted control from intersections, but more study is needed.

4) Intermittent sight distance restrictions at intersections may be satisfactorily addressed through the use of yield control[1].

FUTURE STUDY

A future study may include a long-term analysis of the actual removal/conversion of several stop-controlled intersections. The results of these modifications could be used to quantify the difference in intersection performance between the before and after

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[1] Section 2B.09 YIELD Sign Applications in the Manual on Uniform Traffic Control Devices has been revised to restrict YIELD sign use to intersection where minimum stopping sight distance is available. It is recommended that consideration be given to expanding potential use to that described in earlier editions of the MUTCD. Of particular concern are intersections where sight distance is only restricted part of the year, such as by growing crops. YIELD signs could be used effectively in these situations if expanded application opportunities were included in Section 2B.09 of the MUTCD.

condition. Several intersections with only seasonal sight distance issues could be established with yield control to determine if the performance of a YIELD sign is equal to that of a STOP sign at intersections with only seasonal sight distance issues. If conversions are completed at intersections with very low traffic volumes as well as low crash rates, the after analysis period may need to be significantly long to collect enough data to complete an adequate before and after comparison. Appropriate statistical techniques should also be applied to address the small sample size issues and possible regression to the mean. Additional study of various levels of traffic control would also be beneficial at low-volume urban intersections.

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