SAFETY EFFECTIVENESS OF STOP CONTROL AT ULTRA-LOW VOLUME UNPAVED INTERSECTIONS

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ABSTRACT
Establishment of the proper level of traffic control on low volume rural roads can be problematic for local agencies. This paper presents the results of a study of 10 years of crash data for over 6000 rural, unpaved intersections in Iowa comparing stop to no-control. Crash models were developed using logistic regression and hierarchical Poisson estimation. For ultra-low volume intersections, under 150 vehicles per day, results indicate no statistical difference in the safety performance of each level of control. The effect of excessive use of control on safety performance was also tested for rural and urban applications, generally indicating no detrimental effect.
INTRODUCTION
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 (1), 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 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 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. First, the study was to assess the safety performance of STOP versus no control 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. These are available in the project report but are not presented in this paper due to length limitations.

LITERATURE REVIEW
We reviewed applications for the installation of stop and yield control at intersections as contained in the MUTCD (1) and the Institute of Transportation Engineers (ITE) Traffic Control Devices Handbook (2). While providing basic guidance for the establishment of intersection control, neither document includes definitive recommendations for ultra-low volume roadways or any guidance for removal of unneeded control.

The most common criteria for establishing or increasing control at intersections are traffic volumes, sight distance, and crash history. However traffic volumes considered in many studies are much higher (approximately 2000-6000 DEV.) than commonly exist on local roads in rural Iowa. In addition, several studies found that the most frequent crash factor at these locations was not STOP sign violations, but failure to yield right of way from the stop position (3, 4, 5, and 6). Other research found that available sight distance at low volume intersections may have negligible effect on safety and operations (7 and 8). These studies concluded that major road traffic volume should be the most prevalent factor in determining level of control.

The FHWA conducted a study in 1981 to attempt to establish definitive criteria for the application of two-way STOP or YIELD at low volume intersections (8). After completing an analysis of variance, the researchers observed a significant increase in crash experience when the volume on the major roadway reached 2000 vehicles per day.

Based on AASHTO recommendations (9), most rural intersections in Iowa would require stop control at least part of the year due to crops. The MUTCD (1), however, recommends that if a full stop is not necessary at all times, consideration of less restrictive control should be given. Both AASHTO and ITE methods assume that drivers reduce speeds when approaching an uncontrolled intersection.

NCHRP Report 320 discusses the conversion of stop to yield control (3). The report found that converted intersections experienced an increase in crashes, the severity and distribution of crashes did not significantly change, and converted intersections had higher crash
rates than unchanged intersections. According to the study, candidates for conversion to yield control should have adequate sight distance, volume less than 1800 DEV, and less than three crashes in two years.

Finally, conflicting conclusions as to the safety effectiveness of stop control were evident in some research (10, 11).

SURVEY AND DATA COLLECTION
To determine the scope of practice in Iowa, we chose to survey 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.

Of the counties responding, five indicated no uncontrolled intersections in their jurisdictions, while eleven had more than 200 without control, all in unpaved locations. Three counties have no all-way stop intersections, but two have more than 100 all-way stop locations, all with at least one paved approach. The use of Yield signs is not common on local rural roads and twelve counties have no Yield signs in use.

Crash history is the most popular determinant for stop control in the counties, followed by sight distance. The majority of responding counties employ an engineering study prior to installing STOP signs, but most have not adopted a formal policy for this application. We also found that the two most popular references used by county engineers in Iowa for engineering studies are the MUTCD and the guidelines used by the Iowa Department of Transportation (Iowa DOT).

In addition to the survey responses, nineteen counties furnished data describing the location of STOP and YIELD signs in their jurisdictions. From these data, it was possible to determine the location of all stop, yield, and uncontrolled intersections in these counties and maps were prepared to illustrate these control types. Following the selection of all unpaved study intersections, crash history was reviewed for a ten-year period. To better assess the effects of stop and yield control, only multi-vehicle crashes of specific types and only those occurring within 150 feet of the intersection were included. Daily entering vehicle volumes were compiled and Iowa DOT crash costs were used to assess severity.

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, most crashes (~80%) on local rural roads in Iowa involve only single vehicles and were thus not included. 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 initially, 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. Two variables were considered: Daily entering vehicles and type of control. Maximum traffic for the study intersections included in this analysis was 200 DEV.

A crash type examination revealed that most crashes at intersections on ultra-low volume, unpaved rural roads are caused by driver failure to yield the right of way. At stop controlled

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1 DOT criterion for intersection-related
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. For both stop and uncontrolled intersections, vision obscured due to crops or other obstacles was not noted as a major contributory factor. Broadside/right angle was the primary crash type at both control types.

An initial analysis indicated that crashes and rate both increase as DEV increases. In addition, a difference in safety performance between stop and uncontrolled intersections was first noted around 70 DEV (See Figure 1). A traffic volumes above this point, stop controlled locations exhibit fewer crashes, while with lower DEV, little difference between types of control can be observed. Average severity per crash was similar for all traffic levels, regardless of control type. Considering only safety cost, it is at this divergent point that consideration should first be given to control. However, total costs would of course include crash, maintenance, and delay costs.

An approximate cost analysis was completed assuming a delay of seven seconds per vehicle for stop control (verified in field trials), vehicle operating cost of $15.00/hr., and annual
maintenance/replacement cost of fifty dollars per intersection. Factoring in total costs, the performance of stop and no control is therefore essentially the same below about 150 DEV.

**Regression Analysis**
Following the initial analysis, more in-depth study was undertaken. 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. Available sight distance was not included in the regression. In this analysis, safety performance of stop and uncontrolled diverges at a point near 100 DEV (see Figure 2.). A ninety-five percent confidence interval for this divergent point is between 66 and 140 DEV. Above this traffic volume level, the probability of at least one crash in a ten year period increases more dramatically for uncontrolled intersections than stop controlled. At lower volumes, little difference in safety performance was noted.

![FIGURE 2 Probability of one or more crashes in ten years.](image)

**Effect of Driver Age**
Impacts of driver age on crash statistics were examined considering specifically drivers 65 years of age and older as well as those 19 years 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.

**Quantifying Excessive Use**

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. To do this, several individual analyses were undertaken. First, the percentage of stop controlled intersections for each county was determined and plotted against average crash rate (See Figure 3). This plot indicated that crash rates seem to decline as the level of control is 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, as percent control increases, crash rates appear to decline.

![Intersection Performance](image)

**FIGURE 3** Safety performance based on the percentage of stop controlled intersections per county.

As a STOP sign placed in response to sight distance limitations is not considered excessive, and sight distance was not available for study area intersections, 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 “justified” stop controlled intersections were calculated. When the fraction of excess STOP signs was plotted against crash rate, again it was found that adding
STOP signs appeared to reduce crash rates. See Figure 4 produced using a volume threshold of 100 (the approximate level at which stop control appears to provide some safety benefit) and one of the terrain factor formulations (set 3). 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).

![Graph of Volume threshold of 100 DEV, terrain set 3](image)

**FIGURE 4** Percentage of excess stop controlled intersections, adjusted for terrain and volume threshold.

**An Alternative Excessive Use Formulation**

The effect of excess 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), average topography, traffic volumes, and land cover was selected as “average”. A ratio based on Cherokee County stop control was calculated for all study counties and plotted against average observed crash rates (See Figure 5). 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 of stop controlled intersections as compared to Cherokee County was compared to performance in other counties (See Figure 6). When plotted, trends for the two groups cross at approximately 125 daily entering vehicles, indicating that above that volume, the excessive use of STOP signs may be detrimental to safety performance. This finding is contradictory to our earlier findings.

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2 Subjectively determined to explore the potential explanatory power of the factor.
URBAN APPLICATION

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. Figure 7 illustrates the crash performance of each type of control. The best safety performance was observed at all-way stop control (see Table 1). Yield control exhibited the highest crash rate followed by no control, traffic signal, and two-way stop, respectively (the rates for the latter three control types were very similar).

<table>
<thead>
<tr>
<th>Control Type</th>
<th>No Control</th>
<th>Yield</th>
<th>Stop</th>
<th>Stop (All Way)</th>
<th>Signal</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Rate per MEV</td>
<td>1.00</td>
<td>1.50</td>
<td>0.90</td>
<td>0.57</td>
<td>0.95</td>
<td>0.91</td>
</tr>
<tr>
<td>Avg DEV</td>
<td>730.64</td>
<td>902.11</td>
<td>5105.92</td>
<td>6129.95</td>
<td>17608.92</td>
<td>5865.39</td>
</tr>
<tr>
<td>Avg Crashes</td>
<td>1.68</td>
<td>3.96</td>
<td>5.92</td>
<td>10.90</td>
<td>61.54</td>
<td>12.25</td>
</tr>
<tr>
<td>Number of Intersections</td>
<td>33</td>
<td>9</td>
<td>130</td>
<td>21</td>
<td>26</td>
<td>219</td>
</tr>
<tr>
<td>% Total Intersections</td>
<td>15.1</td>
<td>4.1</td>
<td>59.4</td>
<td>9.6</td>
<td>19.9</td>
<td>19.9</td>
</tr>
<tr>
<td>Max Rate</td>
<td>5.49</td>
<td>6.38</td>
<td>13.70</td>
<td>2.19</td>
<td>3.65</td>
<td>3.65</td>
</tr>
<tr>
<td>Min Rate</td>
<td>0.00</td>
<td>0.41</td>
<td>0.04</td>
<td>0.06</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Max Dev</td>
<td>3646</td>
<td>1250</td>
<td>21903</td>
<td>10685</td>
<td>24350</td>
<td>24350</td>
</tr>
<tr>
<td>Min Dev</td>
<td>50</td>
<td>300</td>
<td>50</td>
<td>1206</td>
<td>8900</td>
<td>50</td>
</tr>
<tr>
<td>Max Crashes</td>
<td>5</td>
<td>7</td>
<td>40</td>
<td>29</td>
<td>123</td>
<td>123</td>
</tr>
<tr>
<td>Min Crashes</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total Crashes</td>
<td>52</td>
<td>32</td>
<td>788</td>
<td>229</td>
<td>1600</td>
<td>2682</td>
</tr>
</tbody>
</table>

Table 1 Summary for City of Ames.
Statistical Assessment

We fitted a hierarchical Poisson model to the Ames crash data. The model states that crash frequencies at an intersection are distributed as Poisson variables with mean $\lambda \cdot \text{DEV}$, where here $\lambda$ 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 dataset, we grouped the Yield-controlled and the intersections with no control. 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 $(\lambda)$ is also normal).

Estimates of model parameters were obtained using a Bayesian approach (12). The regression coefficients associated to control types were assigned non-informative normal prior distributions with zero mean and very large variance, indicating 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 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.

We fitted the model using WinBUGS and Markov chain Monte Carlo methods. We obtained 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 2.5\(^{\text{th}}\), 50\(^{\text{th}}\) and 97.5\(^{\text{th}}\) percentile. A central 95\% posterior credible set is given by the set bounded by the 2.5\(^{\text{th}}\) and the 97.5\(^{\text{th}}\) posterior percentiles. Table 2 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, we conclude 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 no-control intersections. The plots in Figure 8 show the posterior distributions of crash rates for the various intersection types.

**TABLE 2 Expected Crash Rates**

<table>
<thead>
<tr>
<th>Type</th>
<th>Mean</th>
<th>Std</th>
<th>2.5(^{\text{th}}) perc</th>
<th>Median</th>
<th>97.5(^{\text{th}}) perc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.90</td>
<td>0.02</td>
<td>0.87</td>
<td>0.91</td>
<td>0.95</td>
</tr>
<tr>
<td>Two-way</td>
<td>0.28</td>
<td>0.01</td>
<td>0.27</td>
<td>0.29</td>
<td>0.30</td>
</tr>
<tr>
<td>All Way</td>
<td>0.46</td>
<td>0.03</td>
<td>0.40</td>
<td>0.46</td>
<td>0.52</td>
</tr>
<tr>
<td>No Control</td>
<td>0.41</td>
<td>0.04</td>
<td>0.33</td>
<td>0.41</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**FIGURE 8 Crash rate distributions based on control type.**
Effect of Excessive Use
To investigate the possible effect of excessive stop sign use, neighborhood crash rates were compared to city-wide averages. Figure 9 plots overall and stop controlled crash rates for each neighborhood versus percent control. For this limited urban application, increased use of stop control would seem to have a positive impact on safety performance (note that the x-axis indicated uncontrolled portion).

![Figure 9: Safety performance of Ames neighborhoods.](image)

CONCLUSIONS AND RECOMMENDATIONS
This research has found that ultra-low volume, unpaved rural intersections experience no adverse impact to safety performance due to type of control. Agencies may have erected Stop signs in these locations in the past and may desire to remove perceived unneeded control.

Conclusions drawn from this research include:
- In general, ultra-low volume, rural, unpaved intersections exhibit crash rates much lower than those experienced on local rural roads in general.
- The most prominent crash type at study intersections was failure to yield right of way, regardless of control type.
- Additional STOP sign use at these ultra-low volume intersections did not appear to adversely affect safety performance.
- Above approximately 150 DEV, uncontrolled intersections exhibit increasingly higher crash rates than stop controlled.
- For both stop and uncontrolled ultra-low volume rural unpaved intersections, older drivers have less crashes than would be expected.
- For intersections with DEV less than approximately 150, type of control has
  negligible effect on the safety performance of ultra-low volume unpaved rural
  intersections
- restricted sight distance is not a major contributing crash factor at ultra-low volume
  intersections, regardless of control type
- In urban areas, excessive use of stop control may adversely affect safety performance,
  but more research is needed to verify.
- Several sources of references for conversion of all-way to two-way stop control are
  available, but guidelines for removal of two-way STOP signs have not been
  published.
- The effect of excessive use of stop control on safety performance of stop controlled
  intersections is statistically inconclusive
- If proper techniques and criteria are followed, it appears that agencies could remove
  or convert stop controlled low volume intersections without exposure to liability.

Recommended procedures for removal or conversion of 2-way Stop control from 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, (5) documentation and follow-up review.

If removal or conversion of unneeded STOP signs is desired, agencies should 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.

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