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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 320

GUIDELINES FOR CONVERTING STOP TO YIELD CONTROL AT INTERSECTIONS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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GUIDELINES FOR CONVERTING STOP TO YIELD CONTROL AT INTERSECTIONS

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- (Highway Transportation)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. OCTOBER 1989

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report is recommended to state and local traffic and safety engineers concerned with conversion of STOP control to YIELD control at intersections. The findings presented are based on an extensive literature search, a survey of state and local traffic engineers, and an analysis of accident data at 765 intersections. Based on this information, the researchers developed guidelines for the conversion of STOP control to YIELD control and suggested warrants for improved STOP and YIELD control for potential inclusion in the *Manual on Uniform Traffic Control Devices* (MUTCD).

YIELD control is an intermediate form of control between normal right-of-way under no sign control and STOP sign control. YIELD control was first used in the United States in 1951 even though the YIELD sign did not appear in the MUTCD until 1954 when it was designated as an experimental sign. It was not until 1964 that the YIELD control was identified as accepted practice in the MUTCD. Since its first use, many studies have been conducted to evaluate the effectiveness of YIELD control. The results of these studies have been mixed, indicating the complexity of the subject matter and the difficulties associated with accounting for all pertinent variables.

NCHRP Project 17-7 was initiated based on the hypothesis that there could be significant savings in fuel consumption, vehicle operating costs, motorists delays, and vehicle emissions if YIELD control was substituted for STOP control at appropriate locations. It was envisioned that these potential cost savings and improved operations would set the stage for possible conversion of many STOP-controlled intersections to YIELD control. However, it was also known that these user savings may be offset by increased accident costs if there were more accidents or more severe accidents, where intersections were converted from STOP to YIELD control. Previous studies on low-volume intersections concluded that control type has no appreciable effect on accident experience and that YIELD control is more economical than STOP control because of the reduced delay and road user costs. For higher traffic volume intersections, however, insufficient accident data had been collected to demonstrate the relative safety of STOP versus YIELD control.

The objectives of this study were to determine the accident experience when STOP-controlled intersections were converted to YIELD control and to develop guidelines for converting STOP control to YIELD control. To achieve these objectives, the researchers identified current traffic engineering practice through a reveiw of the technical literature and a survey of state and local highway agencies. In addition, the researchers collected existing accident data and conducted new field studies to determine the safety consequences of converting STOP control to YIELD control for a full range of applicable traffic volumes. The researchers analyzed the information gathered and developed definitive guidelines regarding YIELD control as a substitute for STOP control and suggested wording for improved STOP and YIELD control warrants. It is believed that implementation of these guidelines and warrants will improve the safety and efficiency of many roadway intersections.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was conducted by Bellomo-McGee, Inc., with Hugh W. McGee as the Principal Investigator. Michael R. Blankenship was the principal research analyst. Dr. John C. Keegal was a statistical consultant and authored Appendix D. Derek Joost, formerly with BMI, assisted Dr. McGee in the early stages of the project.

Grateful acknowledgment is made to the agencies that cooperated in this project by converting sites, assisting in data collection, and providing data. Those agencies include: Saginaw, Pueblo, Madison, Milwaukee, Seattle, and Rapid City. Appreciation is also extended to all the states and local agencies who responded to the questionnaire survey.

GUIDELINES FOR CONVERTING STOP TO YIELD CONTROL AT INTERSECTIONS

SUMMARY

Prior research has indicated that there could be large savings in fuel consumption, vehicle operating costs, motorists delay, and vehicle emissions if YIELD control were substituted for STOP control at appropriate locations. While YIELD control has been found to be as safe as STOP sign control at very low volumes, the safety impacts are not well established for higher volume levels. If more use of the YIELD sign for intersection control is to be made, it is necessary to establish the comparative accident experience and cost effectiveness of both controls at as wide a range of volumes as possible. In recognition of these issues, objectives of this project were to: (1) determine the accident experience when STOP-controlled intersections are converted to YIELD control, and (2) develop guidelines for converting STOP control to YIELD control.

Initially, a literature review and survey of highway agencies was conducted to determine current engineering practice and safety experience at STOP and YIELD controlled intersections. The survey of state and local agencies showed that very few agencies had changed their control from STOP to YIELD and there appeared to be widespread reluctance to do so because of the perceived safety consequences and concern over liability.

The literature review focused on: (1) history of YIELD control, (2) studies of YIELD use, and (3) warrants and recommendations on YIELD use. Previous studies of STOP to YIELD conversions showed mixed results, but there was more evidence to indicate an increase in accidents with conversion.

A total of 756 YIELD and STOP controlled intersections in six cities were analyzed in terms of their accident experience. Saginaw, Rapid City, and Pueblo had recently converted some STOP control intersections to YIELD control; therefore, data from these three cities were used in analyzing accident experience both before and after conversion. Data from Seattle, Milwaukee, Madison, and again Rapid City were used in analyzing established YIELD control intersections. These safety results were then integrated with user costs and benefits (which were updated from a previous study) to develop criteria for converting from STOP to YIELD.

The key findings from this research include the following:

1. Intersections converted from STOP to YIELD control are likely to experience an increase in accidents, especially at higher traffic volumes. The expected accident increase is about one accident every 2 years.

2. Accident severity and distribution did not significantly change after conversion from STOP to YIELD.

3. Converted YIELD control intersections have a higher accident rate than established YIELD control intersections.

4. Four-leg intersections with YIELD control have a higher accident rate than T-leg intersections with YIELD control.

5. Because of reduced motorist delay, fuel cost and other vehicle operating costs, YIELD control is more cost effective than STOP control at all volume levels studied.

The guidelines developed for conversion of STOP to YIELD control are as follows:

1. Have adequate sight distance.
2. Intersection volume less than 1,800 ADT, major street volume less than 1,500 ADT, and minor street volume less than 600 ADT are potential conversion candidates.
3. Intersections experiencing less than three accidents in 2 years are candidates for conversion.

Although YIELD control was found to be more cost effective than STOP control, the possibility of an increase in accidents occurring at an intersection converted from STOP to YIELD control does exist. For this reason, engineers should be cautious when converting from STOP to YIELD. However, for new intersections, wider use of YIELD control is recommended where volumes are within the ranges stated above and where there is adequate sight distance.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM BACKGROUND

Research indicates there could be large savings in fuel consumption, vehicle operating costs, motorist delay, and vehicle emissions if YIELD control were substituted for STOP control at appropriate locations. These user savings may offset increased accident costs, if there are more accidents where intersections are converted from STOP to YIELD control. This potential for cost savings and improved operations sets the stage for possible large-scale conversions of many STOP-controlled intersections to YIELD control.

Studies of low volume intersections have concluded that control type has no appreciable effect on accident experience. These studies indicate YIELD control is more economical than STOP control because of the reduced delay and road user costs. For higher traffic volume intersections, however, insufficient accident data have been collected to demonstrate the relative safety of STOP versus YIELD control.

The extent of noncompliance with STOP signs at certain locations also suggests that YIELD control may be more appropriate. Research has shown that a very high percentage of motorists do not comply with STOP signs where they perceive a full stop is not needed for safe entry into the intersection.

OBJECTIVES AND SCOPE

In recognition of the foregoing findings, the National Cooperative Highway Research Program sponsored this study which has the following stated objectives: (1) to determine the accident experience when STOP-controlled intersections are converted to YIELD control, and (2) to develop guidelines for converting STOP control to YIELD control.

The research was to include both four-leg and T-type intersections and cover the full range of applicable traffic volumes.

To meet these objectives there are six major task assignments. These are enumerated, as follows:

Task 1. Determine the current traffic engineering practice and safety experience at STOP and YIELD controlled intersections through a review of the technical literature and contacts with state and local highway agencies.

Task 2. Prepare a study design to determine the safety consequences of converting STOP control to YIELD control for the full range of applicable volumes.

Task 3. Collect existing accident data and/or conduct new field studies to carry out the approved study design.

Task 4. Analyze the accident data according to the approved study design.

Task 5. Update the user costs and benefits from previous studies and integrate these costs with the safety results to develop criteria for converting STOP to YIELD control.

Task 6. Prepare a final report to include appropriate guidelines for converting STOP to YIELD control and suggested wording for improved STOP and YIELD control warrants for potential inclusion in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*).

Further description of the study methodology is provided in the next chapter.

Two points should be made that provide further clarification of the scope of the study: (1) The focus was on YIELD control use and especially on converting existing STOP control to YIELD control. No special studies or analysis was done to define warrants for uncontrolled intersections or STOP control intersections. (2) This project focused on the use of YIELD signs as a control measure for the approach leg of the side street at an at-grade intersection. Hence, its application for controlling merge points or acceleration lanes, second entrances on divided highways, or for channelized right-turn was not examined.

STUDY APPROACH

The identification of current practice and safety experience required in Task 1 was based on a literature review and a questionnaire sent to all 50 states and 200 local jurisdictions (cities and counties) of varying sizes throughout the country. The questionnaire was also used to identify jurisdictions that had useful data and were willing to participate in conversions.

The primary focus related to data collection and analysis was to determine the safety consequences of converting STOP control to YIELD control for a full range of volumes. It was intended that at least 250 intersections in several cities where STOP to YIELD conversions had recently been made, or would be made during the course of the project, would be used for this evaluation. Unfortunately, because of the reluctance of agencies to make conversions, the desired sample size was not attained. Therefore, the study design was modified to include accident occurrence at numerous YIELD control intersections concentrating on higher volume locations.

The study design was built upon the study design accident data from the following locations: *Saginaw, Michigan* (60 STOP control intersections converted to YIELD control between 1980–1987, and 39 STOP control intersections, used for comparison, 1980–1987); *Pueblo, Colorado* (72 STOP control intersections converted to YIELD control in 1986 or 1987, and 16 STOP control intersections used for comparison, 1985–1987); *Rapid City, South Dakota* (19 STOP control intersections converted to YIELD control in 1983 or 1984, 9 STOP control intersections used for comparison, 1981–1986, and 123 intersections that had always been under YIELD control, 1985–1986); *Seattle, Washington* (172 YIELD control intersections for 1985–1986); *Milwaukee, Wisconsin* (178 YIELD control intersections for 1983–1986); and *Madison, Wisconsin* (68 YIELD control intersections for 1983–1986).

Data collection activities (Task 3) varied slightly among the different cities, depending on the availability of data, but in general consisted of: obtaining relevant accident information, obtaining traffic volumes, and conducting a site reconnaissance.

The accident data were analyzed using appropriate statistical procedures to establish: if the accidents changed with conversion; if the converted sites experienced any adverse "novelty" effect; which variables might influence the accident increase, if any; and the expected accident rate for YIELD control sites.

The final analytical effort involved conducting a cost-benefit analysis as a basis for establishing the more cost-effective control. Following the procedures used by Upchurch (*2*) in his analysis of intersection control: (1) The Texas Model for Intersection Traffic (*36*) was employed to determine user delay and fuel use with STOP or YIELD control under different operating conditions. (2) Costs for vehicle operation, user delay, and accident occurrence were updated. (3) Cost and benefits were calculated for a range of operating conditions for both STOP and YIELD control.

The results of this analysis compiled with those from the literature review and the jurisdiction survey were then used as a basis for final recommendations.

CHAPTER TWO

FINDINGS

LITERATURE REVIEW

The focus of the literature review was on the following items: (1) the history of YIELD control use; (2) prior studies that have made comparative evaluations of STOP and YIELD control and evaluations of conversions of STOP to YIELD control; and (3) proposed and accepted warrants or guidelines for using YIELD control or for converting STOP to YIELD control.

Appendix A provides a full documentation of the literature review. This section provides a summary of findings.

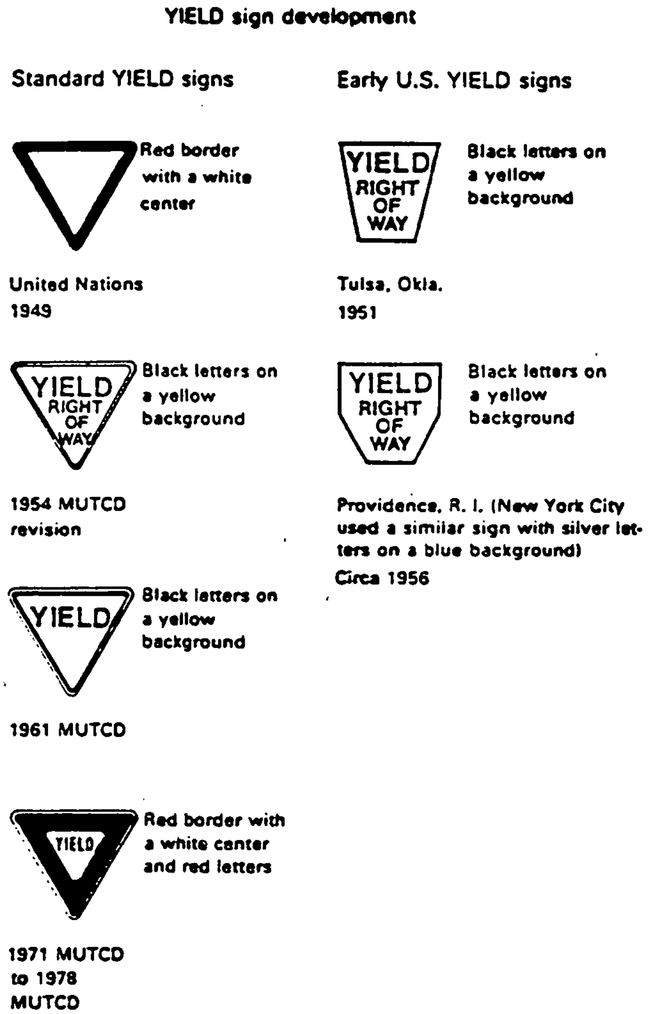
History of YIELD Control

Figure 1, extracted from a review by Rosenbaum (*3*), traces the history of the YIELD sign development. The YIELD sign did not appear in the MUTCD until its 1954 revision and was regarded as experimental. Since then the design has changed twice to its current form which was adopted from the international symbol for "give way."

In the 1961 MUTCD, YIELD control became an accepted practice and the first recommended YIELD warrants were introduced. These warrants continued through the 1983 MUTCD with only minor wording change. The warrants will be discussed later.

Prior Studies

Appendix A presents, in chronological order, a review of the literature that deals with the safety and operational effects of YIELD control in comparison to no control and STOP-sign con-



Source: Reference (3)

Figure 1. Historic development of YIELD *signs.* Source: "A Review of Research Related to the Safety of STOP versus YIELD Sign Traffic Control," Public Roads, Vol. 47, No. 3, p. 78, December 1983).

Warrants and Recommendations on YIELD Use

The MUTCD provided its first warrants on YIELD control in 1961. Except for minor wording changes they have remained unchanged through the current version. Figure 2 provides the entire discussion of the current warrants for YIELD signs presented in the MUTCD. It should be noted that this study deals with YIELD signs used under warrants 1 and 5, i.e., the use of YIELD sign as the control for the minor approach leg of an intersection.

The MUTCD warrants are somewhat limited in that they do not provide specific guidelines, such as appropriate traffic volumes, accident experience, and sight distance limits. A condensed view of attempts by others to provide more definitive guidelines is provided below.

- *Volume Warrants.* Various measures were defined as necessary determinants to describe the volume of vehicles using an intersection. Measures such as vehicles per day, per hour, and per average hour were specified for total intersection volumes, major or minor roadway or approach volumes. For those warrants which specified total intersection volumes as criteria, appropriate YIELD control intersection volumes ranged from 1,000 to 5,000 vehicles per day.
- *Sight Distance Warrants.* Minimum corner sight triangle for YIELD control is based on the concept of safe approach speed, which is the maximum speed at which traffic at one intersection approach can avoid colliding with cross traffic (see Appendix C for a complete discussion and procedure for determining safe approach speed). Of the warrants reported by 15 jurisdictions, six required a safe approach speed of at least 15 mph. Other reported thresholds were 12 mph (1 jurisdiction), 10 mph (3 jurisdictions), 8 mph (4 jurisdictions), and 6 mph (1 jurisdiction).
- *Accident Warrants.* Many of the warrants reviewed required a minimum number of accidents before changing from no control to YIELD control. These ranged from less than 1 accident per year to as high as 5 per year.
- *Roadway Classification.* Several of the warrants provided that YIELD control be limited to intersections of collector with local and of local with local. One jurisdiction restricted YIELD intersections to local with local.

Other specific recommendations included the following: YIELD should not be used against the major flow if the major flow is more than 1.2 times the minor flow; and YIELD should be used only if the pedestrian volume is low (i.e., less than 50 pedestrians per hour in peak vehicle hour).

trol. It also includes studies that have specifically examined conversions of STOP to YIELD control.

The salient findings from the studies are the following: (1) Control type has no discernible effect on accident experience for "low volume" intersections. (2) In terms of operating efficiency, YIELD control is superior to STOP control for "low volume" intersections. (3) Conversions of STOP to YIELD control at "low volume" intersections have been met with mixed results of accident change with evidence of increases, no change and decreases.

A key point underlying these statements is the definition of "low volume." The threshold of low volume varied among the studies; consequently, there is no clear demarcation of volume levels where a more restrictive control is appropriate.

STATE AND LOCAL AGENCY QUESTIONNAIRE RESULTS

A questionnaire was used to determine state and local agency experiences with YIELD-controlled intersections and with conversions from STOP to YIELD. It was also used to identify any agencies who would be willing to participate in a STOP to YIELD conversion study. A total of 32 states (64 percent response) and 73 local jurisdictions (36.5 percent response) responded to the survey. The questionnaire, as well as a complete presentation of the results, is found in Appendix B. A summary is provided below.

Concerning the use of YIELD signs for intersection control, 30 percent of the respondents do not use YIELD signs, 32 percent follow MUTCD warrants, and 38 percent have more specific

2B-8 Warrants for YIELD signs

The YIELD sign may be warranted:

1. At the entrance to an intersection where it is necessary to assign the right-of-way and where the safe approach speed on the entrance exceeds 10 mile per hour.

2. On the entrance ramp to an expressway where an acceleration lane is not provided.

3. At intersections on a divided highway where the median between the roadways is more than 30 feet wide. At such intersections, a STOP sign may be used at the entrance to the first roadway of the divided highway and a YIELD sign may be placed at the entrance to the second roadway.

4. Where there is a separate or channelized right-turn lane, without an adequate acceleration lane.

5. At any intersection where a special problem exists and where an engineering study indicates the problem to be susceptible to correction by use of the YIELD sign.

YIELD signs generally should not be placed to control the major flow of traffic at an intersection. However, YIELD signs may be installed to control a major traffic movement where a majority of drivers in that movement are making right turns (see Figure). At such an intersection, YIELD signs should not be erected at any other approach.

YIELD signs should not be used on the through roadways of expressways. They may be used on an entering roadway without an adequate acceleration lane, but in a well designed interchange, the sign would interfere with the free merging movement, and it should not be used under those circumstances.

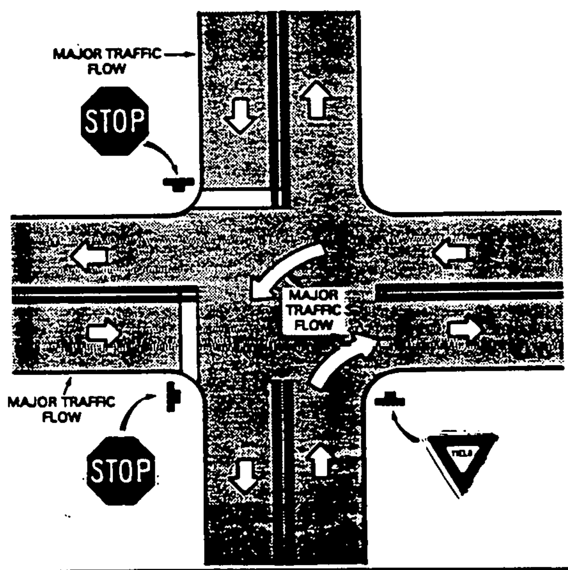


Figure 2. Section 2B-8 from MUTCD on YIELD *sign use.* (Source: *Manual on Uniform Traffic Control Devices,* Section 2B-8, Revision No. 3, September 1984).

warrants or guidelines in addition to the MUTCD. Factors considered by those who have specific warrants are safe approach speed, accident history, traffic volume, roadway classification, and special situations such as heavy left-turn movement.

There were no jurisdictions with a specific policy regarding conversions from STOP to YIELD control. When asked what factors they feel are important in deciding to convert, they were primarily concerned with sight distance, traffic volume, and accident experience. Additional concerns included geometrics, driver understanding, and roadway classification.

From the agencies who provided a response to the question of what procedures are used to minimize any initial negative impact when converting from STOP to YIELD, the collective responses were: news releases through newspaper and radio coverage; neighborhood notices; local politicians and interested citizens are informed; advanced "Traffic Revision" warning signs placed at the time of conversion; and police observation is requested.

Many agencies expressed their opinion as to the efficacy of converting from STOP to YIELD control. Two comments representing those who favored conversions were: (1) "If conversion will reduce delays and not sacrifice safety, it should be done." (2) "Our past usage of two-way STOP signs has substantially paralyzed the motorist. In areas where this is perceived by the public, there tends to be significant amounts of noncompliance."

Comments made by two who were opposed to conversions were: (1) "Experience indicates motorists who frequent the intersection soon no longer respect the importance of the YIELD sign as they would a STOP sign." (2) "I hope this thinking is not made standard. This new idea allows drivers too much 'decision making'."

In summary, the responses to questionnaires and discussions with participating jurisdictions provided some thoughts on why so few conversion sites were available for examination in this study. There are many jurisdictions that feel that YIELD control is unsafe and, thus, will not consider conversions in any case. Other jurisdictions, which have established policies using YIELD control, had already installed YIELD control where they were warranted and now convert only when conditions (i.e., traffic volumes, traffic patterns, accidents, geometrics, sight distance) change. These conversions are almost always YIELD to STOP.

The foremost conclusion one can reach from the results of the questionnaire is that the use of YIELD control in lieu of STOP control at intersections is a sensitive issue. Many agencies have safety concerns over the use of YIELD control, and these concerns can be assumed to relate directly to an ever growing concern over public liability.

ACCIDENT ANALYSIS

The major effort for the project was focused on the accident occurrence that would occur under YIELD control operations. Two major issues were examined:

1. How do accidents change when converting from STOP to YIELD? More specifically: Is there an initial increase when the conversion is made, i.e., an adverse novelty effect? Did the accident experience (frequency, severity, type) change from the one to two-year "before" period to the one to two-year "after" period? If there was a change, which factors are associated with the change?
2. What is the expected accident frequency for YIELD control intersections, and what factors affect the frequency?

The findings from the various analyses that address these underlying issues are presented in this section.

Conversions from STOP to YIELD

The primary accident issue was to establish how accidents change when the intersection control is converted from STOP to YIELD. As indicated earlier, only three jurisdictions were identified which either had converted intersection control in recent years or were willing to do so within the time frame of this project. Those jurisdictions with the number of converted sites and the years of before and after data are provided in Table 1. The table also indicates the number of control sites that were included in the analysis.

The preferred experimental design for this type of analysis is the "before-after with control group" design. In this design two comparable groups of intersections are used, with one set receiving the treatment, which in this case was the change from STOP to YIELD, and the other set remaining as is, in this case under STOP control. The control set is used to establish if any change in accidents for the treatment set is due to the treatment or not.

The control intersections for this study were not ideal because for the most part they had to be selected after the conversions were made. However, in general, their characteristics (volume, geometry) are similar and, therefore, they should provide more confidence to any identified change in accident experience for the treatment sites.

Table 2 provides summary statistics on the accident change for the converted (treated) sites in each of the three cities. In each city there was an increase in total accidents after conversion. Also, the data show that in Saginaw 47 percent of the 53 intersections experienced an increase, in Rapid City it was 36.8 percent of the 19 intersections, but in Pueblo it was only 8.7 percent of the 69 intersections.

Table 3 provides the results of the statistical analysis used to establish if the observed increase in accidents for the converted sites was statistically different from the change in the control sites. The values in the table are the total number of accidents in the before or after period for the two types of sites. The statistical analysis employed was that suggested by Griffith (*6*) in which a cross product ratio, defined as the tau, τ, statistic, is calculated. A value different from 1.0 indicates that the change in accidents experienced at the converted sites and control sites is dissimilar (i.e., nonparallel slopes). A value greater than 1.0 indicates that the increase in accidents for the converted sites was greater than the increase for the control sites. To determine whether an apparent treatment effect is statistically significant,

Table 1. Sample size of converted and control sites.

Location	Conversion Year	No. of Conversions	No. of Control Sites	Before & After Analysis Period (Years)
Pueblo	1987	16	15	1
	1986	53	15	1
		69		
Saginaw	1986	7	36	1.75
	1985	17	36	2
	1984	10	36	2
	1983	11	42	2
	1982	8	41	2
		53		
Rapid City	1984	19	8	2

Table 2. Summary of accident change of converted sites.

Location	No. of Conversions	No. of Accidents Before	No. of Accidents After	No. of Intersections with Accidents Increase	No. of Intersections with Accidents No Change	No. of Intersections with Accidents Decrease
Rapid City	19[1]	12	26	7	10	2
Saginaw	53[2]	25	68	25	22	6
Pueblo	69[3]	4	12	6	60	3

[1] Data for all sites are for 2 years before and after.

[2] Includes 46 sites with 2 years before and after data, 5 sites with 1-3/4 years and 2 sites with 1 year.

[3] Data for all sites are for 1 year before and after.

a Z statistic is calculated which equals the natural log of the tau statistic divided by the square root of the sum of the reciprocals of the observed accident frequencies, before and after. This Z statistic, when compared to a critical value of ± 1.96 (at $\alpha = 0.05$ for a two-tailed test), indicates if the difference between the two is statistically significant at 95 percent confidence level.

In Pueblo, even though there were 3 times as many accidents (4 to 12) at the 69 converted sites, there were too few accidents, especially for the control sites, to make any meaningful statistical analysis. Rapid City experienced, although statistically insignificant, a slightly higher increase in accidents for the converted sites compared to the control sites. In Saginaw, the increase in accidents for the converted sites was substantial (25 to 68) and very significant, given that the control sites decreased slightly in accident frequency.

Table 3. Comparison of before vs. after accidents for conversion and control sites.

Site Type	Pueblo Before	Pueblo After	Rapid City Before	Rapid City After	Saginaw Before	Saginaw After
Control	0	2	3	6	30	28
Conversion	4	12	12	26	25	68
Statistic: Cross-Product Ratio, τ	Insufficient Data		$= \frac{3 \times 26}{12 \times 6}$ $= 1.08$		$= \frac{30 \times 68}{25 \times 28}$ $= 2.91$	
Z Statistic	Insufficient Data		$= \frac{\ln(1.08)}{1/3+1/6+1/12+1/26}$ $= 0.098$ Not significant		$= \frac{\ln(2.91)}{1/30+1/68+1/25+1/28}$ $= 3.04$ Significant	

Although most of the data analysis indicates an increase in accident frequency after converting from STOP control to YIELD control, the question of how much impact did "regression to the mean" have on this increase still remains. Because 79 percent of the treatment sites and 71 percent of the control sites had zero accidents in the before period, the chance of an increase in accident frequency in the after period was fairly high. Table 4 shows the type of change in accident frequency from the before to the after period. Combining the sites from the three cities, there was no significant difference in the percentage of sites showing an increase in accident frequency for the three categories (sites with 0 before accidents, sites with 1 or more before accidents, and all sites).

If one discounts the combining of the data for the three cities (due to the high number of "zero accident" locations in Pueblo) and only looks at Saginaw, a slightly different picture develops. In Saginaw, 68 percent (36 out of 53) of the treatment sites had 0 before accidents. A statistical analysis (the cross product ratio analysis described earlier) of the sites with zero (0) accidents in the before period revealed that there was no significant difference in the proportion of sites increasing in accidents in the after period (Z = 1.37). The same finding was found for just those sites that experienced at least one accident in the before period (Z = 1.57). These results indicate that the "regression-to-the-mean" phenomenon may have affected the after accident experience. However, the sample sizes (i.e., number of intersections) were low for these two cases, and when all sites are examined a significant difference was found (Z = 2.08).

While these overview data are informative, the remaining results, which are presented for each of the three cities, provide further useful information.

Pueblo. For the converted sites there were only six locations which increased in accidents distributed by frequency as follows:

Increase in Accidents	No. of Sites
5	1
2	2
1	3

With so few accidents occurring in the before and after period for both converted and control sites it is impractical to apply the data to standard statistical analyses to identify statistical

Table 4. Change in accident frequency from before to after period.

Location/ Site Type	Sites with 0 before accidents Increase	Sites with 0 before accidents No Change	Sites with ≥ 1 before accident Increase	Sites with ≥ 1 before accident No Change	Sites with ≥ 1 before accident Decrease	All sites Increase	All sites No Change	All sites Decrease
Saginaw								
Treatment	17	19	8	3	6	25	22	6
Control	6	15	3	3	9	9	18	9
Rapid City								
Treatment	4	6	3	4	2	7	10	2
Control	4	2	0	0	2	4	2	2
Pueblo								
Treatment	7	59	0	0	3	7	59	3
Control	2	13	0	0	0	2	13	0
Total								
Treatment	28	84	11	7	11	39	91	11
Control	12	30	3	3	11	15	33	11

significance or correlations. Still, the examination of why accidents did increase for some intersections is worth presenting.

One intersection in Pueblo experienced five accidents in one year since STOP was changed to YIELD in 1985. This four-way intersection is located in a residential area and has a major volume of 1,400 ADT and minor volume of 750. A review of the accident reports indicated that one of the accidents, while occurring within the intersection, was not related to the YIELD sign control. The other four were diagramed as a two-vehicle right-angle accident involving a failure to yield right-of-way from the YIELD approach. This intersection has less than desirable sight distance resulting from a grade and shrubbery. The City Engineer has since restored the intersection to STOP control.

At another intersection, three accidents occurred within the second month after conversion. In this situation the slightly higher volume through-street had the STOP sign which was changed to YIELD. Apparently, the YIELD sign was not a strong enough control to overcome the expectancy of drivers on a through-street to have the right-of-way. Approaches on both adjoining intersections of the through-street had no control. After the third accident, the control was changed back to its original condition. The data for this site were removed from the accident analysis.

It should also be noted that Pueblo reconverted three other intersections back to STOP control after a short period. None experienced accidents, but complaints had been received about high speeds, nonobservance of the YIELD sign, and generally unsafe conditions. One location had a particularly high percentage of large truck traffic because of an adjoining warehouse area.

Rapid City. In Rapid City, 18 conversions had been made in 1984 with one in 1983 and the data represent a 2-year period for before and after conversion. While the number of converted sites is somewhat limited—only 19—there were enough accidents to draw some findings.

Of the 19 sites, seven experienced an increase in accidents, ten did not change, and two experienced a decrease. Of the sites increasing in accidents the distribution was as follows:

Increase by	No. of Sites
5	1
4	1
3	1
2	1
1	3

With only one accident occurring for all sites within the first month and none in the next two months, there apparently was no adverse novelty effect. However, considering the full 2-year after period, there was an increase in accidents for the conversion. This increase (from 12 to 26), however, was not judged to be due solely to the conversion given that the control sites increased in accidents as well (from 3 to 6 for the eight sites selected).

The severity distribution of the before and after accidents at the converted sites was as follows:

	Before	After
Fatality	0 (0 percent)	0 (0 percent)
Injury	3 (25 percent)	10 (38 percent)
PDO	9 (75 percent)	16 (62 percent)
	12	26

The chi-square statistical analysis reveals that the apparent difference in the distribution is not statistically significant (calculated chi-square (χ^2) = 0.65 vs. χ^2 at α = 0.05 = 3.84).

Another analysis performed was to establish if the types of accidents changed with the conversion from STOP to YIELD. The accidents arrayed by accident type are as follows:

Type	Before	After
Angle	2 (16.7 percent)	11 (42.3 percent)
Rear End	0	2 (7.7 percent)
Turning	3 (25 percent)	4 (15.4 percent)
Sideswipe	2 (16.7 percent)	0
Fixed Object	3 (25 percent)	5 (19.2 percent)
Bicycle	0	1 (3.8 percent)
Other	2 (16.7 percent)	3 (11.5 percent)
	12 (100 percent)	26 (100 percent)

At face value the data above suggest that there is a difference in accident types when STOP is converted to YIELD. There is a greater percentage of angle accidents (as expected) and rear-end (as expected). It is also noted that a bicycle accident occurred with the presence of YIELD control. However, the sample sizes are small, and when the data are exposed to a chi-square Test of Independence the result is that the distributions are not dissimilar.

The influence of traffic volume as a factor in the accident change was also examined. Unfortunately, the sample size, i.e., number of sites and number of accidents, is too small for a reliable statistical analysis; but, it is interesting to observe from Table 5 that the average ADT volume, either major, minor, major plus minor or major times minor, is in all cases higher for those sites which experience an increase in accidents.

Another issue, which could be examined with the Rapid City sites, was the comparison of accident occurrence for those YIELD control sites that had been converted vis-a-vis YIELD control sites that had been YIELD for several years. The data summary is presented in Table 6. These data were statistically analyzed to determine if there were any differences between the two groups of YIELD sites with regard to accidents and volumes. Table 7 shows the results of these analyses. At four-leg sites converted YIELDs had significantly higher accident frequencies than established YIELDs. Because the major volumes were also significantly higher at converted YIELDs another analysis was made using established YIELDs with major volumes greater than or equal to 2,000 ADT. This analysis showed no significant difference in accident frequencies.

T-leg intersections showed no statistical differences in accident frequencies, although converted YIELDs had statistically higher major volumes. Reanalyzing with established YIELDs having major volumes greater than or equal to 2,000 ADT showed no statistical differences in terms of accident frequency or volume.

If the accident frequencies were not statistically different, average accident rates developed for established YIELDs could be hypothesized as being appropriate for converted YIELD sites. However, the accident frequencies were higher for converted YIELDs at α = 0.10. The small sample size of 8 conversion sites casts doubt on the findings however.

Saginaw. Saginaw provided the largest number of conversions with 53 over a period from 1982 to 1986. The number of control sites varied between 36 and 42, depending on the analysis year, because some of the sites that were converted in the later years were utilized for control sites for analyzing earlier year conversion.

As indicated previously (see Tables 2 and 3) there was a statistically significant increase in accidents when the STOP control sites were converted to YIELD control. Twenty-five of 53 converted sites experienced an increase with the distribution as follows:

Accident Increase	No. of Sites
6	1
5	1
4	2*
3	5*
2	4
1	12

The numbers with an asterisk indicate that for both groups one site had been converted for 1¾ years. All the others had been converted 2 years.

For the Saginaw data another statistical analysis method was used to determine if the accident change for the treatment sites was different from the control sites and what factors may have influenced the relative change. The statistical methodology employed contingency table analysis techniques using the principle of minimum discrimination information for model building. The methodology isolates statistically significant variables and develops a prediction model which yields an odds ratio, i.e., estimated before accidents to estimated after accidents. The complete analysis is documented in Appendix D. The key finding of the analysis was that treatment site (i.e., those converted to YIELD) displayed odds of greater than 1 for an increase in accidents and a relative odds of 2.5 (ratio of the odds of treatment to control sites). This can be interpreted to mean that, all other factors equal, the probability of an accident at the treatment site was 2.5 times that at the control site. The analysis also revealed that the interaction of major volume and year of conversion accounted for the difference. This means that the probability of an accident occurring at a treatment site was affected by the combination of the year of conversion and the major volume.

With regard to the expected novelty effect three out of a total of 69 accidents occurred within the first month (all at different locations), another two in the second month (different locations), and six in the third month (two at one location). One of the sites experienced three accidents within the first 3 months. This site was changed back to STOP control after the third accident. This site was unusual in a couple of aspects. A library was adjacent to this intersection; consequently, the neighborhood was very familiar with the intersection. Also, during conversion from STOP to YIELD control, the sign location was revised, forcing the major street traffic (uncontrolled traffic) to now YIELD. These factors, combined with driver expectancy violation, probably contributed heavily to the increase in accidents at this site.

Table 8 shows the distribution of accidents by severity type for both the conversion sites and the control sites. There were no fatalities. As seen, the ratio of injury to property damage only (PDO) accidents is nearly the same for the before and after for both groups. The minor differences are not statistically different. Hence, in Saginaw the same result has occurred, i.e., no increase in the severity of accidents when intersections are changed from STOP to YIELD.

Table 5. Average ADT volumes for conversion sites with increasing and without increasing accidents.

Sites	Average Major Volume	Average Minor Volume	Average Major + Minor Volumes	Average Major x Minor Volume
Increasing accidents from before to after	4,363	648	5,011	3.4×10^6
No change or decrease in accidents before to after	4,026	478	4,504	2.1×10^6

Table 6. Comparison of converted YIELDs to established YIELDs for Rapid City.

Site Type	Number of Sites	Average Major Volume (ADT)	Average Minor Volume (ADT)	Accidents/ Site/ Year	Accidents/ Million Vehicles
4-Leg					
Converted YIELD	8	4,509	575	0.94	0.54
Established YIELD	72	1,633	530	0.47	0.60
Established YIELD with major volume ≥2,000	28	3,312	680	0.46	0.32
T-Leg					
Converted YIELD	11	3,890	516	0.50	0.33
Established YIELD	51	2,392	428	0.26	0.27
Established YIELD with major volume ≥2,000	27	4,152	526	0.26	0.16

Table 7. Results of statistical analysis of comparison of converted to established YIELD.

Comparison Group	Variable	Statistical Significant Difference ($\alpha = 0.10$)
4-leg		
Converted YIELD/Established YIELD	Acc./Site	Yes[1]
	Major Volume	Yes[2]
	Minor Volume	No
Converted YIELD/Established YIELD with Major Volume ≥ 2,000 ADT	Acc/Site	No
	Major Volume	No
	Minor Volume	No
T-leg		
Converted YIELD/Established YIELD	Acc/Site	No
	Major Volume	Yes[3]
	Minor Volume	No
Converted YIELD/Established YIELD with major volume ≥2,000 ADT	Acc/Site	No
	Major Volume	No
	Minor Volume	No

[1] Computed t-statistic = 1.92, probability = 0.03

[2] Computed t-statistic = 4.35, probability = 0.00

[3] Computed t-statistic = 1.88, probability = 0.03

Table 8. Distribution of accidents by severity for Saginaw.

Severity Type	Conversion Sites Before	Conversion Sites After	Control Sites Before	Control Sites After
Fatal	0	0	0	0
Injury	7 (28%)	17 (24.6%)	37 (24.7%)	36 (25.5%)
PDO	18 (72%)	52 (74.4%)	113 (75.3%)	105 (74.5%)
Total	25 (100%)	69 (100%)	150 (100%)	141 (100%)

Table 9. Distribution of accidents by type for Saginaw conversion and control sites.

Type	Conversion Before	Conversion After	Control Before	Control After
Angle	17 (68%)	56 (81%)	87 (58%)	85 (60%)
Rear End	0	1 (1.4%)	5 (3.3%)	8 (5.7%)
Turning	0	1 (1.4%)	7 (4.7%)	6 (4.3%)
Sideswipe	0	2 (2.9%)	11 (7.3%)	10 (7.1%)
Fixed Object	2 (8%)	2 (2.9%)	16 (10.7%)	13 (9.2%)
Bicycle	1 (4%)	1 (1.4%)	6 (4%)	2 (1.4%)
Pedestrian	2 (8%)	0	3 (2%)	6 (4.3%)
Head on	1 (4%)	0	4 (2.7%)	3 (2.1%)
Other	2 (8%)	6 (8.7%)	11 (7.3%)	8 (5.7%)
TOTAL	25	69	150	141

Table 9 shows the distribution of accidents by accident type for both the converted and control sites. As expected, angle accidents predominate for both groups of intersections. The percentage of angle accidents increased from 68 to 81 percent for the converted sites, but this increase was found to be statistically insignificant. For the control sites the percent of angle accidents was nearly the same in the before and after period.

In the discussion of Rapid City sites, a comparison was made between converted YIELD sites and established YIELD sites that showed a significantly higher accident frequency for the converted sites. An identical analysis could not be done for Saginaw because data were not collected for established YIELD sites. The following comparison can be made of the average accident frequency of the converted YIELDs to all YIELDs:

Site Type	Accident Frequency
Saginaw Converted YIELD sites	0.66 accidents/year
Saginaw Total YIELD sites	0.55 accidents/year

A higher average accident per year per site is observed for the converted sites. It should be noted that approximately 15 percent of the YIELD sites in Saginaw are converted YIELDs.

Accident Experience at YIELD Control Intersections

A primary objective of this study was to gather additional information on accident experiences at YIELD control intersections, especially at the higher volume levels. Upchurch's (*2*) analysis relied on accident experience reported in *NCHRP Report 41* (*16*), which was believed to be unreliable because of small sample sizes. While the sites that were converted to YIELD control provided some data, it was necessary to augment these accident data from several other locations. Accordingly, accident and other geometric and volume data were collected for numerous YIELD control sites for the cities of Milwaukee, Seattle, Rapid City, and Madison. Each of these cities uses YIELD control for many of their lower volume intersections.

The data from these four cities were used to develop expected accident frequencies under different volume and geometric conditions for YIELD control intersections. These frequencies were then used to develop accident costs for the economic analysis.

Table 10 gives an overview of the accident data. Seattle showed the highest accident frequency and accident rate for four-leg intersections (0.92 accidents per site per year and 1.37 accidents per million vehicles, respectively). Rapid City had the highest accident frequency for T-leg intersections (0.26 accidents per site per year), while Milwaukee had the highest accident rate for T-leg intersections (0.61 accidents per million vehicles). All four locations showed higher frequencies and rates for four-leg intersections than for T-leg intersections. This agrees with findings from the literature review.

Table 10. Summary of data for established YIELD control sites.

Location/ Intersection Type	Number of Sites	Average Major Volume (ADT)	Average Minor Volume (ADT)	Accidents/ Site/ Year	Accidents/ Million Vehicles	Analysis Period
Milwaukee						
4-leg	169	839	733	0.65	1.13	1983-1986
T-leg	9	890	471	0.25	0.61	
	178	842	720	0.63	1.11	
Seattle						
4-leg	163	1,154	683	0.92	1.37	1983-1986
T-leg	9	1,490	208	0.03	0.05	
	172	1,172	658	0.87	1.31	
Rapid City						
4-leg	72	1,633	530	0.47	0.60	1985-1986
T-leg	51	2,392	428	0.26	0.27	
	123	1,948	488	0.38	0.44	
Madison						
4-leg	57	610	415	0.19	0.51	1983-1986
T-leg	11	716	393	0.05	0.15	
	68	627	411	0.17	0.46	
Totals						
4-leg	461	1,046	644	0.66	1.07	
T-leg	80	1,891	403	0.20	0.26	
	541	1,171	608	0.59	0.92	

Table 11 shows accident data for those intersections where the minor street volume was higher than the major street volume. For four-leg intersections the accident frequency is slightly higher (0.74 to 0.66) for these sites. The accident rate shows an even greater difference (1.36 to 1.07). (The sample size for T-leg intersections was too small to draw any reliable conclusions). This finding agrees with a 1964 study by Leisch and Barry (*15*).

Upchurch (*2*), in his economic analysis of STOP and YIELD control intersections, stated that "there was a reason to be skeptical of the *NCHRP Report 41* predicted accident rates for YIELD control." Therefore, expected accident rates were derived from the accident data obtained from Seattle, Milwaukee, Rapid City, and Madison. Various volume groups were established and the average accident frequencies for these groups were calculated. For volume groups with no sites, accident frequencies were interpolated from surrounding volume groups. Table 12 shows expected yearly accident frequencies for four-leg YIELD intersections with various volume combinations. The sample size (80 sites) was too small to generate a similar table for T-leg intersections.

Another analysis generated accident frequencies and rates using total intersection volume. The results are given in Table 13. This table shows that accident frequency increases and accident rate decreases with increasing volumes.

In comparing these expected accident frequencies to those obtained from *NCHRP Report 41* by Upchurch for four-leg YIELD intersections, one sees below that the *NCHRP Report 41* numbers are quite higher than the frequencies developed in this study:

Major Street Volume/ Minor Street Volume (ADT)	Accidents Per Year By: NCHRP 17-7	NCHRP 41
1,000/1,000	1.00	1.77
2,000/1,000	1.19	1.75
3,000/1,000	1.29	1.73

It is also observed that the *NCHRP Report 41* frequencies decrease rather than increase with an increase in major street volume, which is contrary to that found in this study.

Tables 14 and 15 show accident severity distribution and distribution of accidents by type, respectively. Of the two fatal accidents, one occurred at a very high volume intersection (major street ADT of 6,864, minor street ADT of 2,500). The other fatal accident occurred at an average volume intersection (major ADT of 850, minor ADT of 380).

The accident frequencies developed in this study for YIELD control intersections seem reasonable: an increase in volume leads to an increase in accident frequency. Therefore, these frequencies (instead of *NCHRP Report 41* numbers) were used in calculating accident costs for the economic analysis.

Table 12. Expected yearly accidents at 4-leg YIELD control intersections.

Major Street Volume (ADT)	Minor Street Volume (ADT) ≤201	201-400	401-600	601-800	801-1000	1001-1500	>1500
>3,000	0.56	0.79	1.01	1.22	1.33	1.40	1.50
2,001-3,000	0.50	0.75	0.98	1.19	1.29	1.36	1.45
1,501-2,000	0.43	0.69	0.92	1.13	1.15	1.28	1.24
1,001-1,500	0.36	0.65	0.80	0.93	1.05	1.24	1.29
501-1,000	0.33	0.55	0.70	0.83	0.95	1.09	1.14
<501	0 .28	0.42	0.55	0.69	0.85	0.94	1.00

Table 11. Summary data for sites with minor street volume > major street volume.

Location/ Intersection Type	Number of Sites	Average Major Volume (ADT)	Average Minor Volume (ADT)	Accidents/ Site/ Year	Accidents/ Million Vehicles
Milwaukee					
4-leg	73	536	952	0.63	1.16
T-leg	2	425	545	0	0
	75	533	941	0.61	1.14
Seattle					
4-leg	44	636	1,017	1.05	1.74
T-leg	0	--	--	--	--
	44	636	1,017	1.05	1.74
Rapid City					
4-leg	16	325	606	0.63	1.85
T-leg	5	290	623	0.10	0.46
	21	317	610	0.50	1.61
Madison					
4-leg	8	255	1,404	0.22	0.36
T-leg	2	425	750	0	0.00
	10	289	1,273	0.18	0.33
Totals					
4-leg	141	527	959	0.74	1.36
T-leg	9	350	634	0.06	0.25
	150	516	940	0.70	1.34

ECONOMIC ANALYSIS

This task involved obtaining and updating results from previous studies of user costs and benefits related to STOP and YIELD control. Upchurch's (*2*) procedure, being the most recent study, was selected and his user delay, vehicle operating and pollution costs were updated to 1988 values. Because of the low sample sizes that were used in generating accident frequencies

Table 13. Accident analysis for YIELD control intersections.

Intersection Volume (ADT)	Geometry	Average Intersection Volume (ADT)	Number of Sites	Accidents/ Site/ Year	Accidents/ Million Vehicles
<1,001	4-leg	679	148	0.37	1.48
	T-leg	524	35	0.12	0.63
1,000-3,000	4-leg	1,708	263	0.76	1.22
	T-leg	1,816	24	0.29	0.44
>3,000	4-leg	4,594	50	1.00	0.60
	T-leg	5,030	21	0.26	0.14

in *NCHRP Report 41,* the accident data collected during this study were used to obtain accident costs.

Upchurch divided the "total cost of operation" into five categories: fuel costs, other vehicle operating costs, delay costs, air pollution costs, and accident costs.

Table 14. Distribution of accidents by severity for YIELD control sites.

Location	Number of Intersections	Accidents Fatal	Accidents Injury	Accidents PDO
Milwaukee				
4-leg	169	1 (0.2)	154 (35.2)	282 (64.5)
T-leg	9	0 (0)	2 (22.2)	7 (77.8)
	178	1 (0.2)	156 (35.0)	289 (64.8)
Seattle				
4-leg	163	0 (0)	210 (35.0)	390 (65.0)
T-leg	9	0 (0)	0 (0)	1 (100)
	172	0 (0)	210 (34.9)	391 (65.1)
Rapid City				
4-leg	72	1 (1.5)	21 (30.9)	46 (67.6)
T-leg	51	0 (0)	9 (33.3)	18 (66.7)
	123	1 (1.0)	30 (31.6)	64 (65.1)
Madison				
4-leg	57	0 (0)	12 (27.9)	31 (72.1)
T-leg	11	0 (0)	1 (50.0)	1 (50.0)
	68	0 (0)	13 (28.9)	32 (71.1)
Totals				
4-leg	461	2 (0.2)	397 (34.6)	749 (65.2)
T-leg	80	0 (0)	12 (30.8)	27 (69.2)
	541	2 (0.2)	409 (34.5)	776 (65.4)

Note: ( ) = %

Fuel costs were updated by using a 1988 average gasoline price of $1.12 per gallon obtained from the American Automobile Association (AAA) and by using revised fuel economy ratings and updated fleet model distribution obtained from the Motor Vehicle Manufacturers Association. Other vehicle operating costs, delay costs, and air pollution costs were updated by using the August 1988 Consumer Price Index.

Accident costs were updated by using the developed accident frequencies and the values from FHWA's *Technical Advisory T-7570.1* (June 30, 1988). These values are: $1,700,000 for a fatal accident, $14,000 for an injury accident, and $3,000 for a property damage only accident. These costs, when applied to the observed severity distribution, yield an average accident cost of $10,764.

Again, because of the low sample size (and very high predicted accident frequencies) used in *NCHRP Report 41* to estimate accident frequencies at four-leg, two-way STOP control intersections, new frequencies were developed using data collected from Saginaw, Rapid City, and Pueblo with the same procedure that was used in developing accident frequencies for YIELD control intersections. These are shown in Table 16. Table 17 gives accident frequencies and rates based on total intersection volume. The accident frequencies and the accident rates both increase with an increase in volume. These data come from a small sample size of 45, but the accident frequencies seem more reasonable than those from *NCHRP Report 41:*

Major Street Volume/ Minor Street Volume	Accidents Per Year NCHRP 17-7	Accidents Per Year NCHRP 41
1,000/1,000	0.46	10.11
2,000/1,000	0.74	10.17
3,000/1,000	1.29	9.13

Table 15. Distribution of accidents by type for YIELD control sites.

Location	Angle	Turning	Fixed Object	Sideswipe	Rearend	Bike	Other
Milwauke							
4-leg	361 (82.6)	19 (4.3)	7 (1.6)	4 (0.9)	3 (0.7)	7 (1.6)	36 (8.2)
T-leg	8 (88.9)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1(11.1)
	369 (82.7)	19 (4.3)	7 (1.6)	4 (0.9)	3 (0.7)	7 (1.6)	37 (8.3)
Seattle							
4-leg	579 (96.5)	0 (0)	0 (0)	6 (1.0)	0 (0)	8 (1.3)	7 (1.2)
T-leg	0 (0)	0 (0)	1 (100)	0 (0)	0 (0)	0 (0)	0 (0)
	579 (96.3)	0 (0)	1 (0.1)	6 (1.0)	0 (0)	8 (1.3)	7 (1.2)
Rapid City							
4-leg	42 (61.8)	6 (8.8)	5 (7.4)	2 (2.9)	2 (2.9)	0 (0)	11 (16.2)
T-leg	3 (11.1)	1 (3.7)	9 (33.3)	3(11.1)	3(11.1)	1 (3.7)	7 (25.9)
	45 (47.4)	7 (7.4)	14 (14.7)	5 (5.3)	5 (5.3)	1 (1.1)	18 (18.9)
Madison							
4-leg	39 (90.7)	1 (2.33)	0 (0)	0 (0)	1 (2.3)	0 (0)	2 (4.7)
T-leg	2 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	41 (91.1)	1 (2.22)	0 (0)	0 (0)	1 (2.2)	0 (0)	2 (4.4)
Totals							
4-leg	1,021 (88.9)	26 (2.3)	12 (1.1)	12 (1.1)	6 (0.5)	15 (1.3)	56 (4.9)
T-leg	13 (33.3)	1 (2.6)	10(25.6)	3 (7.7)	3 (7.7)	1 (2.6)	8(20.5)
	1,034 (87.1)	27 (2.3)	22 (1.8)	15 (1.3)	9 (0.8)	16 (1.3)	64 (5.4)

Note: ( ) = %

Table 16. Expected yearly accidents at 4-leg, 2-way STOP control intersections.

Major Street Volume (ADT)	Minor Street Volume (ADT) >201	201-400	401-600	601-800	801-1,000	1,001-1,500	>1,500
>3,000	0.54	0.71	0.91	1.12	1.17	1.23	1.33
2,001-3,000	0.48	0.57	0.68	0.78	0.89	1.04	1.10
1,501-2,000	0.38	0.50	0.58	0.66	0.74	0.83	0.89
1,001-1,500	0.30	0.35	0.39	0.43	0.51	0.68	0.75
501-1,000	0.20	0.28	0.34	0.40	0.46	1.55	0.61
<501	0.05	0.14	0.21	0.28	0.35	0.42	0.53

Table 17. Accident analysis for 4-leg STOP control intersections.

Intersection Volume (ADT)	Average Intersection Volume (ADT)	Number of Sites	Accidents/ Site/ Year	Accidents/ Million Vehicles
<1,001	915	10	0.10	0.29
1,001-3,000	1,809	32	0.45	0.68
>3,000	3,440	3	0.33	0.26

Table 18. Daily cost of operation, in dollars, assuming low value of time.

Major Street Volume (ADT)	Intersection Type	Minor Street Volume (ADT) 1,000	2,000
4,000	Yield	381	466
	Stop	411	529
3,000	Yield	312	395
	Stop	335	454
2,000	Yield	240	324
	Stop	265	382
1,000	Yield	168	
	Stop	191	

Table 19. Daily cost of operation, in dollars assuming medium value of time.

Major Street Volume (ADT)	Intersection Type	Minor Street Volume (ADT) 1,000	2,000
4,000	Yield	389	479
	Stop	431	566
3,000	Yield	318	405
	Stop	354	490
2,000	Yield	246	332
	Stop	282	417
1,000	Yield	172	
	Stop	208	

Table 20. Daily cost of operation, in dollars, assuming high value of time.

Major Street Volume (ADT)	Intersection Type	Minor Street Volume (ADT) 1,000	2,000
4,000	Yield	400	495
	Stop	458	616
3,000	Yield	326	418
	Stop	378	537
2,000	Yield	252	343
	Stop	305	462
1,000	Yield	178	
	Stop	231	

Table 21. Increase in accidents (YIELD control over STOP control) necessary to equalize daily costs of operation assuming low value of time.

Major Street Volume (ADT)	Minor Street Volume (ADT) 1,000	2,000	3,000	4,000	5,000
9,000	1.09	2.17	3.36	4.54	5.87
8,000	1.12	2.34	3.42	4.68	6.04
7,000	1.12	2.34	3.42	4.85	6.07
6,000	1.19	2.41	3.80	4.85	6.24
5,000	1.22	2.24	3.63	4.92	6.24
4,000	1.22	2.31	3.63	4.92	
3,000	1.22	2.34	3.66		
2,000	1.22	2.34			
1,000	1.22				

After updating each of the five cost components they were summed to give a daily cost of operation. Three tables showing the differences in daily costs between STOP and YIELD were developed. Tables 18, 19, and 20 show costs reflecting a low time value ($1.49/hour), a medium time value ($6.71/hour), and a high time ($13.60/hour) value, respectively. These time values are 1988 updates, based on the Consumer Price Index, from those used by Upchurch. The three tables show that for all volume combinations, YIELD is more cost effective than STOP control. (Because the collected accident data were for a limited range of volumes, only major street volumes less than 4,001 and minor street volumes less than 2,001 were used in calculating total costs.) Tables 21, 22, and 23 show how many more accidents per year a YIELD intersection would have to experience than a STOP intersection to equalize the daily costs; in other words, if an intersection is converted from STOP to YIELD control because YIELD control is more cost effective, what is the accident increase that would negate the cost effectiveness of the conversion to YIELD control?

Table 22. Increase in accidents (YIELD control over STOP control) necessary to equalize daily costs of operation assuming medium value of time.

Major Street Volume (ADT)	Minor Street Volume (ADT) 1,000	2,000	3,000	4,000	5,000
9,000	1.53	3.05	4.81	6.88	9.39
8,000	1.53	3.15	4.91	7.12	9.69
7,000	1.53	3.22	4.91	7.29	9.56
6,000	1.59	3.28	5.22	7.32	9.86
5,000	1.53	3.11	5.15	7.35	9.80
4,000	1.56	3.11	5.15	7.29	
3,000	1.59	3.22	5.15		
2,000	1.59	3.32			
1,000	1.70				

Table 23. Increase in accidents (YIELD control over STOP control) necessary to equalize daily costs of operation assuming high value of time.

Major Street Volume (ADT)	Minor Street Volume (ADT) 1,000	2,000	3,000	4,000	5,000
9,000	2.03	4.20	6.78	9.96	14.10
8,000	2.00	4.30	6.91	10.27	14.51
7,000	2.00	4.37	6.95	10.54	14.24
6,000	2.06	4.47	7.25	10.61	14.58
5,000	2.00	4.23	7.12	10.57	14.47
4,000	2.10	4.27	7.22	10.51	
3,000	2.13	4.37	7.15		
2,000	2.17	4.47			
1,000	2.27				

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATION

This chapter interprets the findings presented in Chapter Two so that they can be used for application of YIELD signs and, specifically, conversion from STOP to YIELD control. Towards this end several basic issues are discussed.

SAFETY IMPLICATIONS OF CONVERTING STOP CONTROL TO YIELD CONTROL

The accident analysis conducted in this study and the findings from the literature are interpreted as follows.

1. In general, accidents are more likely to increase at locations where STOP control is converted to YIELD control. The evidence, albeit not overwhelming, is: (a) While no statistical difference was found for Pueblo and Rapid City, a statistically significant increase in accidents was observed for Saginaw, which had the largest data base. (b) Results of other studies (*3, 10*) have found that at some intersections accidents increase after converting from STOP control to YIELD control, particularly at higher volume intersections.

2. As expected, the probability of an increase in accidents is greater with higher volumes. Higher increases in accidents were observed in Saginaw for higher volumes, either major street, minor street, or the sum of major and minor street volumes, as shown in Table 24. The highest increase in accidents occurred at these ADT volumes: (a) major street volume > 1,500, (b) minor street volume > 600, and (c) major + minor street volume > 1,800.

3. Accident severity, i.e., the proportion of fatal or injury accidents, does not appear to increase with conversion of STOP to YIELD control.

4. The distribution of accident types does not appear to change significantly with conversion of STOP to YIELD control. While accidents with bicyclists and pedestrians were in the "after" data base, the sample sizes are not adequate to conclude that these types of accidents will occur with higher frequency upon conversion to YIELD control.

5. Regardless of the number of accidents occurring before conversion from STOP control to YIELD control, an accident increase of approximately one accident over 2 years can be expected at a site after conversion. This is interpreted from the Saginaw and Rapid City data as shown below:

Table 24. Accident increase by volume group for Saginaw conversions.

Approach	Volume Group (ADT)	Number of Sites	Average Accidents Per Site for a 2-year period Before	2-year After	Increase
Major Street	<501	3	0.00	0.00	0
	501-750	17	0.41	0.94	0.53
	751-1,000	17	0.47	1.35	0.88
	1,001-1,500	4	·1.25	2.00	0.75
	1,501-2,000	5	0.40	2.40	2.00
Minor Street	<301	13	0.15	0.69	0.54
	301-600	25	0.52	1.16	0.64
	601-1,000	8	0.88	2.62	1.74
Major Street Plus Minor Street	<1,001	16	0.38	0.75	0.37
	1,001-1,400	13	0.15	0.85	0.70
	1,401-1,800	10	1.20	2.10	0.90
	1,801-2,300	7	0.29	2.14	1.85

Number of sites	Accident frequency for a 2-year period Before conversion	After conversion
42	0	1.00
15	1	1.73
5	2	3.00

6. Situations that are particularly hazardous for conversion are: (a) intersections where the controlled approach has the higher volume, and (b) intersections where the YIELD sign is placed on the originally uncontrolled approach.
7. The accident frequency of a converted YIELD site is higher for the 2-year after period than the accident frequency of an established or existing YIELD site, as shown in Table 25. There were insufficient data to establish conclusively whether or not the accident rate of converted sites would reduce to the level of existing YIELD sites over a long period of time.

Table 25. Summary comparison of converted YIELDs to established YIELDs.

Location	Site Type	Average Accidents/Site/Year
Saginaw	Converted YIELDs	0.66
	Existing YIELDs	0.55
Rapid City	Converted YIELDs	0.68
	Established YIELDs	0.38
Madison, Milwaukee, Rapid City, Seattle	Established YIELDs	0.59

COST EFFECTIVENESS IMPLICATIONS OF CONVERTING STOP CONTROL TO YIELD CONTROL

Overall, for all conditions studied, YIELD control was more cost effective than STOP control. Even assuming the lowest value of time for the motorist ($1.49 per hour) and the lowest volume levels (the most conservative scenario), YIELD control was found to be cost effective over STOP control. A YIELD control site would need to experience more than one accident per year more than the STOP control site to offset the benefits derived from the reduction in user costs and vehicle operating costs.

It should be realized, however, that most of the potential conversion site locations are in residential areas. When looking at an individual vehicle trip, through one or possibly two YIELD control intersections, the average time and operating cost savings will be very small and insignificant compared to the total trip costs. Hence, the potential decrease in safety may have a greater effect on the decision to convert from STOP control to YIELD control. It should also be realized that many vehicles do not come to a complete stop at STOP signs, and since the Texas Model for Intersection Traffic, which provided the vehicle delay values, assumes full compliance, the actual difference in cost effectiveness between STOP and YIELD control could be less than the calculated difference. Therefore, decision-making on the converting to YIELD signs based solely on cost-effectiveness may be inappropriate.

GUIDELINES FOR CONVERSION FROM STOP CONTROL TO YIELD CONTROL

The results of this study as well as the literature indicate that there are many locations where conversion to YIELD control would be both cost effective and safe. There are three factors, sight distance, volume, and accidents, which should be considered in the use or nonuse of the YIELD sign for intersection control. Each of these is discussed with regard to results of this study and findings of previous research.

Sight Distance

The sight distance of concern is the corner sight triangle. To date, the concept of Critical or Safe Approach Speed has been used to determine the appropriate vehicle right-of-way control at an intersection. The critical approach speed is the threshold speed above which a vehicle approaching an intersection would not be able to react to a vehicle on another approach in time to avoid a possible accident. A method for determining the critical approach speed is presented in Appendix C. Another discussion of it is found in *Fundamentals of Traffic Engineering* (*33*).

As discussed in Chapter Two, different values of critical approach speed have been proposed and adapted by various agencies. The MUTCD states that YIELD signs can be used if the safe approach speed exceeds 10 mph. Stockton et al. (*4*) suggested that this value may be overly conservative, but they still recommended adherence to it.

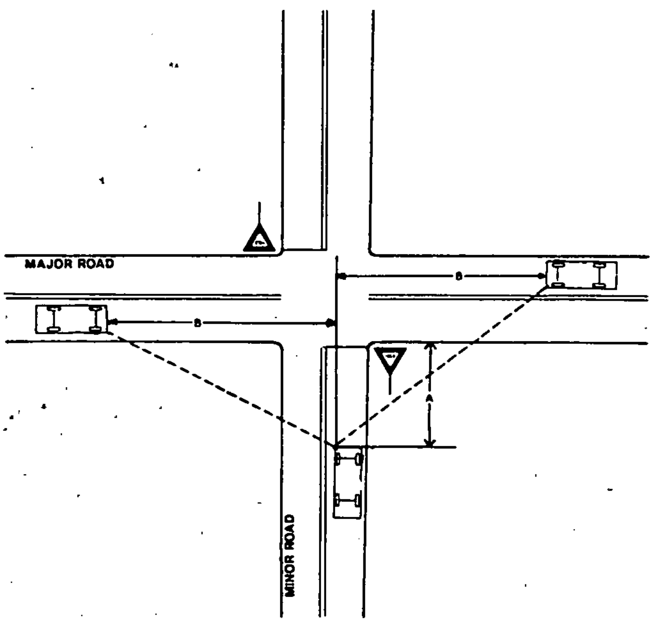
Because the data collected in this study did not include actual sight distance, this research was unable to develop any relationship between sight distance and accident frequency and, therefore, has no better value to recommend. However, what is suggested is a revised sight distance standard based on the principle that the driver on the minor street should be able to see across the two corners any approaching vehicle at a sufficient distance that would allow the driver to come to a stop if necessary. This principle is consistent with the at-grade intersection sight distance for "Case II-YIELD Control on Secondary Roads" as stipulated in AASHTO's *A Policy on Geometric Design of Highways and Streets* (*34*). In that manual it states on page 779:

> . . . The sight distance for the vehicle operator on the minor road must be sufficient to allow the operator to observe a vehicle on the major roadway, approaching from either the left or right, and then through perception, reaction and braking time, bring the vehicle to a stop prior to reaching the intersecting roadway. . . .

Table 26 provides a matrix of minimum sight distances along the major street that a driver must be able to see from a prescribed point on the minor approach to be able to come to a stop for a vehicle on the major street. These are rounded-off values determined as follows: (1) The "minor road distances" are based on AASHTO (*34*) stopping sight distances. A 2.5 sec perception-reaction time is used because it is the value used for stopping sight distance design criteria and because it was determined to be appropriate through field research by Hostetter et al. (*35*). (2) The sight distances along the major road are determined by multiplying the major street speed by the time it takes for the minor road vehicle to come to a stop. This time is equal to perception-reaction time (2.5 sec) plus the time to decelerate from the operating speed to zero at a deceleration rate of 16 fpsps.

Table 26. Minimum corner sight triangle for YIELD sign control use.

Minor Road Speed (mph)	Minor Road Distance, "A", (ft)	Sight Distance "B" In Feet Along Major Road for Speed of: 25	30	35	40	45 (mph)	50	55	60	65
10	45	130	155	180	205	230	255	280	305	330
15	75	145	175	200	230	260	285	315	345	375
20	110	160	195	225	255	290	320	355	385	415
25	150	180	215	250	285	320	355	390	425	460
30	200	-	235	270	310	350	390	425	465	505
35	250	-	-	295	340	380	420	465	505	550
40	315	-	-	-	365	410	455	500	545	590
45	385	-	-	-	-	440	490	540	585	635
50	465	-	-	-	-	-	525	575	630	680



These values could be used for a field inspection to determine if there is sufficient corner sight triangle to permit a YIELD sign control. In the case of the minor road the distance (column 2) is from the nearside curb or extension of the major street edge of the roadway to the driver's position. It would represent the location on the minor road where the field inspector should check to determine if there is sufficient sight line across the intersection. For example, for a minor street with a speed of 25 mph and a major street with a speed of 40 mph, the inspector should position himself 150 ft from the intersection and establish if a vehicle on the major street can be seen 285 ft from the intersection. If he can see that far, the YIELD sign would be acceptable from the sight distance viewpoint. If not, a STOP sign should be used.

Since YIELD control is most likely to be used for residential streets that usually have a speed limit of 25 mph, the values of required sight distance for 25 mph are those most often to be used. In using Table 26, it should be understood that the speeds for both the minor and major roads are operating speed. Hence, for example, if the speed limit on both roads was 25 mph, a conservative approach would be to assume at least a 5-mph faster speed in selecting the speeds for the table. On the other hand, a lower speed for the minor road could be used if it is assumed that motorists will reduce their approach speed upon seeing the YIELD sign.

Volume

The literature review did not identify any consensus as to the volume levels either for the minor road, major road or combination, where YIELD control would be the most appropriate. In the most recent study, that by Stockton et al. (*4*), it is recommended that YIELD signs be used if there is adequate sight distance at intersections with minor roadway volumes greater than 300 vehicles per day, and if no more than three accidents involving minor roadway vehicles have occurred within the last 3 years.

For this study the Saginaw analysis provided the best data and volume/accident relationship to support a recommendation for appropriate volume levels. Figure 3 displays the suggested volume levels where YIELD control would provide an acceptable level of safety. These values were derived from conversion sites in Saginaw that experienced an accident increase of less than one accident over the 2-year period after conversion.

Accidents

This and other studies, e.g., Stockton et al. (*4*), have conducted cost-benefit analyses trading off the monetary value of accident increase against the value of delay and vehicle operating costs saved under YIELD control. However, this may not be appropriate in deciding whether YIELD or STOP control should be used. A fairly high number of accidents can occur before the scales tip to the favor of STOP control. Hence, in establishing guidelines for use of a YIELD sign, an acceptable level of safety should be the criterion.

The sites analyzed in this study were fairly low accident sites, i.e., none of the sites experienced more than three accidents in the 2-year period before conversion to YIELD control. Because the sites with higher before accidents did not show a greater accident increase than the sites with lower before accidents, the following guideline is suggested: Sites experiencing no more than three accidents during the last 2 years may be potential YIELD conversion candidates.

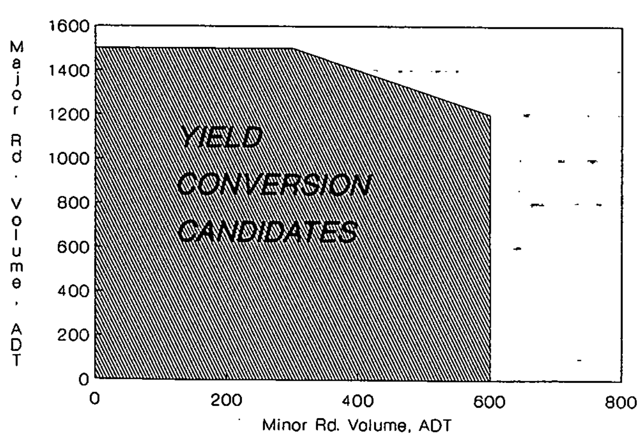


Figure 3. Suggested volume levels for YIELD *control.*

SUGGESTED REVISIONS TO THE MUTCD

A stated objective of the project was to suggest wording for improved STOP and YIELD control warrants for potential inclusion in the MUTCD. These suggestions are provided, as follows, for each control type.

STOP Sign Warrants

Based on the results of this study and the findings and recommendations from previous studies it is recommended that Section 2B-5, "Warrants for STOP Sign," of the MUTCD be revised as follows:

1. **Replace warrant number 1 with the following: "Intersection of a less important road with a main road where one or more of the following conditions exist:**
   a. **The sight distance at any quadrant is insufficient to permit a YIELD sign control.**
   b. **The volume levels exceed those which would permit a YIELD sign control.**

YIELD Sign Warrants

For Section 2B-8, "Warrants for YIELD Signs," in the MUTCD, it is recommended that the first warrant be changed to the following:

1. **On the minor approach(es) of intersection where the corner sight triangle meets or exceeds the values shown in the following Table 2B-1** [Table 26 in this report] **and one or more of the following conditions exist:**
   a. **Volumes are less than 1,500 vehicles per day on the major road or less than 600 vehicles per day on the minor road, or**
   b. **No more than two accidents involving minor roadway vehicles have occurred within the last three years.**

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The objectives of this project were to determine (1) the accident change that might occur if STOP-controlled intersections were changed to YIELD control, (2) which control is more cost effective and under what conditions, and (3) guidelines for conversion of STOP control to YIELD control. From the findings of the various analyses the following conclusions related to these objectives are drawn:

1. When intersection control is converted from STOP to YIELD an increase in accident frequency can be expected, especially where the volumes are on the order of 1,800 ADT total, 1,500 ADT for the major road and 600 ADT for the minor road. However, an increase in the severity of the accidents is not likely to occur. The amount of accident increase is about one accident every 2 years assuming the volume remains stable.

2. Even with the anticipated increase in accidents YIELD control is more cost-effective than STOP control. This statement applies to intersections that experience no more than three accidents per year. This is because it takes several accidents to overcome the accrued benefits of reduced motorist delay and vehicle operating costs.

3. Cost effectiveness should not be the sole criterion for deciding whether or not to convert from STOP to YIELD control. The savings in delay, fuel, and other vehicle operating costs for a given trip are insignificant and probably imperceptible to the motorist.

4. While certain low-volume intersections can be converted safely, engineers should be cautious in deciding to convert existing intersections because of the possibility of increased accidents. However, more use of YIELD control is recommended at new intersections which have adequate corner sight distance and volume levels noted above.

SUGGESTED RESEARCH

When analyzing accidents at low volume intersections large sample sizes are required to detect statistical differences with a high level of confidence. While this study included all the conversions that could be identified, continued increases to the data base would add to the confidence of the findings and conclusions. Consequently, concerned agencies should identify further conversions and acquire additional data.

The issue of using STOP versus YIELD for appropriate volume intersections is intertwined with the issue of motorist compliance to these devices. A high level of noncompliance to STOP signs has been observed by others. Increased use of YIELD control, at the STOP control locations, may improve compliance at these locations. This premise should be examined through appropriate research.

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APPENDIX A—LITERATURE REVIEW

The focus of the literature review was on the following areas:

1. The history of YIELD sign usage in order to develop an understanding of the events and thinking that influenced the development of the use of YIELD control and the development of the warrants for their use.

2. Studies determining operational characteristics to STOP and of YIELD controls and studies involving STOP to YIELD conversions.

3. Proposed and accepted warrants for using YIELD control or for converting STOP to YIELD control.

Five important reports were used as primary sources of background information:

1. "Stop, Yield and No Control at Intersections", by Stockton and Mounce (4)*

2. "Development of an Improved Warrant for Use of Stop and Yield Control at Four-Legged Intersections", by Upchurch (2)

3. "A Review of Research Related to the Safety of STOP Versus YIELD Sign Traffic Control", by Rosenbaum, (3)

4. "Re-evaluation of Traffic Control at Non-Signalized Intersections", by Carter and Malhortra (7)

5. "Chapter 5 - Intersections" from *Synthesis of Safety Research Related to Traffic Control and Roadway Elements, Vol. 1.* (8)

All these reports contain historical information and extensive reviews of existing literature concerning YIELD control and related subjects. Literature searches using the Transportation and Highway Research Information Services did not lead to any documents that were not reported in at least one of the above reports.

HISTORY OF YIELD CONTROL

The 1968 *Uniform Vehicle Code* (Revised 1979) *(UVC)* (9) defines the responsibilities of the driver approaching a YIELD sign as:

> ". . . After slowing or stopping, the driver shall yield the right of way to any vehicle in the intersection or approaching on another roadway so closely as to constitute an immediate hazard during the time such driver is moving across or within the intersection . . ."

The only difference between this definition of responsibilities and the *UVC's* definition of responsibilities of the driver approaching a STOP sign is that "After having

* See Reference Section

stopped" replaces "After slowing or stopping" in the YIELD definition. The assignment of right-of-way and the responsibilities of the driver are the same for both STOP control and YIELD control intersections.

The intent of the application of YIELD control was to provide for the definition of right-of-way and to act as an intermediate form of control between normal right-of-way under no sign control and STOP sign control. According to Kell (10) "... one of the main objectives in the development of the YIELD sign was to provide a less restrictive device which could replace many of the unwarranted STOP signs presently installed and thereby attempt to regain motorists' respect for STOP signs in general."

YIELD control was first introduced in Tulsa, Oklahoma in 1951. The YIELD sign used at the time was keystone shaped with black letters on a yellow background and read "YIELD RIGHT OF WAY".

YIELD signs did not appear in the *MUTCD* until its 1954 revision and at that time was "still to be regarded as experimental." (11) The *MUTCD* stated that the sign could be used where normal right-of-way rule must be modified for safety and efficiency and use of the standard STOP sign would be unduly restrictive. The sign design was an inverted equilateral triangle and read "YIELD RIGHT OF WAY" (black letters on yellow background).

In the 1961 *MUTCD*, YIELD control became an accepted practice and the first recommended YIELD warrants were introduced (see Section III-C "Warrants and Recommendations on YIELD Usage"). The wording on the sign was changed to the single word "YIELD" (still with black letters on a yellow background).

In 1965, Lloyd Meader, Chief Traffic Engineer for New York State, argued for the use of red, rather than yellow YIELD signs, in his formal request to the Federal Highway Administration. New York had experimented with red signs and believed them to be superior to yellow signs. (12)

The 1971 *MUTCD* changed the color design of the YIELD from yellow to red adapted from the international symbol for "give way". The 1961 *MUTCD* YIELD warrants have continued through the 1978 *MUTCD* and subsequent revisions with only minor wording changes.

YIELD AND RELATED STUDIES

In the early 1950's, the most frequent application of YIELD signs was at previously uncontrolled intersections as an alternative to STOP control. (5, 10, 13) Kell reported on successful applications of YIELD control experienced in Berkley, CA; Seattle, WA; San Diego, CA; and Napa, CA (5, 10). The Napa study reported on 17 conversions from STOP control to YIELD control. In the study only one intersection was observed to have a large increase in accidents. However, after foliage was trimmed from around the intersection, the frequency of accidents improved.

In contrast to this successful conversion to YIELD control, Kell (5) found that accidents (in particular, right angle accidents) increased dramatically at 13 relatively high volume intersections in Berkley where STOP control had been converted to YIELD control. The average daily major and minor roadway volumes at these locations were 5,000 and 2,500 respectively.

In 1953, the use of YIELD signs in four cities (Dallas, Oklahoma City, Portland and Tulsa) was reported. (14) At most of these intersections, of which many were converted intersections from STOP to YIELD, the operational and accident experience was reported to have improved.

An unsuccessful experiment with conversion of YIELD control from STOP control was reported in San Francisco in 1953 where 13 of 15 showed large increases in the frequency of accidents. The increase was attributed as possibly the result of "inadequate publicity and high minor street volumes". (3)

In 1964, a study (15) of the safety of STOP and YIELD signs reported that, for uncontrolled intersections, the introduction of YIELD control resulted in major temporary decreases in the annual accident rate. For 1 to 2 years after installation, the rates were then found to rise to a level which was still below that of the "before" or uncontrolled condition. Also concluded was that more accidents are likely to occur at intersections where the YIELD signs control the major approach than where the YIELD controls the minor approach.

In 1967, Leisch et al. presented procedures in *NCHRP Report 41* (16) to "aid engineers in the selection of the proper type of intersection control". The procedures allowed for the estimation of vehicle delay and intersection accident rates for intersections controlled by YIELD, two-way STOP and four-way STOP signs. The data for which the procedures were based came from 71 intersections located in four metropolitan areas.

A study (17) examining accident rates for rural Kentucky highways (for the years 1970-1972) showed that the types of accidents occurring at STOP control intersections were 52 percent angle collisions and 30 percent rear end or same direction sideswipe accidents while the types of accidents occurring at YIELD control intersections were 23 percent angle collisions and 56 percent rear end or same direction sideswipe accidents. Additionally, the severity index under STOP control (2.70) was found to be much higher than under YIELD control (2.03).

In 1977, Walton et al., (18) reported on guidelines for the signing of rural intersections with roadway volumes of less than 400 vehicles per day. The cost effective analysis observed that for a combined volume of up to 200 vehicles per day, the expected annual accident and operating cost associated with no control was less than the accident and operating cost with two-way STOP control. The guidelines were based on a theoretical relationship derived from "probability of conflict" analysis.

In 1976, 53 intersections (no control, YIELD and STOP) on low volume roads in Indiana were evaluated as to safety, compliance, and efficiency. Bandyopadhyay (19) concluded that:

- Accident records showed no significant difference in the occurrence of accidents at STOP, YIELD, and uncontrolled intersection.
- At the STOP controlled intersections 31 percent of the vehicles did not come to a stop.
- Annual savings of $16,550 in operating cost and 3,320 vehicle hours of travel time could be realized in West Lafayette, IN, if 80 percent of the signed low volume intersections were changed to a less restrictive form of control.

Expanding on the work of Bandyopadhyay, Hall, in a 1977 report (20), conducted a benefit-cost analysis of STOP, YIELD, and no control at low volume intersections. Using gasoline costs, other vehicle operating costs, delay costs, and accident costs as primary considerations, the analysis showed that YIELD sign control was the most efficient control for volumes greater than 200 vehicles per day (vpd) and that no control was most efficient below 200 vpd.

In an NCHRP project, Glennon (21) performed a benefit-cost analysis in an evaluation of STOP control versus no control. He concluded that, unless there were special problems, such as with sight distance or with right-of-way designations, STOP control could not be justified for two intersecting low-volume (i.e., less than 400 ADT) rural roads.

FHWA sponsored a study (4) which reported on 140 urban and rural low volume intersections in Florida, New York, and Texas to determine the relative operating and safety characteristics associated with two-way STOP, YIELD, and no control intersections. For the purposes of the study, low volume intersections were considered as those non-signalized intersections in which the minor roadway volumes was less than 500 vehicles per day (vpd). Major roadway volumes ranged up to 10,000 vpd. Utilizing data collection in field studies, Stockton et al., in the benefit-cost analysis, showed that in no case was conversion to STOP control cost effective and that conversions to YIELD control were always cost effective. Other significant findings from the study include:

- Control type has no appreciable effect on accident experience at low volume intersections.
- Travel time is significantly affected by signing, with STOP control producing the longest travel time and YIELD control the shortest.
- Geometry (three-leg and four-leg) does not play a major role in either safety or operation of low volume intersections.
- Sight distance has no discernible effect on either safety or operations at low volume intersections.
- The percentage of intersections experiencing accidents increases significantly at 2,000 vpd and again at 4,000 vpd (regardless of control type). Travel time increases significantly at 2,000 vpd, primarily due to increased forced stop rate.

In contrast to the study's findings regarding geometry, the report's literature review gave the following account of four studies comparing four-leg intersections with three-leg intersections:

> "In a California study of 660 intersections, Marks (22) reported that uncontrolled four-leg intersections exhibited 14 times the accident frequency of uncontrolled three-legs in limited access subdivisions and 41 times that of three-legs in gridiron subdivisions. A Minnesota study (23) showed that the geometric advantage of the three-leg intersection with respect to accident rate was more pronounced at high volume locations.
>
> Four-leg intersections were found to experience four times the frequency of T- and Y-types in a study on Indiana County roads (24). A detailed study of two-lane rural roads by Raff (25) showed that three-leg intersections had lower accident rates than four-leg."

In a 1981 report on a behavior study, Mounce (26) noted that full voluntary compliance at STOP signs has steadily declined and is now less than 20 percent. Mounce felt the low compliance was a result of an excess use of STOP control. In the report he states that "the excessive use of STOP contol suggests a failure to fulfill a real need and, consequently, the control's ability to command the respect of the road user is severely impaired."

In 1982, Upchurch (2) completed a Ph.D thesis which compared the effects of three types of signing (YIELD, two-way and four-way STOP) for traffic control at intersections. The economic analysis detailing costs for fuel, vehicle operating, accidents, delay, air pollution and sign material, installation, and maintenance found YIELD control to be the most economic. He concluded that "nationwide intersection costs can be reduced by as much as $15.1 billion per year if sign controls are more effectively applied through use of the improved warrant." Upchurch based his accident costs on the methods for predicting accident rates developed in *NCHRP Report 41* (reviewed above). Upchurch qualified the findings of his report by stating that "there was a reason to be skeptical of the NCHRP predicted accident rates for YIELD control" and "that better accident information is needed to completely evaluate YIELD control". (27) (This observation was an impetus for this NCHRP project.)

The University of Maryland concluded a study (7) in 1986 in which 21 intersections were evaluated for possible STOP to YIELD conversion. A step by step procedure was recommended for selecting candidate conversion sites. Eleven intersections were actually converted and before/after field studies were conducted using a "modified driver-behavior traffic conflicts analysis". The methodology used for the traffic conflicts analysis was adapted from a technique developed by General Motors and documented in *NCHRP Report 219* (28). The analysis involved observing traffic conflicts "before" and "after" intersection control was converted from STOP to YIELD. Among the conclusions reported were:

- YIELD control provided a more efficient intersection operation than STOP control in terms of overall shorter delay to motorists, lower gasoline consumption, and lesser air pollution at the intersection.

- A decrease in the number of conflicts (from the before STOP to the after YIELD) at all intersections indicated an overall improvement in safety.

- Average annual savings per intersection per vehicle consisted of fuel - $0.28, emissions - $0.002, and delay - $2.04. The author noted that the delay rate was based on automobiles only. A significant number of truck movements at an intersection would result in higher delay costs.

Summary

Most of the studies reviewed above support YIELD control as a viable alternative to STOP control for low-volume intersections. After reviewing these studies on YIELD control, two major points can be concluded regarding low volume intersections:

1. Control type has no appreciable effect on accident experience.

2. In terms of operating efficiency, YIELD control is superior to STOP control.

Research relating to control of intersections that are not low volume and research relating specifically to STOP/YIELD conversions have been lacking, however. During the early 1950's there were several studies which reported on STOP to YIELD conversions and

resulting accident experiences. None of those studies developed accident relationships to converted (STOP to YIELD) intersections nor any relative comparisons of accident experience at converted intersections to the population of YIELD control intersections.

Since then, the University of Maryland study is the only study, reviewed in the literature search, that addresses converted intersections as a group. As a result of conflict analysis, the study concluded that "overall, one can see there is no difference in the drivers behavior and the conflict rates "before" and "after" the change in control signs from STOP to YIELD at the ten intersections studied."

Several YIELD control issues, however, remain unclear or have not been addressed; these are:

1. At what volume ranges can YIELD control be considered effective?

2. What are the accident and operating characteristics at higher ADT levels?

3. Is the accident experience at a converted (STOP to YIELD) intersection any different from a YIELD intersection that was not the result of a conversion?

4. Noting that there are fewer conflict points at three-leg intersections than at four-leg intersections, are accident rates different between the two?

5. Acting under a premise that minor right turns are safer than minor left turns, can an accident relationship be established which would assign relative risks to turning movements?

WARRANTS AND RECOMMENDATIONS ON YIELD USAGE

A review was conducted of previously recommended warrants or guidelines for the use of YIELD control and of recommendations or guidelines relating to STOP to YIELD conversions. The following is a listing of those recommendations and a listing of other warrants or guidelines documented in the literature.

The *MUTCD* provided its first warrants on YIELD control in 1961 and except for minor wording changes, have remained unchanged through 1978 *MUTCD*. The current warrants are found in Section 2B-8 and are repeated in Figure A-1.

The warrants are limited in that they do not provide specific guidelines such as the appropriate traffic volumes, accident experience, sight distance limits, etc. The safe approach speed mentioned in Warrant 1 is the maximum speed at which a vehicle can approach an intersection and still be able to stop in time to avoid a collision with a vehicle approaching on the intersecting street. A discussion on determining safe approach speed is provided in Appendix C.

In a 1958 article on the applications of YIELD signs, Kell (10) suggested that traffic volume, volume split, speed, visibility and accident experience were important considerations in the selection of YIELD control and that installation at intersections previously controlled by two-way STOP should be undertaken cautiously. He also advised that caution be exercised at rural intersections involving high speed traffic when converting STOP control to YIELD control. He states, "If such installations are contemplated, suitable advance warning signs and markings should be included. Where speed is not a factor, the replacement of STOP should give comparable results to similar urban installation."

2B-8 Warrants for YIELD signs

The YIELD sign may be warranted:

1. At the entrance to an intersection where it is necessary to assign the right-of-way and where the safe approach speed on the entrance exceeds 10 mile per hour.

2. On the entrance ramp to an expressway where an acceleration lane is not provided.

3. At intersections on a divided highway where the median between the roadways is more than 30 feet wide. At such intersections, a STOP sign may be used at the entrance to the first roadway of the divided highway and a YIELD sign may be placed at the entrance to the second roadway.

4. Where there is a separate or channelized right-turn lane, without an adequate acceleration lane.

5. At any intersection where a special problem exists and where an engineering study indicates the problem to be susceptible to correction by use of the YIELD sign.

YIELD signs generally should not be placed to control the major flow of traffic at an intersection. However, YIELD signs may be installed to control a major traffic movement where a majority of drivers in that movement are making right turns (see Figure). At such an intersection, YIELD signs should not be erected at any other approach.

YIELD signs should not be used on the through roadways of expressways. They may be used on an entering roadway without an adequate acceleration lane, but in a well designed interchange, the sign would interfere with the free merging movement, and it should not be used under those circumstances.

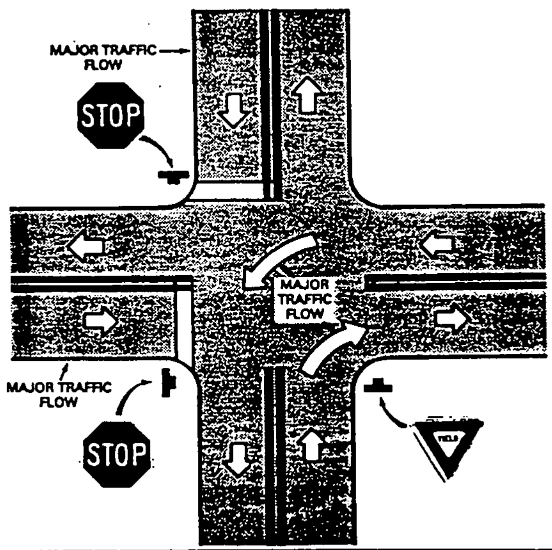


Figure A-1. Section 2B-8 from MUTCD (1) on YIELD sign usage

As a general guide or warrant on YIELD control, Kell offered the following:

"YIELD signs can be effective control devices for intersections where there is an apparent need for definition of right-of-way to provide safe convenient and efficient traffic flow but where STOP signs are unduly restrictive." (10)

The benefit-cost analysis conducted by Hall (20) led to the recommendation that YIELD control be used in the volume range 200 to 800 vehicles per day and that no control be used for volumes of less than 200 vehicles per day.

The FHWA study conducted by Stockton and Mounce (4) provided a list of YIELD control guidelines used by various state and local agencies (Table A-1). The report on that study concluded that a comparison of expected accident costs and road user savings showed that YIELD control is preferable for locations with up to two accidents in three years. If the minor road volume is greater than 300 vehicles per day, YIELD control is cost effective with up to three accidents in three years. Higher accident frequencies justify STOP control consistent with the "conventional wisdom" that STOP control will reduce the potential for accidents (see Figure A-2).

Beginning in 1972, the ITE Technical Council Committee 4A-A conducted a study (29) to "develop a state-of-the-art report on the use of YIELD signs and on the effectiveness of these devices on controlling traffic at intersections and elsewhere." As part of the study, the Committee conducted a survey of ITE members to document the use of YIELD signs. Table A-2 presents a listing of the warrants reported by that survey. The recommended warrants resulting from the study are presented in Table A-3. Warrants for YIELD control at rural intersections were not included since there was insufficient data to support any recommendation. Their recommendation of allowing safe approach speed of 8 mph was qualified with the comment that "this is contrary to the *MUTCD* and as such, its use is not recommended until such a time as the *MUTCD* would allow such a change." The report concluded that "YIELD control can be used effectively to control traffic at minor intersections in urban areas" and "a (relatively) low accident frequency can be expected, particularly with street volumes under 900 ADT and intersection volumes of under 1,500 ADT". (29)

Warrants which were considered for the installation of YIELD signs in Wichita, Kansas, were presented in an article (30) in the MOVITE Journal and are shown in Figure A-3. Further description of those warrants suggested that "ordinarily, YIELD signs would not be installed when warrant 1 or 2 is satisfied to minimum extent; all the factors should be weighed before YIELD signs are installed. The traffic volumes are intended to be used as guidelines and not exact warrants. Volumes in the 1,500 to 3,000 range should be supplemented by other factors before YIELD signs are installed".

At a District 6 ITE convention in 1977, Mitchell (31) presented the traffic control warrants on low volume streets for the City of Concord, CA. In that presentation, Mitchell recommended that additional warrants should be established for residential streets. Mitchell contended that "the need to 'minimize delay' is secondary to that of maintaining the primary residential character of the neighborhood". Figure A-4 shows the recommended warrants for YIELD control.

Table A-4 presents guidelines that have been recommended by the Traffic Institute at Northwestern University. (32)

Table A-1. Reported guidelines by Stockton, Brackett and Mounce. (4)

	VOLUME	ACCIDENTS	SIGHT DISTANCE CRITERIA	OTHER (School, Ped., etc.)
State of Delaware				Minor approach serves 5 or more homes.
State of New York			Critical approach speed greater than 8 mph.	
State of North Dakota	Less than 150vpd on major approach AND		Greater than AASHTO Case II modified for rural and urban separately, AND	Rural-gravel roads only. Urban-city streets only.
City of Baltimore, MD				At intersections where STOP is not warranted.
City of Concord, CA	Major street 500vpd (or 50 vph) peak and minor street 250vpd (or 25vph) peak.	Two or more of correctable type in 12 months (if only STOP warrant met).	Critical approach speed between 15 and 20 mph.	
Montgomery County, MD			Sight distance along major from 35ft back on minor is greater than 125ft.	Some control dictated by geometrics, accidents, or volumes.

<table>
<tr><th rowspan="2">Sight Distance</th><th rowspan="2">Accident History</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></td></tr>
</table>

*If minor roadway is greater than 300 vpd, YIELD control is appropriate for intersections with less than 4 accidents in 3 years.

Source: Reference (4)

Figure A-2. Proposed guidelines by Stockton, Brackett and Mounce.

Table A-2. Reported warrants to ITE Technical Council Committee 4A-A

REPORTED WARRANTS
YIELD CONTROL AT MINOR INTERSECTIONS

SOURCE	VEHICULAR INTERSECTING VOLUMES (ADT) MIN.	MAX.	ACCIDENTS (RT. ANGLE)	SIGHT DISTANCE MIN.	MAX.	ST. SYSTEM	OTHER
Kell, Suggested ITE Practice - April, 1960	Urb.=1000 Rur.= 500	5000 (except w/caution)	3 or more/yr.	over 8 MPH[1]	less than 85 Percentile		Not against major flow.
Traffic Institute Northwestern Univ., 1976	1500	3000	3 or more/yr.	over 10 MPH[2]	less than 85 Percentile	collector/ local or local/local	Not against major flow if over 1.2 x minor flow.
Cincinnati, Ohio Any One Warrant	125/hr. for 8 hrs. 150/hr. for any 2 hrs. above		3 or more/yr. +6 or more/3 yrs.	Approx. 6 MPH[3]	Approx. 12 MPH[3]		
Cincinnati, Ohio Combination of 2 Warrants	75/hr. for 8 hrs. 100/hr. for any 2 hrs. above		2 or more/yr. +4 or more/3 yrs.	Approx. 6 MPH[3]	Approx. 12 MPH[3]		
Milwaukee, Wisconsin Requires any 3 of 4 Warrants	2000	3000	3 or more/yr.	over 10 MPH[2]	less than 85 Percentile	collector/ local or local/local	Consider alternate Yield arrangement to avoid creating collector.
Galveston, Texas				15 MPH[1]	30 MPH[1]		+ MUTCD warrants.
Sacramento, California					15 MPH[1]		
Austin, Texas*	Approach over 100/day		5 or more/yr.	over 8 MPH[1]	less than 85 Percentile		
Houston, Texas*	100/hr. for 8 hrs.		2 or more/yr.	8 MPH[1]	15 MPH[1]		
Lansing, Michigan*			5 or more/5 yrs.				
Oakland, California*	Yield Street 1000						
Rockford, Illinois*			2 or more/yr.	over 15 MPH[3]			
Santa Ana, California*	1,000		2 or more/yr.	equal to[1] critical speed at mid block in advance			Major street 50% more volume than minor
Skokie, Illinois*	100/hr. Total Entering	200/hr. Total Entering 200/hr. Entering From Collector Street		15 MPH[1] 20 MPH[1]		Local/Local Local/Collector	
Dade County, Florida*				8 MPH			
MUTCD				Over 10 MPH[1]			At any intersection where a problem exists and where an engineering study indicates the problem to be susceptable to correction by use of a "Yield" sign

*From NCHRP, Report 41, 1967 (See Bibliography, Page A-1)

1 No Measuring Method Stated
2 Using Method in this Report
3 Uses Own Method which results in speeds calculated by method in this Report

Source: Reference (29)

Table A-3. Recommended warrants by ITE Technical Council Committee 4A-A

RECOMMENDED WARRANTS
YIELD SIGN USE

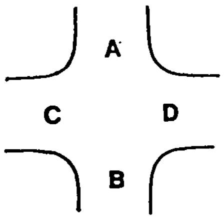
TYPE OF USE	AREA	VOLUMES (ADT)	ACCIDENTS	MINIMUM SIGHT DIST.	STREET CLASS	OTHER
MINOR MOVE AT A MAJOR INTERSECTION (BYPASS)	Urban	Mainline (2-Way) / Bypass Under 10,000 / Any Volume 10,000-20,000 / Under 3,000 Over 20,000 / Under 2,000		SSSD[1]		Low pedestrian volume across bypass - under 50 ped./hr. in peak vehicle hour, or[3]
	Rural	NO RECOMMENDATION				
INTERSECTION OF TWO MINOR STREETS	Urban	Intersection Min. 1,500 Max. 3,000	3 or more rt. angle	0 MPH[2]	Local/Local	Consider alternate pattern to avoid creating collector, or[3]
	Rural	NO RECOMMENDATION				
COLLECTORS (MINOR THRU HIGHWAYS)		NO RECOMMENDATION				
MEDIAN CROSSINGS	Urban	NO RECOMMENDATION		SSSD[1]		Median width exceeds 30' or[3]
	Rural	Minimum 2-Way Mainline 5,000 Cross Road 1,000		SSSD[1]		Median width exceeds 30' or[3]
MERGE POINT ON-RAMP		NO RECOMMENDATION				
MISCELLANEOUS USES		NO RECOMMENDATION				

1 Safe stopping sight distance for traffic on Mainline.
2 As measured on Appendix, Page A-17.
3 At any intersection where a special problem exists and where an engineering study indicates the problem to be susceptible to correction by the installation of a Yield sign.

Source: Reference (29)

WARRANTS TO BE CONSIDERED FOR THE INSTALLATION OF YIELD SIGN

1. The sum of the ADT's on the intersecting streets is at least 1,500 vpd but not more than 5,000 vpd.



$$\frac{(A + B)}{2} + \frac{(C + D)}{2} = \text{1500 to 5000 vpd}$$

2. The occurrence of at least two accidents unpreventable by less restrictive means in the two latest 12-month periods. The accidents should be of the type correctable by yield signs.

3. The safe stopping sight distance speed must be greater than 12 mph (triangle distance of about 45 feet).

Source: Reference (30)

Figure A-3. Warrants for installation of YIELD sign for Wichita, KS

WARRANT FOR YIELD SIGN INSTALLATION

Yield sign installation may be considered if any of the following conditions exist:

1. VOLUME

   (a) Total vehicular volume on the major street of 500 vehicles per day or 50 per hour during the peak hour on an average day.

   (b) Total vehicular volume on the minor street of 250 vehicles per day or 25 vehicles per hour during the peak hour on an average day.

   (c) Subsequently higher volumes than above warrant consideration of stop sign.

2. ACCIDENTS

   Indication of an accident hazard susceptible of correction by yield signs.

3. VISIBILITY

   Critical approach speeds less than 20 mph, but not less than 15 mph.

4. PHYSICAL CONFIGURATION

   Right of way assignment is needed to prevent confusion and expedite traffic flow.

NOTE: All yield sign installations shall be checked at approximately three-month intervals for one year to determine if operation is satisfactory. If there is continued accident experience replacement of yield signs by stop signs shall be considered.

Source: Reference (31)

Figure A-4. Recommended warrants for YIELD control for City of Concord, CA

Table A-4. Recommended guidelines by the Traffic Institute at Northwest University

A SUGGESTED GUIDE FOR DETERMINING THE NEED FOR TRAFFIC CONTROL DEVICES

		No Control	Yield Sign	Stop Sign 2-Way	Stop Sign 4-Way	Signal
Volume per hour	(Major)				300	600
	(Minor)				200	200
	(Total)	100	100-300	250	500	800
24 Hour	Total	1000 to 1500	1500 to 3000	1500 to 8000	5,000	8,000
Safe Approach Speed (Sight Distance) in m.p.h.		Near Speed Limit or 85%	Over 15	Under 15	Blind	
Accidents per year Right Angle		Less than 3	3 or more	3 or more	5 or more	5 or more
Street Classification		Local - Local	Local - Local Collector - L·cal	Thru Street Major - Collector Major - Local	Major - Major	Major - Major Major - Collector
Other Factors						Pedestrians Gaps Progression

Source: Reference (32)

Summary

Most of the existing and recommended warrants that were reviewed used sight distance or safe approach speed, roadway or intersection volumes, and accident history as primary guidelines when assessing YIELD control. A condensed view of those guidelines follows:

- Sight Distance Warrants - Of the warrants reviewed:

  6 required a safe approach speed at least 15 mph,
  1 " " " " " " " 12 mph,
  3 " " " " " " " 10 mph,
  4 " " " " " " " 8 mph and,
  1 " " " " " " " 6 mph.

- Volume Warrants - Various measures defined as necessary determinants to describe the volume of vehicles using an intersection. Measures such as vehicles per day, per hour, and per average hour were specified for total intersection volumes, major or minor roadway volumes, or major or minor approach volumes. For those warrants which specified total intersection volumes as criteria, appropriate YIELD control intersection volumes ranged from 1000 to 5000 vehicles per day.

- Accident Warrants - Most of the guidelines reviewed provided minimum thresholds when YIELD control would be warranted. They are:

  1 required an accident history of ≤ 1 or more acc/yr.
  5 " " " " " ≤ 2 " " "
  6 " " " " " ≤ 3 " " "
  1 " " " " " ≤ 5 " " "

  One other guideline allowed for YIELD control at intersections with an accident history of 2 or less.

- Roadway Classification - Several of the warrants provided that YIELD control be limited to intersections of collector with local and of local with local. One jurisdiction restricted YIELD intersection to local with local.

Other specific recommendations include:

- YIELD should not be used against the major flow if the major flow is more than 1.2 times the minor flow.

- Should be used only if the pedestrian volume is low, (i.e., less than 50 pedestrians per hour in peak volume hour.

APPENDIX B—QUESTIONNAIRE RESULTS

A questionnaire was prepared to determine the experience of state and local highway departments with YIELD controlled intersections and with conversions from STOP to YIELD. Also, they were questioned on their willingness to participate in a STOP/YIELD conversion study and on the type of information they would be able to provide.

Much of the questionnaire was designed to get a free response from the jurisdiction being surveyed. For instance, rather than providing a checklist of factors which were felt important considerations for STOP/YIELD conversions, the respondent was asked to provide his/her own thoughts. The idea was to avoid molding the response into preconceived thoughts. The questionnaire is presented in Figure B-1.

The list of those jurisdictions which were contacted for the survey came from an Institute of Transportation Engineers (ITE) list of 700 traffic engineers who head local traffic engineering departments. The local jurisdictions from the list were categorized into five regional areas, four population groupings, and county or city/town jurisdiction. One hundred jurisdictions were then selected at random from that list to form a survey data base. A categorized distribution of that list is as follows:

Population	
< 25,000	15%
25,000 - 100,000	45%
100,000 - 500,000	30%
>500,000	10%

Region	
Northeast	28%
Southeast	20%
North Midwest	9%
South Midwest	14%
Far West	29%

Jurisdiction	
City/Town	75%
County	25%

In the hope of identifying a larger number of potential STOP to YIELD conversion sites, an additional set of questionnaires were sent out to another 100 jurisdictions. The second questionnaire was primarily targeted toward county jurisdictions. The first questionnaire inquired primarily on jurisdiction's experience with converted intersections. Since the results of the first questionnaire indicated that identification of converted sites would be difficult, the second questionnaire was modified to help identify jurisdictions with overall experience with YIELD control intersections as well as with STOP to YIELD conversions.

The number of respondents from the two questionnaires is summarized below:

	Number of Questionnaires	Number Responding (%)	Number Willing To Participate (%)
Survey 1 Local	100	44 (44%)	12 (12%)
State DOT	50	32 (64%)	4 (8%)
Survey 2 Local Only	100	29 (29%)	3 (3%)
Total Surveys	250	105 (42%)	19 (8%)

NCHRP PROJECT 17-7
"Guidelines for Converting STOP to YIELD Control at Intersections"

Questionnaire

AGENCY_______________________ Agency Contact: Name_______________________
Address_______________________ Title_______________________
_______________________ Phone_______________________
City, State, Zip_______________________

PART I - YIELD control and STOP/YIELD Conversion Experience

1. What is your jurisdiction's policy, guideline, or warrant regarding use of YIELD control at unsignalized intersections?_______________________

2. What is your jurisdiction's policy, guideline, or warrant regarding conversion from STOP to YIELD control?_______________________

3. If there is no policy or guideline in converting, what factors do you feel are important in the consideration?_______________________

4. If you have made conversions, have you experienced safety problems (such as increased accidents, vehicle and pedestrian conflicts, traffic violations, etc.) after the STOP/YIELD conversion has been made? Yes_____ No_____
Explain_______________________

5. Has it been necessary to reconvert any intersections back to STOP from YIELD? Yes_____ No_____ What types of problems forced those reconversions?

Figure B-1. Questionnaire

NCHRP Project 17-7
Questionnaire - Part I
Page Two

6. What procedures (e.g. special signing, media notices, etc.) has your jurisdiction followed to minimize any initial negative impacts when converting from STOP to YIELD?

7. What additional observations regarding STOP/YIELD conversion do you feel should be pointed out?

If available, please provide documentation of any studies conducted that support these guidelines.

Figure B-1. Questionnaire (Cont'd)

PART II - STUDY SITES AVAILABILITY

Since STOP and YIELD controlled intersections are generally associated with small numbers of accidents, a meaningful accident study on YIELD conversion will require many test and control sites. Consequently, we are seeking the cooperation of several agencies. Your assistance in this important study would be greatly appreciated.

1. Have you converted any intersections from STOP control to YIELD control within the past six years? Yes_____ No_____ If so, indicate how many for those years:
1985_____ 1984_____ 1983_____ 1982_____ 1981_____ 1980_____

2. Have you evaluated the accident experience associated with the conversion? Yes_____ No_____ If so, what have been your findings? (Please provide details)

____
____
____
____

3. Are you planning to convert any intersections from STOP control to YIELD control? Yes_____ No_____ If so, how many?_______________

4. Would you be willing to participate in a before/after study? Yes_____ No_____ If yes, would candidate sites be: sites already converted_____, planned conversions_____, or both_____?

If you choose to participate it will be necessary for your agency to provide some accident, traffic and highway data. The following data elements are being considered in the design of our study. Please indicate which of these are available from your files or which you would be willing to collect:

_______ Type of intersection (i.e. T-, 4-way, etc.)
_______ Land use (e.g., rural, residential, outlying business district (OBD), etc.)
_______ Approach speed (limit), major and minor street
Approach volumes:
_______ ADT
_______ Peak hour
_______ Pedestrian volumes
_______ Bicycle volumes
_______ Approach grades
_______ Intersection sight distance determination (adequate/inadequate)
_______ Sketch of intersection
Accident data
_______ Police report
_______ Summary report
_______ Computer accident record

RETURN TO:

Hugh W. McGee
Bellomo-McGee, Inc.
901 Follin Lane, Suite 220
Vienna, VA 22180
(703) 255-3312

Figure B-1. Questionnaire (Cont'd)

The poor response exhibited in the second survey was disappointing but understandable. Many of the jurisdictions contacted in that survey were small rural agencies where the transportation departments were one person operations. In conversations with several of these agencies a common complaint was that budget restraints did not allow time or manpower to become involved with surveys or studies.

Another technique employed to identify agencies willing to cooperate by providing conversion sites was the placement of a notice in the ITE Journal (Vol. 56, No. 2, Feb. 1986). Only two jurisdictions responded to this notice.

RESPONSES TO PART I QUESTIONS

The remainder of this appendix provides the results of the responses to the seven questions posed in Part I of the questionnaire:

QUESTION 1 - "What is your jurisdiction's policy, guideline, or warrant regarding use of YIELD control at unsignalized intersections?" - 90 responses.

29 Jurisdictions - had no specific guidelines other than the guidelines as stated in the *MUTCD*.

34 Jurisdictions - utilized other guidelines (in addition to those in the *MUTCD*), and

27 Jurisdictions - stated that they do not use YIELD as a traffic control device at intersections.

The guidelines that were reported showed concerns in the following areas:

- Safe Approach Speed

Most jurisdictions agreed with the *MUTCD* restraint that the minor approach should have a safe approach speed of at least 10 mph (minimums ranged from 8 mph to 15 mph). Two jurisdictions required that the safe approach speed should not exceed a maximum speed of 20 mph and 25 mph.

- Accident History

Five jurisdictions correlated the need for YIELD control with the occurrence of right-angle collisions. Guidelines include:

- "the occurrence of at least two such right-angle collisions in a 12-month period,"
- "average right-angle accident per year of three or more."
- "an accident history of an average of 1 accident (angle collision) per year for three years."

- Volume

Four jurisdictions provided guidelines relating to volumes:

- average highest 8 hour: 100-300 vph or greater; 24 hour volume: 1500-3000
- average 8 hour: at least 90 vph for each roadway
- ADT on major roadway less than 2000; total intersection ADT less than 2500
- 24 hour intersection volume: 1500-4000; peak hour volume: 100-300

Other jurisdictions showed concerns over specific turning movements. "YIELD control should be discouraged where there are predominant or significant left turns," and should be installed "only at intersections with high right turn movements."

Other important guidelines used by jurisdictions are:

- Should be used where the assignment of right-of-way is necessary. In a contrasting point of view, one jurisdiction reported that "experience has shown that YIELDs are only effective where it is obvious to the driver that he should yield."
- YIELD signs should not be placed to control the major flow of traffic.
- YIELD control should be used with intersections of roadways of low classification - i.e., residential streets, local with local, and local with collector.
- Intersections should exhibit low pedestrian activity.

Several agencies sent copies of worksheets used to evaluate intersection control. These worksheets are presented at the end of this appendix.

QUESTION 2 - "What is your jurisdiction's policy, guideline, or warrant regarding conversion from STOP to YIELD?"

There were no jurisdictions with policies regarding conversion from STOP to YIELD control.

QUESTION 3 - "If there is no policy or guideline in converting, what factors do you feel are important in the consideration?" (107 responses)

The free responses of those surveyed produced several observations. The respondents were primarily concerned with sight distance, traffic volumes, and accident experience. Additional concerns were placed on geometrics, driver understanding, and roadway classification. A tabulation of those responses is presented in Table B-1.

Table B-1. Considerations when converting to yield control

The factors that were considered important by the survey when converting from STOP control to YIELD control are:

Conversion Factor	Number of Answers	Percent of All Answers	Percent of Respondents
Sight Distance	71	28%	88%
Traffic Volumes including: - Available Gaps - Greatest Movement of Traffic - Predominant Left Turn Movements - Low Opposing Volumes - High Yielding Volumes - Vehicle Type in Area	57	22%	70%
Accident Experience	39	15%	48%
Geometrics including: - Angle of Approach - Flat Angle Entrance (<60°) - Number of Lanes - Grades - Acceleration Lane - Number of Approaches	23	9%	28%
Driver Understanding	18	7%	22%
Roadway Classification	12	5%	15%
Benefits from Conversion	7	3%	9%
Intersection Type	6	2%	7%
Pedestrian Volumes	5	2%	6%
Motorist Compliance w/STOP	3	1%	4%
Other: - Field Conditions - Capacity - Amount of Street Lighting - Unusual Conditions - Enforcement - Safety	13	5%	16%

QUESTION 4 - "If you have made conversions, have you experienced safety problems after the STOP to YIELD conversion was made?" (4 responses)

Since very few converted sites were identified by the questionnaire, there were few responses. One jurisdiction reported a "failure to yield to pedestrians" while another reported that "motorists tend to ignore yield signs".

QUESTION 5 - "Has it been necessary to reconvert any intersections from YIELD back to STOP?" "What type of problems forced those reconversions?" (17 responses)

The reported problems that led to conversion from a converted YIELD back to STOP control were similar to the problems that could be encountered by any YIELD intersection. Intersections were converted back to STOP because traffic volumes had increased, sight distances had changed or accidents had increased. Unique to converted STOP/YIELD intersections are citizens' complaints regarding the change from STOP to YIELD. Even if a conversion is totally justified, political pressures are familiar obstacles to traffic engineers.

One agency had experience in converting, over a period of years, many unwarranted STOP control intersections to YIELD control and presented the following reasons for "retreating" back to STOP control:

1. YIELD signs don't seem to work as well at four-legged intersections where the priority street has any functional resemblance to serving as a minor collector. Accident histories and resultant complaints from residents have resulted in changes back to STOP control along collectors and "near collectors" at four-legged intersections. The intersections along collectors usually present no problem using YIELD sign control.

2. Trees and bushes grow, and over time as visibility triangles diminish, YIELDs get converted to STOP sign control. The collective pain of maintaining sight distances sufficient for safe YIELD sign control is not even closely counterbalanced by expressions of delight from motorists, or complaints from motorists when the YIELDs are changed to STOPs.

3. YIELD signs don't seem to work even at the intersections along four and five major streets, except in rare special cases. I don't know if it's the width of the major street or the speed of traffic along the major street (posted for 40 or 45 mph) but the few places we've tried them, we've removed them."

QUESTION 6 - "What procedures (e.g., special signing, media notices, etc.) has your jurisdiction followed to minimize any initial negative impacts when converting from STOP to YIELD?" (12 responses)

Among the reported procedures are:

- News releases through newspaper and radio coverage.
- Neighborhood notices
- Local politicians and interested citizens are informed.

- Advance "TRAFFIC REVISIONS" warning signs placed at the time of conversion.
- Police observation is requested.

QUESTION 7 - "Please give additional observation regarding STOP/YIELD conversion. (37 responses)

Many of the responses to this question were negative toward the use of YIELD control. Typical comments were:

"Experience indicates motorists who frequent the intersection soon no longer respect the YIELD sign's importance as they would a STOP sign."

"... drivers don't know how to use YIELD."

"I am of the opinion that many drivers do not understand how they should drive a YIELD sign and similarly, traffic engineers don't know how they are supposed to be driven so they are installed where they really shouldn't be."

"I have never encountered a situation where a STOP to YIELD conversion would be considered."

"We believe that the public is used to a STOP control type intersection. It should be left as such ..."

One jurisdiction sent a copy of an article relating to YIELD control (see Figure B-2) which very strongly demonstrates the concern agencies have with liability.

Other Comments Were:

"An emphasis on the negative aspects of STOP sign installation needs to be made. Besides, I don't think an unwarranted STOP intersection will improve an agency's position in regards to liability."

"On residential streets... if YIELD signs are used, they should be used throughout the area and not randomly mixed STOP signs unless a good reasons for the STOP exists. Politically this becomes difficult to sell if STOP signs have been established in a particular area. The problems: 1) area residents love STOP signs. 2) area motorists hate STOP signs. Area residents tend to turn out in great numbers before political bodies and are unusually successful in getting their way- area motorists, even though they out number area residents, become the silent majority ... voices unheard and therefore not considered."

"Our past usage of 2-way STOP signs has substantially penalized the motorist. In areas where this is perceived by the public, there tends to be significant a amount of non-compliance."

"... most people perceive a higher degree of control as better. The local politician must be in favor of change for it to have any chance of success."

THE DANGEROUS YIELD SIGN

The next example I would like to share with you comes from an article printed in the Register on March 19, 1984, two weeks ago:

> While riding her bicycle on the wrong side of Atlantic Avenue, in Laguna Beach, Heather Brobeck, 7 was struck by a car as she went through a yield sign at Caribbean Avenue. She has been in a coma since the September 1977, accident.
>
> The family sued the driver, who had only $15,000 insurance; a property owner on the corner where the accident occurred for failure to trim shrubs properly; and th city, for its failure to have a stop sign at the intersection.
>
> The city settled the case out-of-court for $3.8 million.

The lesson from this case is clear -- the day of the yield sign is over. If an accident occures within 100 miles of a yield sign, some plaintiff's attorney will use it to sue the city.

Yield signs make for easier driving within a city, and, in particular instances, they may ease traffic problems; but, they are tort liability time bombs.

Figure B-2. Article on YIELD sign use.

"It should only be done at a fairly low volume intersection which has a good sight distance and has had a very good safety record with STOP control."

"Many installations that initially received a STOP sign, could have received a YIELD sign."

"If conversion will reduce delays and not sacrifice safety, it should be done."

"... most drivers don't stop anyway so you aren't really changing driver actions. . . . we are a developing city to the south so on new intersections we initially installed YIELD signs where needed. ... in older areas where STOP signs have installed, its usually not worth the battle to change to YIELD, regardless of the justification."

"YIELD signs would best serve a population which could be expected to have good vision and reflexes."

"Extreme care must be taken not to create ambiguous control."

SUMMARY

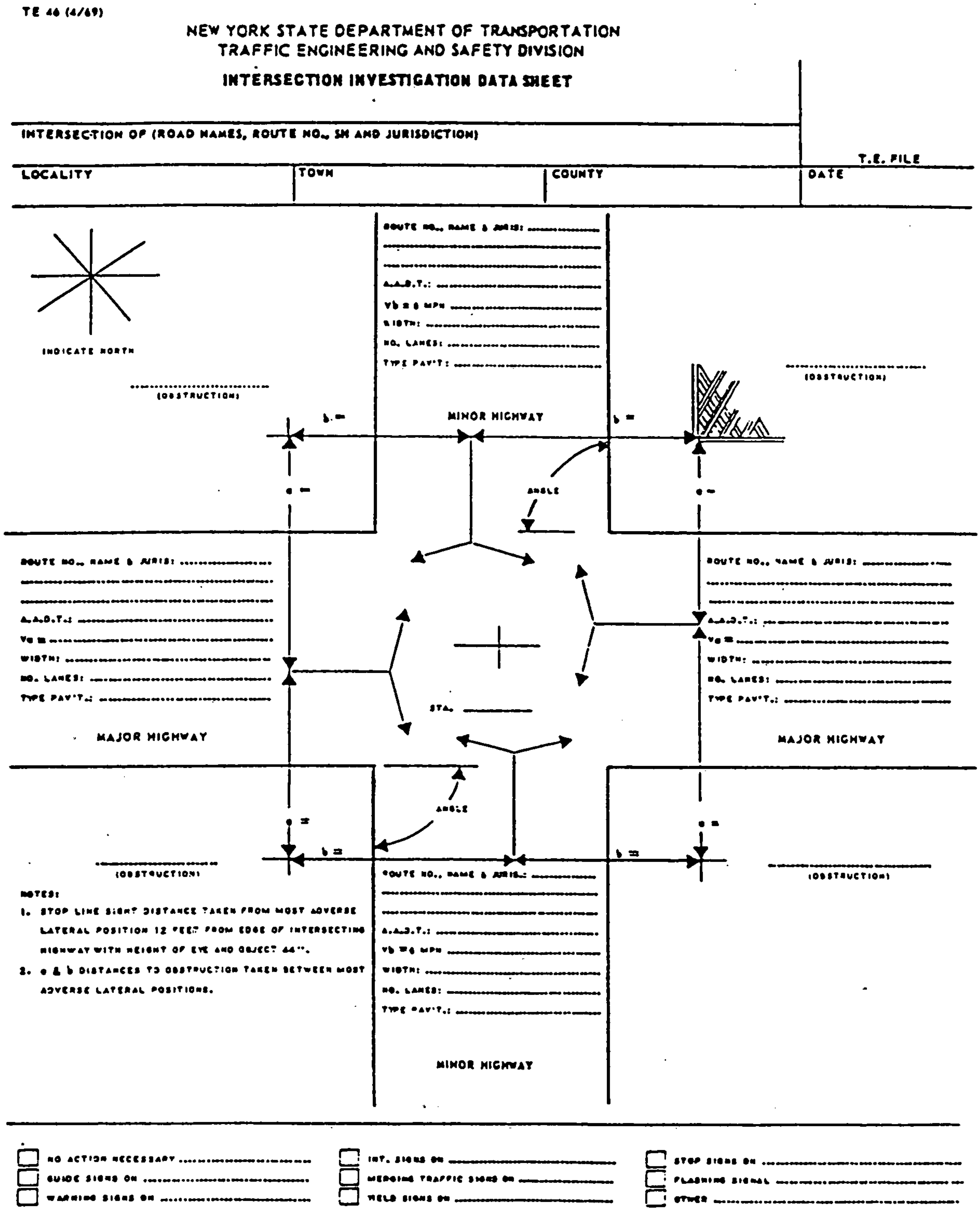
The responses to the questionnaires and discussions with participating jurisdictions provided some thoughts on why so few conversion sites were available.

There are many jurisdictions which feel that YIELD control is unsafe and thus will not consider conversions in any case. Other jurisdictions, which have established policies utilizing YIELD control, had already installed YIELD control where they were warranted and now convert only when conditions (i.e., traffic volumes, traffic patterns, accidents, geometrics, sight distance, etc.) change. These conversions are almost always YIELD to STOP.

The foremost conclusion one can reach from the results of the questionnaire is that the use of YIELD control in lieu of STOP control at intersections is a sensitive issue. Many agencies have safety concerns over the use of YIELD control and these concerns can be assumed to relate directly to an ever growing concern over public liability.

Definitive guidelines regarding YIELD control, as a replacement for STOP control, need to be provided engineers not only to aid them with YIELD control decisions but to also provide some relief from liability pressures. Good guidelines should be based on engineering experience as well as on sound engineering studies. The use of the questionnaire provided many useful comments, based on experience, which are incorporated into the guidelines developed for this project.

Worksheets for the Investigation of Intersection Control


TE 46 (4/69)

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
TRAFFIC ENGINEERING AND SAFETY DIVISION

INTERSECTION INVESTIGATION DATA SHEET

INTERSECTION OF (ROAD NAMES, ROUTE NO., SH AND JURISDICTION)

T.E. FILE

LOCALITY | TOWN | COUNTY | DATE

INDICATE NORTH

(OBSTRUCTION)

ROUTE NO., NAME & JURIS:
A.A.D.T.:
Vb = ___ MPH
WIDTH:
NO. LANES:
TYPE PAV'T:

MINOR HIGHWAY

b =

a =

ANGLE

ROUTE NO., NAME & JURIS:
A.A.D.T.:
Va =
WIDTH:
NO. LANES:
TYPE PAV'T.:

MAJOR HIGHWAY

STA.

ROUTE NO., NAME & JURIS:
A.A.D.T.:
Va =
WIDTH:
NO. LANES:
TYPE PAV'T.:

MAJOR HIGHWAY

(OBSTRUCTION)

(OBSTRUCTION)

(OBSTRUCTION)

NOTES:

1. STOP LINE SIGHT DISTANCE TAKEN FROM MOST ADVERSE LATERAL POSITION 12 FEET FROM EDGE OF INTERSECTING HIGHWAY WITH HEIGHT OF EYE AND OBJECT 44".
2. a & b DISTANCES TO OBSTRUCTION TAKEN BETWEEN MOST ADVERSE LATERAL POSITIONS.

ROUTE NO., NAME & JURIS.:
A.A.D.T.:
Vb = ___ MPH
WIDTH:
NO. LANES:
TYPE PAV'T.:

MINOR HIGHWAY

☐ NO ACTION NECESSARY
☐ GUIDE SIGNS ON
☐ WARNING SIGNS ON
☐ INT. SIGNS ON
☐ MERGING TRAFFIC SIGNS ON
☐ YIELD SIGNS ON
☐ STOP SIGNS ON
☐ FLASHING SIGNAL
☐ OTHER

Figure B-3. Intersection investigation data sheet New York State DOT

TE 47 (4,'69)

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
TRAFFIC ENGINEERING AND SAFETY DIVISION
INTERSECTION INVESTIGATION SUMMARY SHEET

ROAD NAME, ROUTE NO., SH AND JURISDICTION			T.E. FILE
LOCALITY	TOWN	COUNTY	DATE

MAJOR HIGHWAY (1)				
CHARACTERISTIC	1	2	3	
IDENTIFICATION				
A A D T				
Ve (2)				
WIDTH				
NO. LANES				
TYPE PAVEMENT				

MINOR HIGHWAYS (Vb = 8 MPH)

ROAD NAME, ROUTE NO., SH AND JURISDICTION	INTERSECTS FROM	A A D T (THOUSANDS)	NO. LANES	WIDTH	TYPE PAVEMENT	OBSTR DIST a	OBSTR DIST b	SIGHT DIST ALONG HWY LEFT	SIGHT DIST ALONG HWY RIGHT	MAJOR HWY CHARACTERISTIC	MAJOR HWY STATION	RECOMMENDED CONTROL

REMARKS:

(1) Boxes 2, 3, 4 are only used when any characteristic for major highway varies from section to section on study highway.

(2) Ve = legal speed limit or 85 percentile speed, whichever is higher.

Figure B-4. Intersection investigation summary sheet

CITY OF SAGINAW

ADMINISTRATIVE GUIDELINES FOR INTERSECTION SIGN CONTROL

CONDITION	THIS INTERSECTION	NO CONTROL	YIELD CONTROL	STOP CONTROL	ALL-WAY STOP CONTROL
1. Volumes - 24 Hour - Peak Hour (-)	______/day ______/hr.	Under 1500 Under 100	1500 - 4000 100 - 300	Over 2000 Over 250	Both Streets Approx. Equal Over 500/hr. for hours (Total) Over 200/hr. for 8 hours (Minor St.)
2. Safe Approach Speed $v = \frac{-15 + \sqrt{225 + 40 \times d}}{2}$ (Where d= Shortest non-correctable sight distance)	V=___ d=___	At Least 85% of Speed Limit ___%	Over 10 MPH	Under 10 MPH	Under 10 MPH
3. Right Angle Accidents (3 year avg. ' - ')	______	Less Than 2	2 or More	5 or More	5 or More
4. Street Classification	______ ______	Local-Local	Local-Local Collector-Local	Local-Local Collector-Local One Thru St	Collector-Collector Major-Major

5. Other Considerations ______________________________

____

1. If one of the conditions is met, the location <u>may</u> be considered for the indicated control device.
2. If two or more of the conditions are met, the location <u>should</u> be given the indicated control device
3. Guidelines developed From Following Sources:
   - Manual on Uniform Traffic Control Devices, 1979 Edition
   - Traffic Institute, Northwestern University
   - Institute of Transportation Engineers Journal and Technical Notes
   - NTIS; Stop, Yield and No Control at Intersections
   - Fundamentals of Traffic Engineering, 7th Edition
4. See Michigan Manual on Uniform Traffic Control Devices for Traffic Signal Warrants
5. Other considerations include heavy pedestrian use, school areas, bicycle routes, park, etc..

RECOMMENDATION: ______________________________

____

____

BY: ______________________ DATE __________

CONCURRENCE: ______________________________

______________________ BY: ______ DATE __________

APPROVED BY TRAFFIC ENGINEER: ______ DATE __________

TRAFFIC COMMITTEE: ______________ DATE __________

ADOPTED BY CITY COUNCIL: __________ DATE __________

INTERSECTION

______________________ AND ______________

Revised 1-19-84

Figure B-5. Intersection control worksheet City of Saginaw

APPENDIX C—DETERMINATION OF SAFE APPROACH SPEED

The 1983 *Traffic Control Devices Handbook* (33) recommends that the technique described in the *Traffic Engineering Handbook*, (34) Institute of Traffic Engineers, 1965, for the determination of critical approach speed (or safe approach speed). The following discussion of safe approach speed is taken from the *Traffic Engineering Handbook*, Institute of Traffic Engineers, 1965.

Safe approach speed studies are conducted to determine maximum speed at which a vehicle can approach an intersection and still be able to stop in time to avoid a collision with a vehicle approaching on the intersecting street. The value of the safe approach speed can then be used to determine the appropriate vehicle right-of-way control at the intersection.

Figure C-1 shows the typical situation. Two cases are illustrated: vehicle B on the minor street approach is in potential conflict with vehicle A approaching from the left on the major street; or, vehicle C on the minor street approach is in potential conflict with vehicle D approaching from the right on the major street.

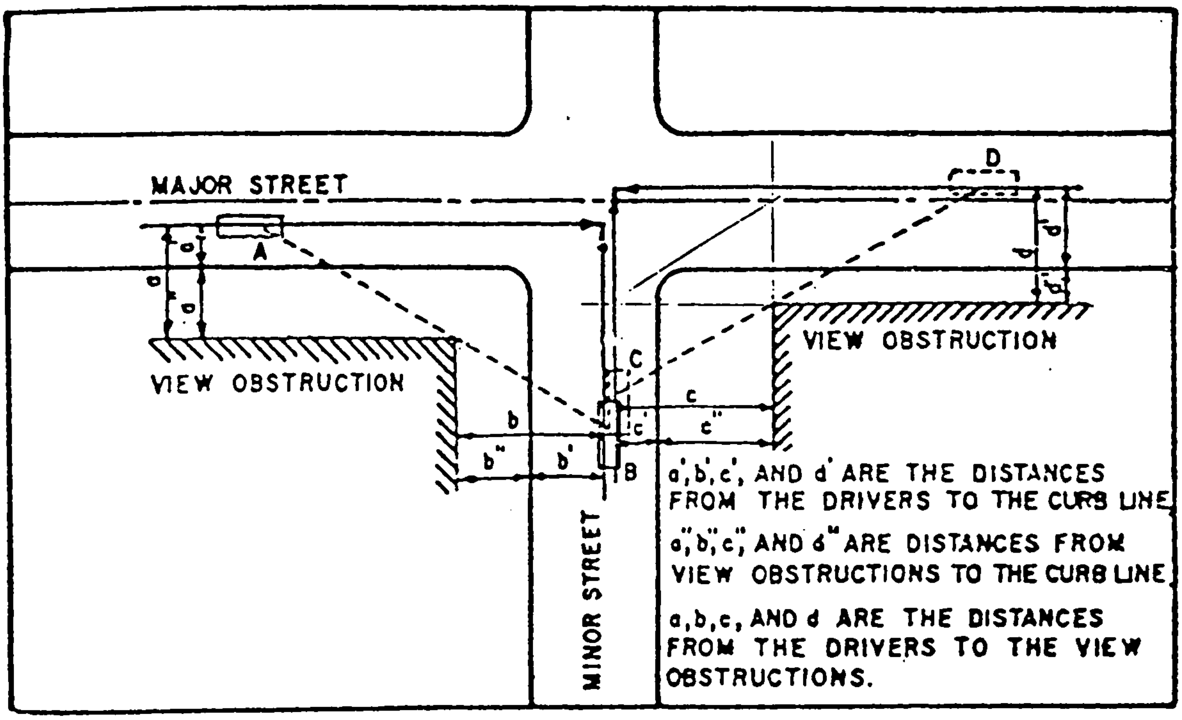
The values of a' and c' are assumed to be either 12 ft. (with curb parking) or 6 ft. (without parking), for both two-way and one-way streets. For two-way streets, the values of b' and d' are either one-half the street width plus 3 ft. or the street width minus 12 ft., whichever is smaller; for one-way streets the values for b' and d' are either 9 ft. (with curb parking) or 3 ft. (without parking). Values for a", b", c" and d" are measured in the field. Values for a, b, c, and d can then be computed.

The approach speed of the major street vehicles used in this analysis must be at least the 85th percentile of the spot speeds observed on this street; use of a higher value than this will provide a safety factor.

In addition to the location of sight obstructions and the speed of the fastest vehicles on the major street, a number of other factors affect the safe approach speed from the minor street. However, to evaluate each of these for every instance is likely to be cumbersome, and several conditions are therefore assumed: approaching vehicles are in the most dangerous legal position in respect to lateral placement on the roadway; driver reaction time is 1 second; deceleration rate is 16 ft./second; and the driver's eye is 7 ft. behind the front bumper and 2 ft. from the left side of the vehicle.

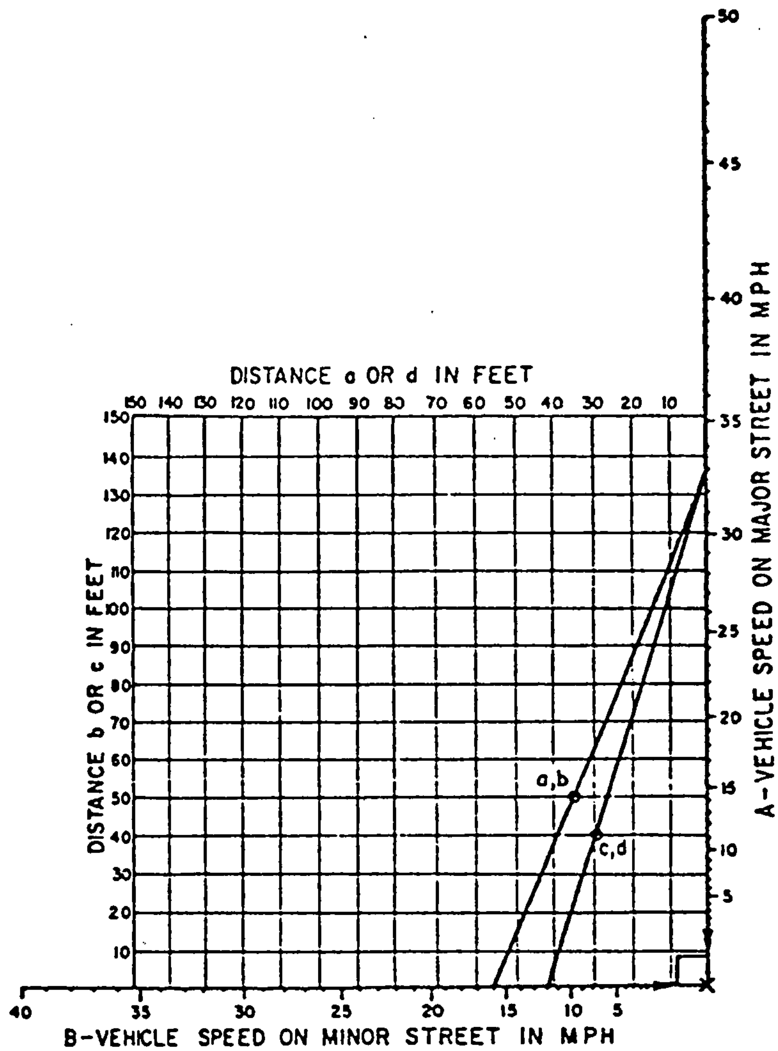
The chart shown in Figure C-2 represents the solution which makes all the foregoing assumptions, and indicates a safe approach speed which will allow the vehicle on the minor approach to come to a stop 8 ft. from the point where the two vehicle paths cross. The chart is used by plotting the coordinates (a, b) and (c, d). A line is drawn through each of these points to the appropriate major street vehicle speed scale A and extended until it intersects scale B for minor street vehicle speeds. The smaller of the two values on the latter scale is the safe approach speed for the approach. In the sample determination of safe approach speed, illustrated in Figure C-2, the following steps were taken: 1) the coordinates a = 35 ft., b = 50 ft. and c = 40 ft., d = 30 ft. were plotted; 2) lines were drawn through each of these plotted points to the assumed 33 mph major street approach speed on scale A; and 3) these two lines were extended until they intersected the minor street speed scale B at the values of 16 mph and 12 mph, respectively. Thus, in this example, the smaller values of 12 mph is the critical approach speed for the minor street approach.

A similar analysis is conducted for the other minor street approach. If the two intersecting streets have almost equal traffic volumes, the entire procedure may have to be repeated after the designations for major and minor streets have been interchanged. Figure C-3 is a blank safe approach speed chart for determining safe approach speeds.



(Source: Adapted from technique developed for the American Automobile Association by the Institute of Transportation and Traffic Engineering, University of California, Berkeley, California and reported in the Traffic Engineering Handbook, Institute of Traffic Engineers, 1965.

Figure C-1. Analysis of safe approach speed for vehicle on minor street approaching a major street.



(Source: Adapted from technique developed for the American Automobile Association by the Institute of Transportation and Traffic Engineering, University of California, Berkeley, California and reported in the Traffic Engineering Handbook, Institute of Traffic Engineers, 1965.)

Figure C-2. Safe approach speed chart illustrating analytical example

To convert from miles per hour to kilometers per hour , multiply by 1.6.

To convert from feet to meters, multiply by 0.30.

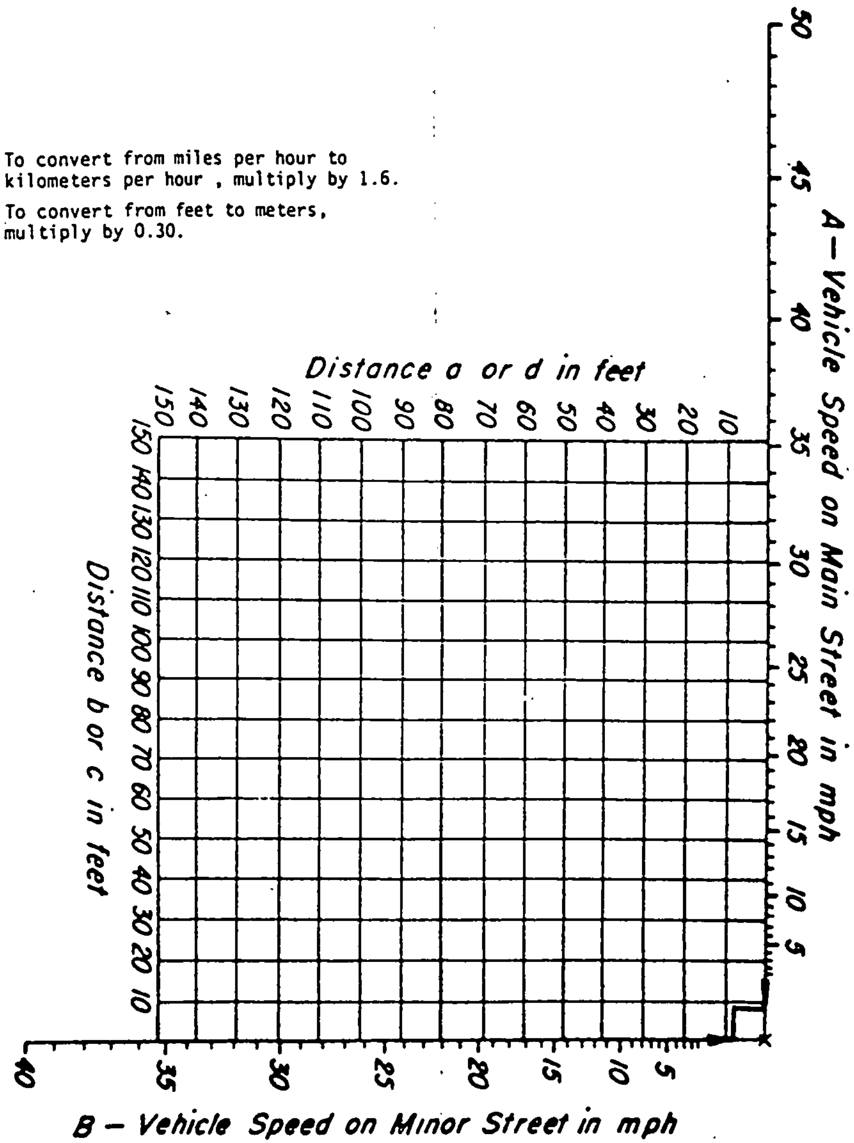


Figure C-3. Safe approach speed chart

APPENDIX D—STATISTICAL ANALYSIS OF SAGINAW DATA*

Of the three cities where STOP to YIELD conversions were made, Saginaw provided the most robust data base for assessing the affect on accident occurrence. Therefore, a special statistical analysis was performed for Saginaw to determine if the observed accident change for the treatment sites was different from the control sites and to establish what factors may have affected the observed change.

The statistical analysis employed contingency table analysis techniques which includes a methodology using the principle of minimum discrimination information (MDI) for model building and model validation. The statistic that judges the overall performance of an estimate is the information statistic which is a symptomatically distributed as a Chi Square (x^2) with the appropriate degrees of freedom. Further explanation of this methodology can be found in *Handbook of Statistics.***

The Saginaw data file consisted of the following data elements:

- Site Number
- Site Type - converted or control
- Road Class - local, collector, minor arterial, etc.
- Area Type - residential, CBD, OBD, fringe, rural
- Intersection Type - 4-way and T
- Corner Radius - tight (<20'), moderate, large (>40')
- Lighted intersection - yes/no
- Sight Distance - adequate, more than adequate
- Major Volume - five ADT groups of 0-500, 501-1,000, 1,001-1,500, 1,501-2,000, and >2,000.
- Minor Volume - four ADT groups of 0-500, 500-1,000, 1,000-1,500, and >1,500.
- Ped Volume - none, low, medium
- Bike Volume - none, low, medium
- Accident - yes/no
- Accident Type - five classes
- Accident Severity - Fatal, Inj., PDO
- Accident Light - Dark, Day
- Accident Time - before/after
- Observation Time - no. of years of data
- Year - year of conversion

* By Jack C. Keegel, Statistical Consultant

** S. Kullbach and J. C. Keegel, "Categorical Data Problems Using Information Theoretic Approach" in *Handbook of Statistics*, Vol. 4, P.R. Krishnaiah and P.K. Sey, ed., Elsevier Science Publishers, 1984.

A preliminary set of one-way frequencies was run on all the variables revealing that certain of the variables were mostly constants and, therefore, not amenable to analysis. Those were:

- Area Type - all cases were coded 1.
- Intersection Type - all but 18 cases were coded 1.
- Radius - all but 20 cases were coded 1.
- Light - all cases were coded 1.
- Pedestrian Volume Class - all but 10 were coded 3.

There were 654 records of which 269 were dummy records representing the non-occurrence of accidents at the given location. Thus there were 385 accident records to analyze.

It was necessary to know if the treatment and control sites were alike in the "before" period in order to ascertain the efficacy of the treatment. There were 175 accidents in the before period. As the records were for periods of different time lengths these cases were appropriately weighted. This gave an adjusted total of 178 accidents.

A sequence of two-way tables in which SITE-TYPE was one of the factors was constructed. The following factors tested different in "before" and "after" as measured by a simple chi-square test of homogeneity:

- Road Class (CLASS)
- Sight Distance (SIGHT)
- Major Volume (MAJ-VOL)
- Minor Volume (MIN-VOL)

The appropriate two-way tables (weighted) are found in Table D-1.

It should be noted that since these four variables are not of great significance in distinguishing "before and "after" cases, as will be demonstrated later. We feel that future conclusions based on assuming homogeneity are valid. Further, all other factors were homogeneous at the outset in both the treatment and control groups.

Various contingency tables were formed using the available data. It was not possible to analyze all the variables simultaneously as there was not sufficient data for this.

The first table formed was configured as YEAR x SEVERITY x ACC-TYPE x SITE-TYPE x PERIOD. This formed a 5 x 2 x 5 x 2 x 2 contingency table. A sequence of nested hypothesis were run on the data with the results provided in Table D-2. At the 5 percent significance level it can be concluded that of the above factors and interactions the statistically significant ones are:

(1) SITE-TYPE (ST)
(2) YEAR X ST

Thus, it can inferred that SEVERITY and ACC-TYPE play no role in explaining any difference that exist between "before" and "after" accidents.

The data was reconfigured as a contingency table with factors SIGHT, CLASS, YEAR, SITE-TYPE and PERIOD (i.e. before vs. after). This formed a 2 x 2 x 5 x 2 x 2 table. Again a series of nested hypothesis were examined with the resulting information statistic found in Table D-3. At the 5 percent significance level it can be concluded that of the

Table D-1. Two-way contingency tables for site type by major volumes, minor volume, road class, and sight distance

SITE TYPE BY ROAD CLASS

SITE TYPE	ACCIDENT COUNT ROAD CLASS Local, Local	Local, Collector	ROW TOTAL
Converted	24	1	25 14.3%
Control	116	37	153 85.7%
COLUMN TOTAL	140 78.7%	38 21.3%	178 100.0%

CHI-SQUARE	D.F.	SIGNIFICANCE
4.17757	1	0.0410

SITE-TYPE BY MINOR VOLUME

SITE TYPE	ACCIDENT COUNT SIGHT DISTANCE TYPE 1	2	ROW TOTAL
Converted	24	1	25 14.3%
Control	90	62	153 85.7%
COLUMN TOTAL	115 64.4%	63 35.6%	178 100.0%

CHI-SQUARE	D.F.	SIGNIFICANCE
11.41695	1	0.0007

Table D-1. Two-way contingency tables for site type by major volumes, minor volume, road class, and sight distance (Continued)

SITE-TYPE BY MAJOR-VOLUME

SITE TYPE	ACCIDENT COUNT MAJOR VOLUME GROUP 1	2	3	4	5	ROW TOTAL
Converted	0	16	5	4	0	25 14.3%
Control	5	40	69	33	6	153 85.7%
COLUMN TOTAL	5 2.8%	56 31.4%	74 41.6%	37 20.7%	6 3.5%	178 100.0%

CHI-SQUARE	D.F.	SIGNIFICANCE
15.29097	4	0.0041

SITE-TYPE BY MINOR-VOLUME

SITE TYPE	ACCIDENT COUNT MINOR VOLUME GROUP 1	2	3	4	ROW TOTAL
Converted	16	9	0	0	25 14.3%
Control	40	56	41	16	153 85.7%
COLUMN TOTAL	56 31.4%	65 36.6%	41 22.9%	16 9.1%	178 100.0%

CHI-SQUARE	D.F.	SIGNIFICANCE
19.62727	3	0.0002

Table D-2. Information statistic for variables of year, severity, accident type and site type

FACTOR	INFORMATION STATISTIC	DF
Year (YR)	4.369	4
Severity (SEV)	0.082	1
Accident Type (AT)	4.379	4
Site Type (ST)	16.530	1
YR X SEV	0.437	4
YR X AT	26.842	16
YR X ST	19.457	4
SEV X AT	6.996	4
SEV X ST	0.351	1
AT X ST	2.088	4

Table D-3. Information statistic for variables of sight triangle, road class, year, site type

FACTOR	INFORMATION STATISTIC	DF
SIGHT TRIANGLE	0.864	1
CLASS	0.621	1
YEAR (YR)	4.620	4
SITE TYPE (ST)	15.523	1
SIGHT X CLASS	0.134	1
SIGHT X YR	2.496	4
SIGHT X ST	0.013	1
CLASS X YR	1.319	4
CLASS X ST	0.027	1
YR X ST	20.995	4

above factors and intersections the only statistically significant one is SITE-TYPE. This conclusion is very similar to those drawn previously. It is further concluded that Sight Triangle and Class play no explanatory role in "before" vs. "after" accidents.

The data was further configured as a contingency table with factors Light Conditions (LC), Major-Volume (categorized into five levels) (MV), Year (YR), Site-Type (ST) and Period (PER). This yielded a 2 x 5 x 5 x 2 x 2 contingency table. (n.b. LC had so few observations at levels 0 and 3 that these levels were excluded from the analysis). The results are displayed in Table D-4.

At the 5 percent significance level the Year x Site-Type interaction and the Major-Vol x Yr interaction are significant.

The data was further configured as a five factor table whose factors were Minor Volume (MinV), Major-Volume (MajV), Year (YR), Site-type (ST) and Period (PER). This formed a 4 x 5 x 5 x 2 x 2 table. The results are found in Table D-5. As before the only significant interaction is YR x ST. Although major volume was not found to be significant it was kept for further analysis since, on face value, it should be a key variable in determining the probability of accident under either control type given a major approach volume.

For the final analysis, a four factor contingency table was formed using the following factors: Major Volume, Year, Site Type and Period. This is a 5 x 5 x 2 x 2 contingency table. The results of the nested hypothesis analysis are shown in Table D-6. Of the variables and interactions listed, site type and the interaction of major volume and year were significant. Thus, the following hypothesis (model):

MajV x YR x ST
MajV x YR x PER
ST x PER

The data was then analyzed using the procedure SKPKUL that looks at the underlying parameters and their convariance matrix. Adjusting for zero cells and marginals the above hypothesis has 9 degree of freedom (df). Now a Chi-Square with 1 df and a value of 13.330 is a very acceptable fit. However, an examination of the 25 parameters estimated and their standardized values indicates that many of these parameters are not significant. Thus, it was decided to remove many of these parameters and see what behavior the information statistic exhibited. As a first pass all main effects except that due to SITE-TYPE were removed from the model. This model had an information statistic of 27.703 with 17 df, which is a very good fit. To judge the significance of the parameters that were removed from the model one has but to notice that the effect of the removed parameters has an information statistic of 14.373 with 8 df. As the critical value of a Chi-Square with 8 df is more than 15 it is concluded that the removed parameters are insignificant. Through a long process, more of the parameters were removed and 7 parameters relating to the MAJ-V, YEAR interaction were equated to each other. The only main effect present in the model is that of SITE-TYPE. The odds factor table relating to this model is shown in Table D-7. This model has an information statistic of 31.130 with 20 degrees of freedom. This is a very good fit with only 5 non-normalizing parameters.

From the information in Table D-7, if one wished to calculate the odds of "before" to "after" for MajV-3, YR=2 and Site-Type=1 (a conversion) the odds is given by:

$$0.678153 \times 2.251475 \times 0.399298 = 0.609666$$

This, of course, implies that the probability of a "before" accident is smaller than the probability of an "after" accident. It should be noted that to show an improvement it must

Table D-4. Information statistic for variables of light condition, major volume, site type and period

FACTOR	INFORMATION STATISTIC	DF
YR X ST	37.315	9
LC	0.518	2
MV	1.504	4
LC X MV	1.498	8
LC X YR	4.836	8
LC X ST	0.047	2
MV X YR	28.836	16
MV X ST	1.588	2

Table D-5. Information statistic for variables of major and minor volumes, year, site type and period

FACTOR	INFORMATION STATISTIC	DF
YR X ST	37.303	9
MinV	0.282	3
MajV	1.825	4
MinV x MajV	4.475	12
MinV x YR	8.101	12
MinV x ST	0.067	3
MajV x YR	25.591	16
MajV x ST	2.299	4

Table D-6. Information statistic for variables of major volumes, year, site type and period

FACTOR	INFORMATION STATISTIC	DF
MajV	2.277	4
YR	4.313	4
ST	15.215	1
MajV x YR	34.185	16
MajV x ST	4.343	4
YR x ST	7.390	4

Table D-7. Odds factor table

BASE
0.678153

MajV x YR
(1,3) 1845.099365

MajV x YR
(1,4) 1844.749268

MajV x YR
(2,1),(2,2),(3,1),(3,2),(3,3),(4,2)(4,4) 2.251475

Site-Type
0.399298 level 1

n.b. all other combinations have value 1

be that the odds exceed one (1), i.e., the "after" probability of accident is smaller than "before" probability. All factors being equal, it can be seen that if a site is a treatment site that the odds (before/after) are approximately 40% of the same odds at a control site. This indicates that there was an increase in the "after" probability at the treatment sites. Further, from the convariance matrix the associated parameter for Site-Type is statistically significant at the .05 level.

In Table D-8, the odds are ordered from highest to lowest for various levels of major volume, year and site-type. Thus the experimental conditions go from least favorable to most favorable. It should be noted from this table that with no exception the conversion sites occupy the least favorable part of the list. Also, the odds fall into distinct segments where all the odds in a given segment have the same odds. The question that is now posted is whether the different odds are statistically different. Using the covariance matrix of the underlying parameters and the values of the parameters themselves it is easy to show that these different odds are in fact statistically distinct.

In the left-hand column of the table is the appropriate function of the tau's (τ)*** associated with the respective odds. The table containing the τ's and their covariance matrix follows the odds table (Table D-9).

One notices that all the favorable odds occur for the control sites. One notices that MajV=5 occur for these; however, no MajV=5 occur for the conversion sites as none were in the study. It is clear that conversion from STOP to YIELD in almost all cases increases the probability of having an accident under experimental conditions encountered. This is reinforced by noting that the odds factor for Site-Type is 0.3992980.

The relative odds (ratio of the odds) is an excellent indication of the effect of the treatment. The following is a list of relative odds:

MAJ-V	YR	Relative Odds
4	4	2.504
4	3	2.504
3	4	2.504
3	2	2.504
2	4	2.504
2	3	2.504
2	2	2.504
2	1	2.504

*** The τ's used in log linear representation of estimates are analogous to the β's use as regression coefficients in ordinary regression analysis. Just as in regression analysis, different models yield different τ's. In fact, in both cases we do not use the underlying true parameters as they are not available and must be estimated. The τ's (i.e., their estimates) appear in the representation of the cell estimates for the appropriate model. Since these τ's are estimated they are statistics and have means, variances and covariances with one another. Further, these τ's represent the main effects and intersection of factors under consideration. The approach we use provides both the estimates of the τ's and their convariance matrix.

Table D-8. Odds table

	Major Volume Group	Year	Site-Type	Odds
$\gamma_1 + \gamma_2$	1	3	2	1251.0864*
$\gamma_1 + \gamma_3$	1	4	2	1250.565*
	4	4	2	1.5268
	4	2	2	1.5268
	3	2	2	1.5268
	2	2	2	1.5268
	2	1	2	1.5268
	3	2	2	1.5268
$\gamma_1 + \gamma_4$	3	1	2	1.5268
	5	4	2	0.6782
	5	2	2	0.6782
	5	1	2	0.6782
	4	5	2	0.6782
	5	3	2	0.6782
	3	5	2	0.6782
	3	4	2	0.6782
	2	3	2	0.6782
	2	4	2	0.6782
	4	1	2	0.6782
	2	5	2	0.6782
	4	3	2	0.6782
	5	5	2	0.6782
	1	1	2	0.6782
γ_1	1	2	2	0.6782
	4	1	1	0.6097
	2	1	1	0.6097
	3	2	1	0.6097
$\gamma_1 + \gamma_4 + \gamma_5$	2	2	1	0.6097
	2	2	1	0.2708
	4	1	1	0.2708
	4	3	1	0.2708
	2	3	1	0.2708
	2	4	1	0.2708
$\gamma_1 + \gamma_5$	3	4	1	0.2708

* These odds are due to the fact that 'after' condition has no accidents recorded; hence; these odds are an aberration and should not be taken seriously.

Table D-9. Matched Pairs of Odds

MAJ-V	YR	ST	Control Odds	MAJ-V	YR	ST	Treatment Odds
4	4	2	1.5268	4	4	1	0.6097
4	3	2	0.6782	4	3	1	0.2708
3	4	2	0.6782	3	4	1	0.2708
3	2	2	1.5268	3	2	1	0.6097
2	4	2	0.6782	2	4	1	0.2708
2	3	2	0.6782	2	3	1	0.2708
2	2	2	1.5268	2	2	1	0.6097
2	1	2	1.5268	2	1	1	0.6097

Thus, it can be seen that, all other factors equal, the odds of having an accident at a treatment site are 2.5 those at a control site. More precisely, as the site-type is homogeneous with respect to all important variables, it can be said that the probability of an accident at a treatment is 2.5 times that at a control site independent of the particular factors that characterize the site.

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