Safety Effectiveness of Highway Design Features

Volume V: INTERSECTIONS

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Safety Effectiveness of
Highway Design Features

VOLUME V

INTERSECTIONS

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PREFACE

This is the fifth volume in a series of six publications providing research results on the safety effectiveness of highway design features. This series provides designers and traffic engineers with useful information on the relationship between accidents and highway geometrics.

The Scientex Corporation, the Highway Safety Research Center at the University of North Carolina, Chapel Hill, and Michael Baker Jr., Inc., have compiled this Compendium under contract with the Federal Highway Administration. The six volumes include:

Volume I:	Access Control
Volume II:	Alignment
Volume III:	Cross Sections
Volume IV:	Interchanges
Volume V:	Intersections
Volume VI:	Pedestrians and Bicyclists

Authors with extensive experience in each subject area have reviewed past research, and significant findings are summarized here, along with an additional bibliography for reference.

INTERSECTIONS

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FOREWORD

In the early 60's, the highway community became increasingly interested in the safety effects of geometric design. The first attempt to quantify the state of knowledge on this topic was undertaken by the Highway Users Federation for Safety and Mobility (HUFSAM) in 1963 and 1971.

Considerable research on geometrics and safety was then initiated, and in the late 1970's, the Federal Highway Administration (FHWA) provided a consolidated resource for the safety impacts of various geometric and traffic control alternatives. This document, the Synthesis of Safety Research Related to Traffic Control and Roadway Elements Volumes I and II (FHWA Report Nos FHWA-TS-82-232, 233), which updated the earlier HUFSAM reports, served a critical and useful purpose by providing valuable geometric/accident relationships.

This present compendium is the result of the FHWA implementing one of the 23 recommendations contained in TRB Special Report 214, "Designing Safer Roads - Practices for Resurfacing, Restoration and Rehabilitation." This report specifically responds to the recommendation, calling for the FHWA to "...develop, distribute, and periodically update a compendium that reports the most probable safety effects of improvements to key highway design features..."

As an initial task, all available United States literature potentially relating a geometric feature with traffic accidents was identified. Resources included the Transportation Research Information Service, libraries at the University of North Carolina and United States Department of Transportation, and the personal documents of the project team. In addition, accident/geometric data bases were identified as possible sources of data which could be used to develop needed relationships.

This identification effort revealed a lack of many new (post-1973) documents for several geometric topic areas. Accordingly, some major pre-1973 reports, along with the post-1973 reports were included for critical review.

Critical reviews of these reports involved determination of the appropriateness of the study design, the adequacy of the sample size, the application of proper statistical tests and correct interpretation of results. Only information meeting all of these criteria is reported in each volume of this report. These documents are listed in the reference section at the end, and an additional bibliography section is included, covering related research of interest, but not used in this report.

INTERSECTIONS

INTRODUCTION

Intersections constitute a very small part of rural and urban street/highway systems, yet are implicated in over half of the motor vehicle accidents. Data from national statistics show that the percent of total motor vehicle accidents classified as intersectional has risen in the past 20 years.[1] As shown in table 1, urban motor vehicle accidents classified as intersectional have increased 14 percent over the past 2 decades, and for rural areas, an increase of 5 percent.

Table 1. Percent motor vehicle accidents classified as intersectional - urban & rural areas.[1]

Year	Urban	Rural
1968	41%	27%
1988	55%	32%

However, high accident rates at these locations are to be expected. Intersections are concentrated conflict points between vehicles and between vehicles and pedestrians. They generally function at decreasing capacity and level of service, as the frequency and severity of their conflicts increase.[2] In spite of this, table 2 shows that the percent of fatal motor vehicle accidents classified as intersectional for both urban and rural areas has dropped in the past 20 years.[1] Thus although the percentage of motor vehicle accidents occurring in intersections has risen, the severity has decreased.

Table 2. Percent fatal motor vehicle accidents classified as intersectional - urban & rural areas.[1]

Year	Urban	Rural
1968	39%	17%
1988	28%	16%

Reduction in fatalities is likely due, in part, to implementation of considerable research over the past 2 decades aimed at improved intersection design/construction, new vehicle designs, and improved availability and use of various passenger restraints. For example, completed work focusing on the separation of pedestrians from vehicles is reflected in design changes for bus loading and unloading zones. Progress in speed reduction methods and channelization, countermeasures like dual turn lanes, enhanced visibility at intersections, traffic control devices, and improved signal timing all have probably helped to reduce fatalities at intersections.

Intersection elements which are related to intersection accident rates include geometric layout and traffic controls. Within the category of geometric layout, there are several features which collectively form an intersection's design, such as type, sight distance, number/width of lanes, turn lanes and channelization. This volume discusses only geometric layout, presenting accident data and research results which will aid highway planners and designers in their decision-making process to provide safe intersection designs.

SUMMARY OF RESEARCH

Type of Intersection

Intersection configurations include a multitude of patterns, the most common being 4-way, T-Type, Y-Type, and Offset. Before 1976, studies indicated rural 4-way intersections had up to a 400 percent increase in the number of accidents as compared to T-types. Then in 1976, a study performed at rural locations reported only a 69 percent increase in accidents for 4-Way intersections compared to T-Types (see table 3).[3] This data includes both STOP and signal controlled intersections. For comparative basis, the average accident rate for all intersection accidents in this study is 1.13 (accidents per million entering vehicles).

Table 3. Total accidents by intersection type in rural municipalities.[3]

Intersection Type	Total No.	Avg Acc Rate[1]
4-Way	1517	1.35
T-Type	373	0.80
Y-Type	127	1.22
Offset	54	0.58

Total Avg Acc Rate[1] for study = 1.13

[1] Accidents per million entering vehicles

note: includes both STOP and Signalized intersections

Data for urban locations was collected in another study, but the sample size for signalized intersections was too small for comparison.[4] At urban intersections with STOP signs, however, the accident rates were very similar for 4-Way and T-Type designs with an Average Daily Traffic (ADT) of under 20,000. Once above that plateau, the accident rate doubled for 4-Way when compared with T-Type intersections (see table 4).

Table 4. Accident rates by intersection type in urban locations.[4]

	Average Accident Rate[1]	
Average daily traffic	T-Type	4-Way
<5,000	1.3	1.3
5,000 to 10,000	1.6	1.9
10,000 to 20,000	2.7	3.0
>20,000	4.2	8.0

[1] accidents per million entering vehicles

note: includes only intersections with STOP signs, data was not available for signalized intersections.

Sight Distance

Deficiencies, such as obstructing foliage, buildings too close to the intersection, and change in vertical and horizontal alignment affect intersection sight distance. Whether urban or rural, studies have shown that the accident rate at most intersections will generally decrease when sight obstructions are removed.

In rural locations, this hypothesis is supported by a study which confirmed that intersections with poor sight distance on one or more traffic approaches tend to have a higher than normal accident rate, particularly with regard to angle collisions (see table 5).[3] In this study, the average accident rate was 1.13, while the average accident rate for intersections with poor sight distance is 1.33, supporting the statement that "intersections with poor sight distance experience a higher than normal" accident rate. Unfortunately, "poor" sight distance was not quantified.

Table 5. Accidents at intersections with poor sight distance for rural municipalities.[3]

Rear End	Angle	Sideswipe	Other
73(20%)	207(56%)	32(9%)	54(15%)

Total number of intersections = 41
Total number of accidents = 366
Avg Acc Rate[1] for poor sight distance = 1.33
Total Avg Acc Rate[1] for study = 1.13

[1] Accidents per million entering vehicles

note: includes both STOP and Signalized intersections

Another study, based on urban settings, found that foliage and buildings obstructed the view at the majority of intersections, whereas linear obstacles (walls and fences) obstructed less often.[4] This study calculated expected reduction in accident rate for increased radius of intersection, stratified by ADT (see table 6). For this calculation, the authors began with an intersection having an obstruction which allows drivers approaching the intersection to see only 20 ft of an approach side leg. The authors then derived the predicted reduction in accidents based on increasing the sight radius along the approach side leg to a given range.

Table 6. Expected effect of increased sight radius on accident reduction by ADT[4]

	Increased Sight Radius[1]		
ADT[2]	20-49ft	50-99ft	>100ft
<5000	0.18	0.20	0.30
5000-10000	1.00	1.3	1.40
10000-15000	0.87	2.26	3.46
>15000	5.25	7.41	11.26

[1] at 50 ft from intersection, increasing obstruction on approaching leg from initial <20 ft from intersection
[2] Average Daily Traffic

note: Accident Reduction = accidents/year/intersection

To illustrate the use of this table, consider the intersection in figure 1, where at 50 ft from the intersection, an obstruction exists which allows drivers to see approaching vehicles on a side approach only if it is within 20 ft of the intersection. Assume an ADT of under 5,000. Increasing the sight radius on the approach leg to more than 100 ft from that intersection should result in an accident reduction of 0.30 accidents per year per intersection.

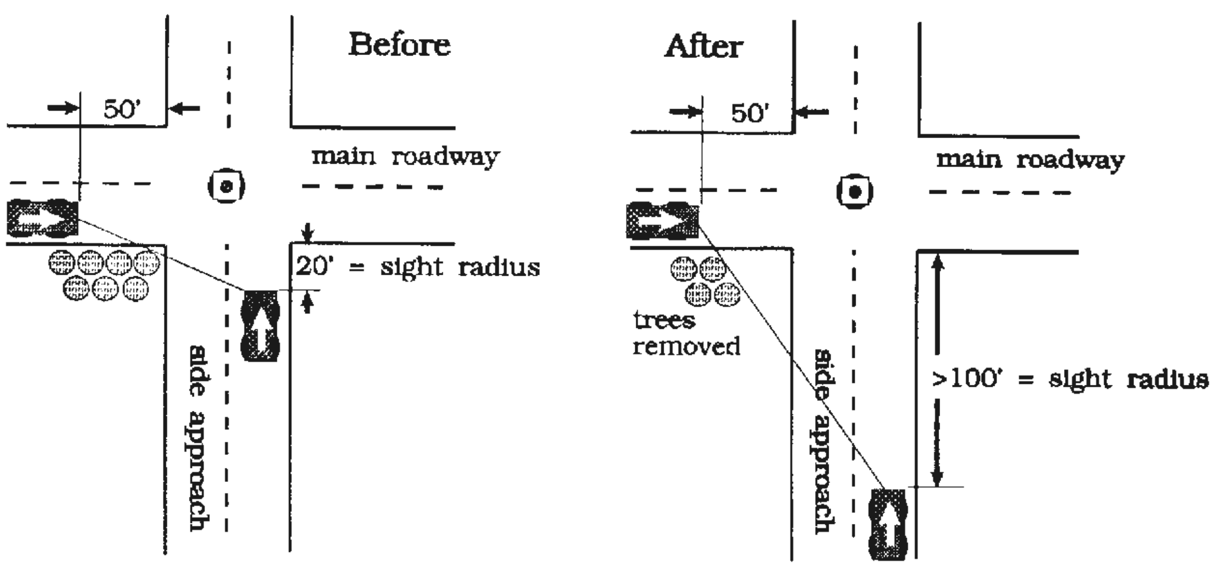

Figure 1. Example of increased sight radius on accident reduction.

In summary, both study authors recommend, and this is supported in other studies, that an increase in sight distance will result in a reduced accident rate.[5,6,7] However, the specific reduction in accident rate expected from specific increases in sight distance remains open. This inadequacy is being addressed by the National Cooperative Highway Research Program, in their fiscal year 1992 program, project number 15-14(1).

Channelization

A critical intersection design element involves provisions for vehicles to make turns at intersections. Where a large number of turns must be accommodated, ADT is high, and/or where the intersection area is complex (multiple lanes, pedestrian accommodations, complex signal timing, etc), channelization is usually deemed appropriate. Since the practice of providing right turn lanes is widely accepted and proven beneficial, a large portion of the channelization research has been devoted to left turn lanes. This section reports on these studies.

One study indicates that in urban locations, multi-vehicle accident involvement decreases when lane dividers are used.[4] These "dividers" included groupings of many different devices, such as raised reflectors, painted lines, barriers, or medians. Interestingly, this study recommends the use of left turn storage lanes in an urban setting only to increase capacity, and not as an accident countermeasure.

While no accident studies directly addressed the safety benefits of left turn lanes in rural areas, one study examined passing accidents at rural intersections.[8] This study concluded that passing accidents at rural intersections do not represent a major safety problem, but providing left turn lanes for new or reconstructed intersections will greatly reduce the potential of passing accidents at these locations.

In addition to calculating the estimated economic costs, the authors calculated (based on a cost-benefit analysis) the minimum number of annual passing accidents required to justify geometric design treatments (see table 7). The authors further note that a careful review of the geometric and traffic conditions should be made to determine the feasibility and overall impact of applying the recommended treatments.

Table 7. Minimum number of passing accidents required to justify design treatments.[8] (abbreviated table)

Geometric Treatment	No. Accidents[1]
Add Left Turn lane	1.47
By-pass at T-Type	1.75
Continuous 2-Way, LT Median Lane	2.81
Add Raised Median	0.74

[1] Annual number of passing accidents needed to implement treatment

note: table displays only those geometric treatments related to channelization.

Miscellaneous

The previously referenced studies presented a majority of the latest findings in relation to urban locations. With respect to rural intersections, additional findings are noteworthy.

Severe grades

The study by Hanna, et.al., which presented rural based data related to intersection type and sight distance, also included an interesting result with regard to severe grades (vertical alignment).[3] Their findings indicate that rural-based intersections with severe grades (greater than 5 percent) "generally operate safely, although they are obviously a potential hazard" (see table 8).

"Generally operate safely" was not defined, other than by inference through comparative average accident rates which showed the rate for intersections with grades greater than 5 percent to be 0.97, in comparison to the overall accident rate of 1.13. The authors note that accident histories should be closely studied before a decision to alleviate a severe grade condition is made.

Table 8. Accidents at intersections with severe grades for rural municipalities.[3]

Rear End	Angle	Sideswipe	Other
106(39%)	104(38%)	24(9%)	37(14%)

Number of intersections = 35
Number of accidents = 271
Avg Acc Rate[1] for severe grades = 0.97
Total Avg Acc Rate[1] for study = 1.13

[1] Accidents per million entering vehicles

note: includes both STOP and Signalized intersections

Passing accidents

As mentioned previously, a study relating rural intersection accidents (passing accidents specifically) and geometric treatments was performed.[8] An economic analysis was conducted to determine the minimum number of passing accidents at rural intersections needed to implement the specific geometric treatment. Table 9 presents the complete listing of the geometric treatments reported.

To illustrate the use of table 9, assume that an investigation revealed that five left turn related passing accidents occurred during a 3 year period at a rural intersection, i.e., 1.67 passing accidents annually. Comparing the 1.67 accidents at the site with the minimum requirement shown in table 9, eight treatments fall under the 1.67, but only four design treatments are directly related to the left turn lane problem and would be economically justified. In this illustration, a left turn lane would be justified.

The authors strongly encourage a review of the geometric and traffic conditions to determine the feasibility and *overall* impacts of constructing a left turn lane in this particular case.

Table 9. Minimum number of passing accidents required to justify design treatments.[9] (full table)

Geometric Treatment	No. Accidents[1]
Add Left Turn Lane	1.47
By-Pass at T-Type	1.75
Continuous 2-Way, LT Median Lane	2.81
Add Raised Median	0.74
Lower Grade/Improve Sight Distance	2.92
Widen Pavement & Shoulders	0.89
Remove/Relocate Obstacles	0.09
Add Right Turn Lane	0.75
Reduce Degree of Horizontal Curve	2.44
Add Bicycle Path	0.43
T-Type Replacing Y-Type	1.47
Remove Trees/Brush	0.12

[1] Annual number of passing accidents needed to implement treatment

Wrong-way movements

A study by Scifres & Loutzenheiser examined wrong-way movements on divided highways.[9] Although no accident data were presented, the authors presented three potential geometric treatments, which they hypothesize would reduce the number of wrong-way movements at intersections of divided highways: (1) where an undivided highway intersects a divided highway, the elevation of the undivided highway should be equal, or greater than that of the divided highway, (2) wherever possible, angles of intersection of other than 90 degrees should be avoided, and (3) at intersections where cross median storage space is not required, medians should be narrow but distinct.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)