RURAL EXPRESSWAY INTERSECTION SYNTHESIS OF PRACTICE AND CRASH ANALYSIS

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16. Abstract

This report presents a national synthesis of rural expressway, two-way stop-controlled (TWSC) intersection safety strategies and intersection designs and an analysis of Iowa expressway TWSC intersection crash characteristics. A rural expressway is a multi-lane highway with a divided median and with mostly at-grade intersections, although some intersections may be grade separated. The synthesis of intersection strategies is conducted in two parts. The first is a literature review and the second part is a national survey of strategies currently being applied by state transportation agencies. The characterization of crash patterns at TWSC expressway intersections is examined through the analysis of 5 years of crash data at 644 intersections.

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RURAL EXPRESSWAY INTERSECTION SYNTHESIS OF PRACTICE AND CRASH ANALYSIS

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EXECUTIVE SUMMARY

Rural expressways are built because they provide the public with improved mobility and safety benefits at a lower cost than freeways. Expressways are less expensive to build because they don't require the construction of as many interchanges or overhead bridges or the purchase of access rights. In addition, although the roadway costs may be similar for a rural expressway and rural freeways, the necessity of full access control can easily result in freeway construction costing double or more than a comparable expressway.

Although rural expressways are safer than two lane roadways, expressway intersections can become a safety concern because vehicles are traveling at high speeds on multiple lanes. In Iowa, traffic safety engineers have already implemented conventional countermeasures to problematic stop-controlled expressway intersections, including installing approach rumble strips, "Stop Ahead," "Cross Traffic Does Not Stop," and large "Stop" signs. Conventionally, another step in making these intersections safer would be to install signals. The benefits of signalization at rural high-speed expressway intersections are unknown, but there is evidence that moving from stop control to signal control often only changes the type of crashes (fewer right angle crashes and more rear-end crashes) rather than reducing the quantity or severity of crashes. Signals require a large capital investment; they increase maintenance, user delay, and operating costs; and they exposure the agency to additional legal liability. The next conventional improvement is to consider a costly interchange at the intersection or provide full access control over an entire segment of roadway.

The purpose of this study was to better understand the characteristics of crashes at expressway intersections and investigate alternate, intermediary countermeasures to signalization and intersections. A synthesis of practice is conducted to determine if other State Transportation Agencies (STA) are experiencing similar issues and what strategies are being applied to reduce safety issues at rural expressway intersections.

Through this research, we found that as volumes on expressways and intersecting roadways increase, crash rates and the severity of crashes at intersections increase. As a countermeasure to crashes and crash severity at expressway intersections, there are a number of safety strategies that may be applied, many of which STAs are currently testing, ranging from very low cost signing and marking strategies to high cost grade separation strategies.

Three important conclusions can be drawn from this report. First, the safety performance of conventional two-way stop-controlled intersections on expressways declines precipitately as volumes on the minor roadway increase. Second, there are a wide variety of strategies that may be applied at expressway intersections to improve safety. Engineers have many alternatives, including conventional countermeasures like installing offset turning lanes, to improve the safety of problematic intersections. Third, many STAs have implemented or are pilot testing several innovative strategies at expressway intersections. As the results of these tests become available, more will be known about the benefits of each intersection safety strategy and when and where the strategy is most appropriate.

1. INTRODUCTION

This report synthesizes safety practices and safety strategies applied at rural expressway intersections and presents the crash characteristics of Iowa expressway intersections. Although design standards vary from state to state, expressways are generally four-lane, divided facilities with interchanges only at intersections with major highways or along bypasses. All other expressway intersections are at-grade with some signalized intersections and, rarely, four-way stop-controlled intersections. Most expressway intersections are two-way stop-controlled (TWSC) with stop control on the minor roadway. Access points to the expressway are generally limited and they may or may not have frontage roads, depending on the density of development and the availability of right-of-way. Although expressways are usually high-speed facilities, the speed limit is generally determined by local conditions rather then a system-wide standard.

Expressways are built because they provide most of the mobility (travel-time) and safety benefits of freeways at a lower cost. At very low access point densities (less than 5 per mile) and at moderate volumes rural expressways can have crash rates that are comparable to freeways, as well as providing similar travel-time performance. But expressways do not involve the expense of building as many interchanges or overhead bridges for through crossroads (without an interchange) or the expense of purchasing access rights from all adjacent land owners. Additionally, expressways may involve a less expensive cross-section, depending on the design standards of the state. The roadway construction costs may be similar for a rural expressway and a rural freeway, but grade separation and full access control can easily result in freeway construction costing double or more than the cost of a comparable expressway.

Although expressways are generally safe, expressway intersections can become a safety concern because vehicles are traveling at high speeds. In Iowa, traffic engineers have already implemented conventional countermeasures to problematic stop-controlled intersections, including installing approach rumble strips, "Stop Ahead," "Cross Traffic Does Not Stop," and large "Stop" signs. Conventionally, the next step in making these intersections safer would be to install signals at the intersection, which is costly. The benefits of signalization at expressway intersections are unknown, but there is evidence that moving from stop control to signal control changes the type of crashes (fewer right angle crashes and more rear-end crashes) rather than reducing the quantity or severity of crashes. Signals require a large capital investment; they increase maintenance cost, operating cost, and user delay; and they expose the agency to additional legal liability. The next conventional improvement is to consider a costly interchange at the intersection or provide full access control over an entire segment of roadway.

The purpose of this study is to better understand the characteristics of crashes at expressway intersections and investigate alternate, intermediary countermeasures to signalization and grade separation.

1.1 Report Organization

This report is divided into five sections. The first chapter is this introduction. The next chapter is a literature review of prior research related to expressway intersections. The literature review examines prior research conducted on intersection design policy, safety impacts of intersection design features, statistical modeling of expressway intersections, and innovative geometric designs and innovative use of technology. The literature review found that although much information is available regarding the positive and negative impacts of special safety treatments at expressway intersections, very little specific guidance about applying improvements exists.

The third chapter of this report includes results from a survey of state transportation agencies (STAs) responsible for extensive expressway networks. The survey was conducted to gather information about STAs' experience with improving safety at expressway intersections. The survey determined that many STAs experience similar safety issues at expressway intersections. Of the STAs that have experienced expressway intersection safety issues, a few have tried or are contemplating innovative safety strategies in these locations. However, none of these STAs have conducted a crash study to quantify the benefits of such treatments.

In the fourth chapter, a descriptive and statistical analysis of crashes at TWSC expressway intersections in Iowa is presented. This analysis found that crash rate and crash severity increases with increased traffic volume. It was also found that increases in crash rates and crash severity are most strongly related to minor roadway volumes.

The last chapter of this report presents summary comments, conclusions, and recommendations for future research.

2. LITERATURE REVIEW

2.1 Methodology

This literature review focuses on issues related to rural TWSC intersections for four-lane divided highways with a two-lane roadway (4x2). Although rural TWSC 4x2 intersections are the focus of this research, these intersections have much in common with other rural intersections. Therefore, some of the literature examined deals with similar intersections with other geometry.

Because of the limited resources available for this study, our review is not exhaustive and we borrow heavily from others that have conducted related reviews of the literature. For our purposes, we have divided the literature into the following segments:

1. **Expressway intersection design policy studies.** Policy studies are defined as studies that determine policies for expressway design standards. For example, a policy might involve defining when grade separation of an intersection is warranted or under what conditions a conventional intersection should be converted to an offset T.

2. **Safety impacts of intersection features.** Although very few studies have been completed on the impact of various geometric features, signing, and marking at TWSC 4x2 intersections, many researchers have investigated the impact of design features at TWSC intersections in general or of specifically TWSC 2x2 intersections. These studies may not offer new information on identical intersection configurations, but they are analogous and provide insight into the impacts of these features at TWSC 4x2 intersections.

3. **Safety performance function modeling studies.** These studies have created statistical models of traffic safety performance at intersections and along highway segments. Several projects have created statistical models for intersection crashes for different geometric and control configurations (e.g., TWSC 2x2 intersections, Four-Way Stop-Controlled 2x2 intersections, signal-controlled 4x2 intersections, etc.). These models are generally developed using cross-sectional data for one highway cross-section or one-intersection geometry. Although the number of through lanes and intersection control remains constant with each member of the data set, variables such as approach volumes, presence of turning lanes, turning volumes, etc. may vary.

4. **Special design treatments and innovative technology.** There are a few examples of studies where researchers have proposed or tested (either through laboratory tests or empirical evaluations) innovative technologies or special design treatments. Technologies evaluated range from low-cost roadside markers that help drivers select safe gaps to ITS technology to assist drivers select a safe gap. Several alternative designs have been proposed and built. Generally, the purpose of the design is to reduce traffic conflicts.

2.2 Expressway Intersection Design Policy Studies

In a 1993 survey of STAs, Bonneson, McCoy, and Truby found that 30 out of the 42 responding STAs were building or have built expressways with at-grade intersections (1). Using the Federal Highway Administration's (FHWA) "Highway Statistics" reports to create Table 2.1, it is evident that several states have continued to increase the size of their expressway systems (2). Table 2.1 summarizes the change in rural expressway mileage in the U.S. between 1996 and 2002. Between 1996 and 2002, the mileage of rural expressways increased nationally by nearly 27%, or almost 3,800 miles. During the same period, the number of miles of multi-lane, divided rural facilities with full access control (interstate and non-interstate) increased national by only 2.4%, or almost 900 miles.

Several states have been adding extensively to their rural expressway systems. For example, between 1996 and 2002, the states of Texas and Missouri added 541 and 387 miles of rural expressway to their highway systems, respectively. Mississippi, Virginia, Tennessee, New Mexico, Ohio, and West Virginia all added over 100 miles. Nebraska, Illinois, Louisiana, Alabama, South Dakota, North Dakota, Maryland, and North Carolina all added over 50 miles. During the same period, 14 states chose to not increase or reduce the size of their rural expressway system. Although rural expressway and expressway mileage continues to grow in the U.S., very little is known about the safety of rural expressways because little research has concentrated on these roadways (3).

Most likely, constructing expressway systems is popular because expressways provide similar mobility benefits to those provided by freeways, without the costs associated with grade separation and complete access control. At low volumes, expressways experience crash rates (crashes per million vehicle miles) that are similar to those of rural freeways (4). However, as traffic volumes increase, crash rates grow, thus reducing the incremental net benefits of expressways when compared to freeways (5).

Table 2.1. Change in the Federal-Aid, Rural Expressway System by State from 1996 to 2002

Sorted by Total Miles

Miles Rank	State	Miles	Percent Increase
1	Texas	1983	37.52%
2	Virginia	1083	18.10%
3	Mississippi	801	27.96%
4	Ohio	775	20.53%
5	Florida	771	5.04%
6	Missouri	700	123.64%
7	Georgia	638	4.76%
8	Minnesota	633	-10.47%
9	Alabama	623	14.52%
10	North Carolina	605	11.42%
11	California	584	5.04%
12	Indiana	566	-0.53%
13	Tennessee	529	37.40%
14	South Carolina	498	9.93%
15	New Mexico	453	44.27%
16	Oklahoma	449	3.70%
17	North Dakota	429	18.84%
18	Maryland	366	20.79%
19	Louisiana	363	32.00%
20	West Virginia	349	47.88%
21	Kentucky	306	-13.56%
22	Wisconsin	296	12.12%
23	**Iowa**	**277**	**4.53%**
24	Pennsylvania	264	14.78%
25	Illinois	247	62.50%
26	Nebraska	246	67.35%
27	Washington	227	24.73%
28	South Dakota	209	58.33%
29	New York	193	-4.46%
30	Colorado	151	-17.93%
31	Delaware	150	40.19%
32	Kansas	133	9.02%
33	Arizona	127	1.60%
34	Michigan	113	52.70%
35	Oregon	104	-14.75%
36	New Jersey	96	17.07%
37	Arkansas	92	13.58%
38	Utah	72	-8.86%
39	Idaho	53	0.00%
40	Nevada	38	-34.48%
41	Montana	21	40.00%
42	Vermont	18	63.64%
43	Rhode Island	15	15.38%
44	Alaska	13	333.33%
45	Wyoming	7	600.00%
46	Massachusetts	5	-54.55%
47	Hawaii	3	-25.00%
48	New Hampshire	1	-88.89%
49	Connecticut	0	-100.00%
50	Dist. of Columbia	0	0.00%
51	Maine	0	0.00%

Sorted by Percent Increase from 1996 to 2002

% Rank	State	Miles	Percent Increase
1	Wyoming	7	600.00%
2	Alaska	13	333.33%
3	Missouri	700	123.64%
4	Nebraska	246	67.35%
5	Vermont	18	63.64%
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44	Kentucky	306	-13.56%
45	Oregon	104	-14.75%
46	Colorado	151	-17.93%
47	Hawaii	3	-25.00%
48	Nevada	38	-34.48%
49	Massachusetts	5	-54.55%
50	New Hampshire	1	-88.89%
51	Connecticut	0	-100.00%

Sorted by Miles Increased from 1996 to 2002

Rank	State	Miles Increase
1	Texas	541
2	Missouri	387
3	Mississippi	175
4	Virginia	166
5	Tennessee	144
6	New Mexico	139
7	Ohio	132
8	West Virginia	113
9	Nebraska	99
10	Illinois	95
11	Louisiana	88
12	Alabama	79
13	South Dakota	77
14	North Dakota	68
15	Maryland	63
16	North Carolina	62
17	South Carolina	45
18	Washington	45
19	Delaware	43
20	Michigan	39
21	Florida	37
22	Pennsylvania	34
23	Wisconsin	32
24	Georgia	29
25	California	28
26	Oklahoma	16
27	New Jersey	14
28	**Iowa**	**12**
29	Arkansas	11
30	Kansas	11
31	Alaska	10
32	Vermont	7
33	Montana	6
34	Wyoming	6
35	Arizona	2
36	Rhode Island	2
37	Dist. of Columbia	0
38	Idaho	0
39	Maine	0
40	Hawaii	-1
41	Connecticut	-3
42	Indiana	-3
43	Massachusetts	-6
44	Utah	-7
45	New Hampshire	-8
46	New York	-9
47	Oregon	-18
48	Nevada	-20
49	Colorado	-33
50	Kentucky	-48
51	Minnesota	-74

Very little literature exists that identifies specific warrants for designing to higher standards (e.g., moving from an at-grade divided highway to a full access control, grade separated divided highway) or provides specific guidance about when to consider geometric improvements at intersections (these generally aimed at removing conflict points like indirect left-turns through median crossovers).

Figure 2.1 shows one innovative safety design improvement for reducing intersection conflicts. The indirect left, median crossover is commonly used in urban and suburban areas in Michigan (and possibly other states) but there is no policy defining where it should be used at rural expressway intersections (6).

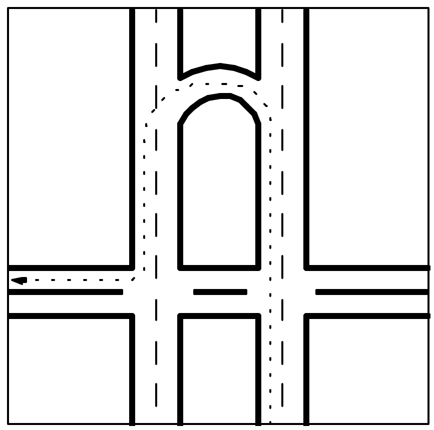


Figure 2.1. Indirect Left with Median Cross Over (7)

Some geometric improvements for expressway intersections are identified by the American Association of State Highway and Transportation Officials (AASHTO) Strategic Highway Safety Plan (SHSP) for intersections without signals. The SHSP identifies characteristics where a designer should consider such geometric improvements (8), but the SHSP stops short of identifying characteristics that would warrant implementation of an unconventional design.

Bonneson and McCoy conducted a study of practices for determining whether to grade separate intersections of expressways with other major highways for the Nebraska Department of Roads in the early 1990s. Their study focused on two tasks. The first was to conduct a survey of practices in other states and the second was to formulate a benefit/cost model for the Nebraska Department of Roads to use when determining whether to improve a stop-controlled at-grade intersection to a signalized intersection or a diamond interchange. Their findings are discussed in two papers (1, 9). Although Bonneson and McCoy found that other STAs had no specific criteria for determining where an expressway should be designed with interchanges (with the exception of intersections with interstate highways), they did find two STAs building newly constructed bypasses with complete access control and grade separation to address the high crash rate found at high-volume, at-grade intersections on expressways already in place. While demonstrating the use of their benefit/cost model, Bonneson and McCoy found that for TWSC 4x2 intersections, grade separation is generally not cost-beneficial when minor roadway volumes are less than 2,000 vehicles per day (vpd) but they are generally cost-beneficial when minor roadway volumes exceed 4,000 vpd.

The SHSP "Guide for Addressing Unsignalized Intersection Collisions" includes guidelines for all types of unsignalized intersections, including TWSC 4x2 intersections on divided highways. This guide lists safety countermeasures and typical characteristics for identifying appropriate countermeasures as well as the relative cost and timeframe for implementation of countermeasures. In general, the SHSP "Guide for Addressing Unsignalized Intersections Collisions" is intended as a guide for individual agencies to consult when addressing issues within each jurisdiction's highway system rather than prescriptive or specific directions for improving safety (7).

The AASHTO's "Policy on Geometric Design of Highways and Streets" discusses the use of such treatments as indirect left-turn treatments at expressways intersections and illustrates several alternative designs (10). Alternative designs reduce the total number of conflict points when compared to a conventional TWSC 4x2 intersections. Only a limited amount of guidance is given regarding appropriate locations to apply such treatments: "where the median is too narrow to provide a lane for left-turning vehicles and the traffic volumes or speeds, or both, are relatively high, safe, efficient operation is particularly troublesome" (10, p. 709). This policy gives no guidance for converting an intersection or a highway from partial access control to full access control.

From this literature review, we learned that many states are adding miles to their expressway systems, making rural expressways a fast-growing segment of the highway system. However, little policy guidance is available regarding application of special treatments to expressway intersections. Although many states are building expressways, innovative designs or access control is applied on a case-by-case basis.

2.3 Safety impacts of intersection features

TWSC 4x2 intersections on divided highways are generally covered in the literature as part of the larger class of unsignalized intersections. A significant amount of literature has been generated regarding the safety impacts of design variables (channelizations, sight distance, signage and markings, intersection, etc.), however, crash frequency is largely explained by traffic volume. For example, Bauer and Harwood report from their review of crash data reports from eight urban intersections that "only 5 to 14% of the crashes had causes that appeared to be related to geometric design features of the intersections" (11). In another study of three and four-legged intersections of rural two-lane roads, Bauer and Harwood found that geometric design features were only able to explain 2% of the variation in crashes while traffic volumes explained 27% (12).

Vogt, in a 1999 study conducted for the Federal Highway Administration, provides an extensive literature review that covers several design and environmental features of intersections (13). Table 2.2 summarizes Vogt's findings.

Table 2.2. Summary of the impacts of design and environmental factors on intersection crashes (12)

Design variables	Safety implications
Channelization	The presence of both left-hand and right-hand turning lanes tends to reduce crash frequency.
Sight distance	Although it seems intuitive, greater sight distances at intersections have been shown to reduce crash frequency.
Horizontal and vertical alignment	Horizontal curves have been shown to be most significantly related to crash frequency. Although the relationship between vertical alignment and crash frequency is not as strong as horizontal alignment, grades different from zero have been shown to increase crash frequencies.
Intersection angle	Geometric design guidance encourages right angle intersections, but research on the safety impacts of skewed intersections provides mixed results. In general, right angle intersections are safer than severely skewed intersections but there is evidence that mildly skewed intersections are safer than right angle intersections.
Median width and shoulder width	Wider medians generally allow for a greater zone of refuse for turning vehicles and generally result in fewer crashes. Wider shoulder widths have been found to lower the probability of serious crashes.
Lighting	Research has shown that intersection lighting reduces the incidents of intersection crashes.
Roadside hazards and driveways	Zegeer, Hummer, Herf, Reinfurt, and Hunter have developed a commonly used method to rate the quality of roadside conditions. On a scale from 1 to 7 (1 being the best) roadsides are evaluated based on sideslopes, clear zone, and distance to the nearest fixed object (i). Roadside hazards tend to increase crash severity and the density of driveways in the proximity of the intersection tends increase crash frequencies.
Environmental variables	**Safety implications**
Truck percentage	There is some evidence that when trucks make up a higher proportion of the traffic there are fewer truck crashes and fewer crashes on rural roads. However, greater truck volumes will necessitate more generous use of auxiliary lanes and improved sight distances.
Speed	Research has shown that higher speeds result in increased frequencies of intersection crashes. However, Pickering, Hall, and Grimmer found that 3-legged intersections have higher operating speeds, resulting in more right-turn crashes, but fewer crashes of all other operating types (ii).

(i.) Zegeer, C.V., Hummer, J., Herf, L., Reinfurt, D., and Hunter, W., "Safety Cost-Effectiveness of of Incremental Changes in Cross-Section Design – Informational Guide," Report No. FHWA-RD-87-094, McLean, VA, 1987. (ii.) Pickering, D., Hall, R.D., and Grimmer, M., "Accidents at Rural T-Junctions," Research Report 65, Transportation and Road Research Laboratory, Department of Transport, Crowthorne, Berkshire, United Kingdom, 1986.

Recently, studies with similar objectives, methodology, and results were conducted in Kansas and Minnesota. The objective of both studies was to identify causes of TWSC rural intersection crashes when drivers on the minor roadway either fails to stop and collides with a vehicle on the major roadway or stops, but fails to yield the right-of-way to a conflicting vehicle. The study in Kansas was conducted by a group of researchers at Kansas State University (Stokes, et al.) and the Minnesota study was conducted by Preston and Storm (14, 15).

The Kansas and Minnesota studies both began by analyzing the database of crash records in their respective states and identifying locations where several right angle crashes had occurred at TWSC intersections. In both cases, police records provided information on the contributing cause of the crash. After conducting a statistical investigation of the crashes using the crash database, the researchers in each study selected a group of intersections for field investigators to examine and use to identify intersection attributes that might lead to right angle crashes. In both studies, the researchers came to the same conclusion: the major contributing factor to TWSC right angle crashes was not a failure to observe the stop control at the intersections but rather driver failure to adequately select gaps when crossing or turning onto the major roadway.

Both studies looked at the conventional countermeasures for reducing the number of stop-sign violations, including installing larger signs and using more "Stop Ahead" or "Cross Traffic Does Not Stop" signs. Both the Kansas and Minnesota researchers came to the same conclusion: although they may marginally reduce crashes, conventional countermeasures do not address the predominate cause of right angle crashes, the selection of unsafe gaps.

To illustrate that the misjudgment of gap size is a common problem, the Kansas study cited a study conducted by the University of Nebraska Psychology Department. In this study, researchers placed stationary human subjects next to rural and urban roadways and asked them to judge the speed of oncoming vehicles and did the same in a simulated (laboratory) environment (16). When seated 3 to 5 meters from the roadway shoulder, observers consistently underestimated the speeds of oncoming vehicles in rural environments and consistently overestimated oncoming vehicle speeds in urban environments. There was a consistent bias related to vehicle size; observers were more prone to underestimate the speed of smaller vehicles than larger vehicles. When making observations in a simulated environment, the subjects consistently estimated that the vehicles were traveling at a lower speed than they did in the field.

The authors of the Kansas study were satisfied that the current signing practice is sufficient. They identified sources from the literature to further confirm that improved signage is unlikely to significantly reduce right angle crashes, including a field study by Mounce and a study of low volume intersection control in Minnesota by Chalupnik (17, 18). Mounce made "2,830 observations at 66 low-volume intersections and found that 1) stop sign violation rate decreases with increasing major roadway volume, 2) stop sign violation rate is significantly higher when sight distance on the approach is unrestricted than it is when sight distance is restricted, and 3) there is no correlation between stop sign violations rates and accidents." Chalupnik found that at low volume intersections, the type of control (stop, yield, and no control) has little impact on crash rates. In other words, the type of control does not seem to have an impact on crash frequencies and, in the opinion of Stokes, et al., the current Kansas Department of Transportation signing standards are sufficient. Further, given that crash frequency decreases with speed, the authors recommended the Kansas Department of Transportation implement some signage for traffic calming on the mainline.

The Minnesota study identified 768 right angle crashes at rural TWSC intersections. In the crash record, the reporting officer indicated whether the minor road vehicle ran the stop sign or stopped and then pulled out. For 57% of the crashes, the officer noted that the vehicle stopped and then pulled in front of crossing traffic. The vehicle ran the stop sign 26% of the time, and in 17% of the cases, there was conflicting information or action prior to the crash was unknown. In other words, the majority of the crashes were clearly caused by an inability to judge a safe gap.

The Minnesota study conducted field studies of 10 intersections with a large number of right angle crashes where the action before the crash was a failure to stop, 10 intersections with a large number of crashes where the action before the crash was to stop and then pull out into crossing traffic, and 10 intersections where no right angle crashes have occurred. In general, these comparisons found that conventional measures may tend to reduce the crashes where the movement before the crash is a stop-sign violation. This includes such strategies as larger and brighter stop signs, the use of “Stop Ahead” signs, and the presence of streetlights. One of the non-conventional strategies identified was the proximity of other stop-controlled intersections. That is, if there is another stop-controlled intersection on the minor roadway within a mile, drivers are more likely to stop at TWSC intersections. To address crashes that are caused by drivers selecting an inappropriate gap, the authors suggest new technology, both low-tech and high-tech, to help drivers judge gaps.

Bonneson, McCoy, and Eitel, in their study of TWSC 4x2, point out that the combination of high speed and only partial access control creates a situation that may adversely impact safety, and they list six factors that may contribute to crashes at intersections. Similar to the Kansas and Minnesota studies, Bonneson et al. found that the inability of drivers to judge gaps is a predominate cause of right angle crashes. Five of the six factors concern the driver’s inability to judge an adequate gap for turning onto the expressway or crossing the expressway. The other factor is expectancy and the driver's unfamiliarity with negotiating an intersection on a divided highway.

Variation in crash rates between TWSC intersections are largely explained by differences in traffic volumes on the approach legs. Traditional safety improvements to intersections, such as adding turning lanes or the use of more, bigger, or brighter signage, only have a minor impact on traffic safety. Traditional safety countermeasures do not address the driver’s inability to judge gaps and they are, therefore, ineffective when trying to reduce crashes at TWSC expressway intersections.

2.4 Intersection safety modeling studies

The crash density (e.g., crashes per spatial measurement, an intersection or a mile of roadway) per unit of time (usually, per year) is most closely related to traffic volume. Other measurable variables explain much less variance in crash density than traffic volumes. Statistical models where crash density is a function of traffic volume are known as safety performance functions (SPF) (19). Researchers have been estimating SPFs for various roadway and intersection types for more than 50 years. For example, in 1953, McDonald estimated the relationship shown in Equation 2-1 using ordinary least squares (OLS) (20). The crash data used to fit Equation 2-1 are from 150 three and four-legged intersections on rural multi-lane highways in California.

$$N = 0.000783(V_d)^{0.455}(V_b)^{0.633} \tag{2-1}$$

Where N = the number of crashes per intersection per year
V_d = the average daily entering volume on the major roadway
V_b = the average daily entering volume on the minor roadway

SPFs can contain variables other than volume. For example, Equation 2-2 shows a SPF estimated by Zegeer, et al. for two-lane roadways (21). In this case, several additional variables related to crash frequency are included, although traffic volume explains more of the variation in the crash frequency than the other variables.

$$N = 0.0031(A)^{0.9425} \times 0.897^{B} \times 0.9157^{C} \times 0.94^{D} \times 0.9739^{E} \qquad (2\text{-}2)$$

where N = crashes per kilometer per year
A = average daily traffic volume
B = lane width
C = average paved shoulder width
D = average unpaved shoulder width
E = median recovery distance from edge of shoulder

Recognizing that crash frequency is a Bernoulli sequence, researchers have moved to regression techniques which accommodate data from a Bernoulli sequence. A Bernoulli sequence is a series of trials with the following characteristics (22):

- Each trial has only two possible outcomes, the occurrence or non-occurrence of an event. In this case, a trial is a vehicle traveling through an intersection and the event is a crash.
- The probability of occurrence remains constant with each trial.
- The trials are statistically independent.

Since a Bernoulli sequence has only occurrences and non-occurrences of events, the number of occurrences can only assume values of non-negative integers. This violates the OLS assumption that the data are continuous and normally distributed and therefore, safety researchers started using models estimated with approaches other than OLS. Specifically, Poisson and negative binomial regression models are used to model crash density. These models are sometimes called “count data models” because they estimate the mean number of occurrences of a discrete event over a period of time.

Until the mid-1990s, Poisson models were popular because they approximate rare event count data like crashes (23). However, a Poisson model assumes that the mean of the count process equals its variance (24). When the variance is significantly larger than the mean, the data are over-dispersed. One of the primary reasons for over-dispersion is that the variable influencing the Poisson rate across observations have been omitted from the regression. Because crashes are caused by a wide variety of variables, some of which are not easily measured (e.g., causes for driver error), over-dispersion is a common problem. Over-dispersed count data can be successfully modeled using a negative binomial model.

Bonneson and McCoy provide an example of the use of negative binomial regression to estimate a traffic safety performance function for rural TWSC intersections using data from 125 rural Minnesota intersections (25). In this database, 17 of the intersections are multi-lane, divided highways. Their model is shown in Equation 2-3.

$$N = 0.00379(V_{Major})^{0.256}(V_{Minor})^{0.831} \quad (2\text{-}3)$$

where N = Crashes per year per intersection
V_{Major} = annual average traffic volume on the major road
V_{Minor} = annual average traffic volume on the major road

In the course of this research, documentation for two SPF modeling projects that are particularly relevant to this study was discovered. The first model, which uses estimation of a SPF for rural multi-lane highways, was created by Wang, Hughes, and Steward. The second model was created by Vogt and estimates SPF for three and four-legged stop-controlled 4x2 intersections on rural multi-lane highways and for signalized 2x2 intersections (26, 27).

The objective of the modeling research by Wang, Hughes, and Steward was to identify highway cross-sectional variables that are statistically associated with the occurrence of crashes. To do this, they developed a crash and roadway database containing crash frequencies, several geometric variables, and traffic volume and traffic classification data and estimated the model of the crash frequency using Poisson regression. Their database development started with the Highway Safety Information System (HSIS) database. HSIS is a multi-state highway safety database developed and maintained by the Federal Highway Administration and by the Highway Safety Research Center at the University of North Carolina. When the researchers conducted their study, data were available through HSIS for five states; Illinois, Maine, Michigan, Minnesota, and Utah. Since the researchers intended to include cross-sectional elements beyond what is available in the HSIS database, they looked for an automated method to collect field data. Of the states participating in HSIS, Minnesota was the only one that collected a roadway videolog on videodisc. A special application was developed to assist in collecting data from the videodisk and integrating data on roadside condition and intersection/driveway access.

The data elements included in the modeling database were roadway functional classification, roadway type (undivided and divided), road surface width, median width, median type, traffic volume, percent commercial vehicles, driveways per mile, unsignalized intersection with turning lanes per mile, unsignalized intersection without turn lanes per mile, average shoulder width, average roadside hazard rating, access control (partial or no access control), and area type (rural or urban). The final model specification and parameter estimates are shown in Equation 2-4.

$$N=0.002(V)^{1.073}\exp(0.131X_1-0.151X_2+0.034X_3+0.163X_4+0.052X_5-0.572X_6-0.094X_7-0.003X_8+0.429X_9) \quad (2\text{-}4)$$

where N = crashes per year
V = daily vehicle miles of travel
X_1 = average roadside hazard rating
X_2 = access control (partial control=1, no control=0)

X_3 = driveways per mile
X_4 = intersection with turn lanes per mile
X_5 = intersections without turn lanes per mile
X_6 = functional class (rural principal arterial=1, rural others= 0)
X_7 = shoulder width (ft)
X_8 = median width (ft)
X_9 = area location type (rural municipal=1, rural non-municipal=0)

When discussing the results, Wang, Hughes, and Steward noted that "accidents on multi-lane highways occurred at intersections and interchange areas. Therefore, intersections, interchanges, and driveway access were part of the major consideration in both data screening and modeling processes. The model results show that intersections and driveways were significant predictors of accident occurrences." This finding is hardly surprising, but indicates that the largest safety benefits are available through improvement at points of entering and crossing traffic.

Vogt also uses the HSIS data in his study of rural three and four-legged 4x2 stop-controlled rural intersections and signalized 2x2 intersections. Our review of this work is limited to the 4x2 intersections. The HSIS data Vogt uses are from Michigan and California and includes data for the years 1993 to 1995 for 84 three-legged intersections and 72 four-legged intersections. The author added a number of data elements to HSIS data for these intersections through additional data collection. The additional data elements gathered include the following:

- Total number of crashes per intersection (within 250 feet of the intersection center on the major roadway for both states and 100 feet from the intersection center on the minor road in Michigan and 250 feet in California)
- Total number of injury crashes per intersection
- Total number of intersection-related crashes (crashes involving a merging, crossing, or turning vehicle)
- Total number of intersection-related injury crashes
- Average daily traffic on the major roadway
- Average daily traffic on the minor roadway
- Peak period truck percentage
- Peak period turning percentage (total turning on all approaches)
- Peak period left-turn percentage (total turning left on all approaches)
- Peak period through percentage on the major road
- Peak period left-turn percentage on major road
- Peak period left-turn on minor road
- Roadside hazard rating
- Number of residential driveways on major road
- Number of commercial driveways on major road
- Left-turn lane on major road
- Right-turn lane on major road
- Left-turn lane on minor road
- Right-turn lane on minor road

- Median width on major road
- Median type on major road
- Degrees of skewed intersection from 90 degrees
- Longitudinal sight distance on major road (in feet)
- Left-side sight distance on minor road (in feet)
- Right-side sight distance on minor road (in feet)
- Degree of horizontal curvature within 800 feet of the center of the intersection
- Degree of vertical curvature grade change within 800 feet of the center of the intersection
- Degree of vertical crest grade change within 800 feet of the center of the intersection (crest curves are vertical curves for which the grade decreases)
- Absolute value of the grade on the major road
- Speed limit on major road
- Speed limit on minor road
- Light at intersection (yes or no)
- Terrain (flat, rolling, or mountainous)
- State (Michigan or California)

Vogt used a negative binomial regression to estimate models for three and four-legged 4x2 intersections. For each intersection type, Vogt estimates a model of the total crashes, the total injury crashes, and the total number of intersection-involved crashes. Although he presents several model specifications, what he describes as the main model of total crashes for each type of intersections is shown below. Equation 2-5 contains the model for the three-legged intersection and Equation 2-6 contains the model for the four-legged intersection.

Three-legged Intersection Model

$$N = \exp(-12.2196) \times (\ln V_1))^{1.148} \times (\ln(V_2))^{0.262} \times \exp(-0.0546\ MW + 0.0391\ DW) \quad (2\text{-}5)$$

Four-legged Intersection Model

$$N = \exp(-9.463) \times (\ln(V_1))^{0.850} \times (\ln(V_2))^{0.329} \times \exp(0.110LT - 0.484LL) \quad (2\text{-}6)$$

where N = Total crashes per year (within 250 feet of the intersection)

V_1 = average daily traffic on the major roadway
V_2 = average daily traffic on the minor roadway
MW = median width on the major roadway
DW = number of residential and commercial driveways on the major road
LT = percentage of major roadway traffic turning left in the peak
LL = presents of left-turn lane on the major road (0=no lane, 1=lane)

In both cases, the parameter estimates of the variable included were statistically significant. When other variables were added, their parameters were not significant at the 10% level. The model shown in Equation 48 clearly illustrates that crash density increases with an increase in the number of left-turns during the peak. This implies that crash density could be reduced by reducing left-turns through such strategies as indirect left-turns through median crossovers, jug-handles, and loops.

Researchers have been modeling safety performance functions since the 1950s and consistently, minor and major roadway volumes have been the primary predictors of crash density. Other variables that typically impact crash density at expressway intersections include median width, access points (driveways) in the neighborhood of intersections, and the presence or absence of turning lanes. These models are important because they show designers the relative importance of design variables on crash density and, as Bonneson and McCoy illustrated, they can be used in the economic analysis of safety improvements.

2.5 Special Designs: Treatments and Innovative Technology

A number of designs have been developed as countermeasures to characteristic crashes at expressway TWSC 4x2 intersections. Characteristically, such crashes involve the failure of the driver to select an appropriate gap when crossing an expressway or making left-turns. A number of highway design strategies, as well as technologies, have been developed to assist drivers to maneuver through expressway intersections more safely. This section reviews several of these design strategies and reviews the few known technologies used to help drivers make better intersection decisions.

Intersection Median Width

Intersection median width on expressways is generally governed by the width of medians along the entire roadway cross section. AASHTO's "Policy on Geometric Design of Highways and Streets," commonly called "The Green Book," recommends that medians at unsignalized rural intersections should generally be "as wide a practical" (10). In urban and suburban areas, the reverse is recommended: medians should only be wide enough to allow the design vehicle to safely maneuver through the intersection.

Through field observations, Harwood, et al., found that wider medians in urban and suburban areas allowed drivers to make undesirable maneuvers within the median and resulted in more conflicts in the crossover section (28). Undesirable maneuvers, or aggressive driving, includes drivers queuing side-by-side in the median; in wide medians, drivers driving on the inside lane (left lane) when making a left-turn through the intersection; or queuing in line in the median with the last vehicle in line encroaching on the travel lanes. It is possible that what Harwood, et al. are really observing is the impact of higher volumes and peaked volumes that result in aggressive driving and more opportunity for conflicts and undesirable maneuvers.

One of the safety improvement strategies recommended in the AASHTO SHSP's "Guide for Addressing Unsignalized Intersection Collisions" is placement of a double yellow line in the center of the median crossover (29), which helps to delineate the pathway drivers should follow through the crossover, reducing undesirable maneuvers.

Harwood, et al., used a dataset consisting of three years of crash data at 2,140 California median-divided intersections. When Harwood, et al. estimated a safety performance function for 153 rural intersections using Poisson regression, they found an average of 4% reduction in crashes per year with every meter increase in the width of the intersection median (28). AASHTO's SHSP report recommends that rural intersection medians should be wide enough to shelter the design vehicle (10). Harwood, et al., found that many state agencies use a large school bus as their design vehicle and base their design policies accordingly. Therefore, medians in these states must be capable of sheltering a large school bus (28).

Median Opening Widths

AASHTO's SHSP report recommends keeping median opening widths at unsignalized intersection as narrow as possible and if possible, the same width as the crossing roadway. At unsignalized intersections, wide openings give drivers the opportunity to perform undesirable maneuvers such as queuing up in the crossover side-by-side. The report also recommends that openings be sized to only meet the turn radius of the design vehicle (1).

Median Left-turn Acceleration Lanes

An example of a median acceleration lane is shown in Figure 2.2. The median acceleration lane provides six safety benefits. The first benefit that median acceleration lanes provide is an opportunity for left-turning traffic from the minor roadway to accelerate and merge into traffic, thereby making it less difficult for drivers to find a suitable gap in high-speed and high volume traffic. The second benefit occurs when the acceleration lane provides additional median storage and keeps a truck from overhanging into the expressway travel lanes because the median crossovers are not wide enough. The third benefit is that allowing the vehicle to accelerate and then merge with traffic requires less sight distance. The four benefits results from the merger lane allowing drivers on the expressway to see the left-turning vehicles, so vehicles on the expressway can anticipate the merging vehicle. The fifth benefit comes from vehicle merging at speed rather than from dead stop resulting in a more forgiving environment. The final benefit is that the acceleration lane reduces the need for left-tuning drivers to judge a gap at right angles (believed to be a problem for elderly drivers) and allows drivers to select a gap and merge through the use of their rearview mirror.

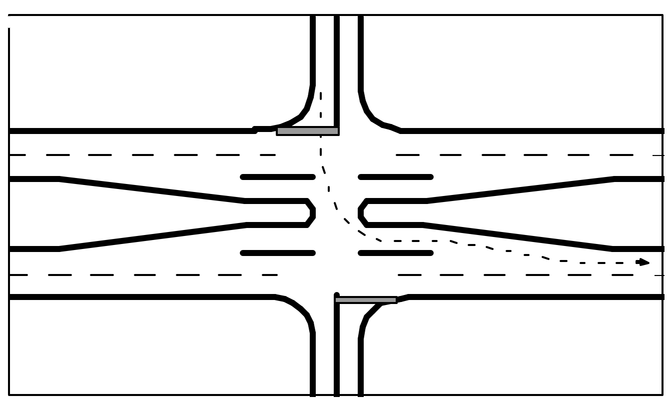


Figure 2.2. Left-turn median acceleration lanes (30)

A 1986 Institute of Transportation Engineer's (ITE) survey of 53 transportation agencies found that 13 of the agencies had constructed median acceleration lanes (31).

Respondents were split in their opinions regarding the desirability of acceleration lanes. ITE concluded that the lanes appear to reduce crashes, promote efficiency in left-turn movements, and reduce conflicts, but insufficient data were available to quantify their safety and operational benefits.

Harwood, et al., recommend that highway agencies consider left-turn acceleration lanes for locations where adequate median width is available to pave an acceleration lane without compromising the median and when the following attributes are true (28):

1. Limited gaps are available in the major-road traffic stream.
2. Turning traffic must merge with high-speed through traffic.
3. There is significant history of rear-end or sideswipe accidents.
4. ISD (intersection sight distance) is inadequate.
5. There is a high volume of trucks entering the divided highway.

As of 2002, the Minnesota Department of Transportation (MnDOT) had constructed 10 expressway intersections with median acceleration lanes (32). In 2002, MnDOT conducted an evaluation involving 9 of these intersections. Their evaluation measures included operational performance, measured by delay; safety, measured by crash rates; and the public's perception, measured through an opinion survey.

When there is no median acceleration lane, automobile drivers on the minor roadway approach will generally make a through or left-turn movement in two steps. After crossing the lanes on the near side of the expressway, they have the opportunity to stop in the median and wait for a gap in the traffic in the far lanes. The waiting time in the median was considered delay by the Minnesota study and this type of delay is reduced by the presence of a median acceleration lane. The Minnesota study found that the percentage of vehicles stopping in the median decreased from 74% to 4% when there was a median acceleration lane and the percentage of vehicles that waited in the median for more than 10 seconds decreased from 17% to 1%.

When the median acceleration lane was constructed, the rear-end crash rate declined by 40%. In comparison to similar intersections without median acceleration lanes, the rear-end crash rate at intersections with a median acceleration lane intersections was 75% lower. Sideswipe crashes, where both cars are traveling in the same direction, also declined.

The Minnesota study also conducted a survey of intersection users. Of 200 questionnaires distributed, 119 were completed. Of the respondents, 95% said they usually or always use the acceleration lane and 70% thought the acceleration lane helped them merge "very much" and another 20% thought that the lanes were of "much" help in merging.

The Minnesota study also makes a recommendation for acceleration lane lengths. For expressways that operate at 55 miles per hour or higher, the study recommends a minimum of 1,000 foot-long acceleration lanes, with longer acceleration lanes being required on expressways with higher traffic volumes. The standard expressway acceleration lane recommended by the study is 1,500 feet.

Offset Right- and Left-Turn Lanes

Vehicles in the right-turn lane tend to obstruct the vision of drivers waiting at the stop bar of the minor roadway. One way to reduce the obstruction of the minor roadway drivers' view is to offset the right-hand turning bay to the right. Similarly, vehicles in the opposing left-turn lane block the views of left-tuning vehicles from the opposite direction, as shown in Figure 2.3. An example intersection with offset right- and left-turn lanes is show in Figure 2.4. Offsetting left-turn lanes to the left as far as is practical improves the visibility of opposing traffic. By improving the visibility of opposing traffic vehicles, drivers can more effectively use available gaps. Offsetting right-turn lanes to the right gives drivers on the minor approach (at the stop bar) an unobstructed view of oncoming traffic in the near expressway lanes, which allows for more effective use of gaps.

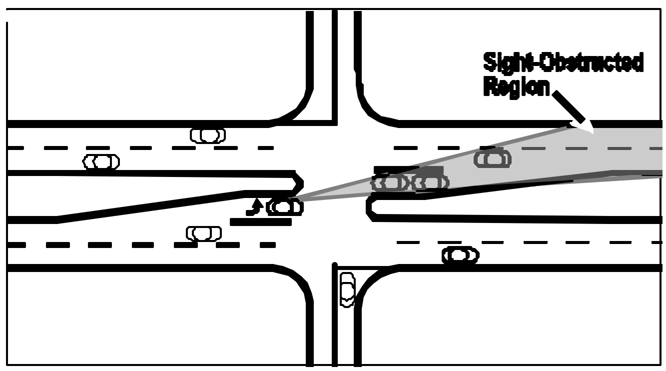


Figure 2.3. Obstructed sight distance due to opposing left (31)

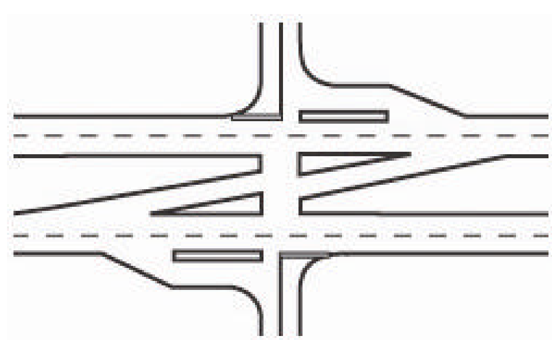


Figure 2.4. Intersection with offset right and offset left-turn lanes

Indirect Left-turns

Indirect left-turn treatments decrease the number of conflicted movements. These treatments restrict left-turns from the mainline to the minor roadway and these movements are made through jug handles, loops, and median U-turns, as shown in Figures 2.5, 2.6, and 2.7, respectively. These treatments reduce conflict points, which in turn, reduce crash rates, with the percentage reduction generally increasing with increasing traffic volume. For high-volume signalized intersections, these treatments actually increase capacity and reduce overall travel time (33). However, disadvantages of using these treatments include a possible delay to left-turning traffic, further distances traveled by left-turning traffic, driver disregard for left-turn prohibition at the main intersection, more stops are required to make a left-turn, additional driver confusion, and the acquisition of additional right-of-way.

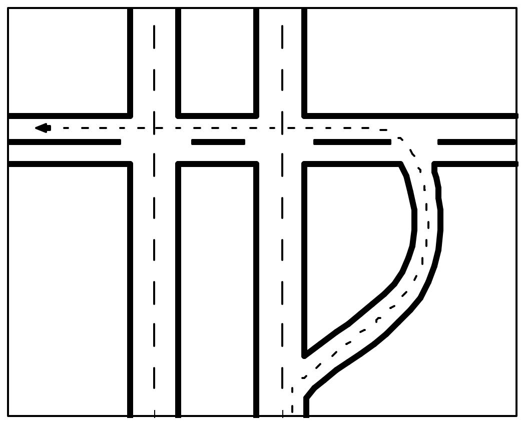


Figure 2.5. Indirect left jug handle (31)

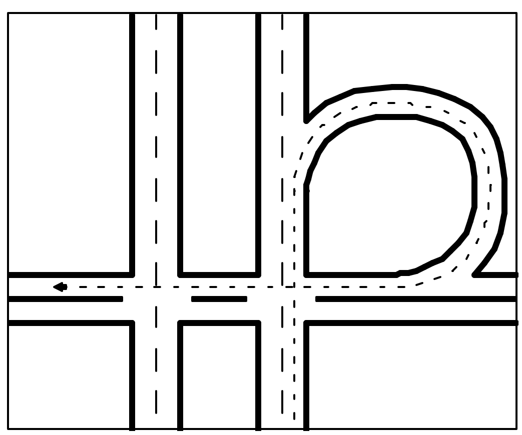


Figure 2.6. Indirect left-turn loop (31)

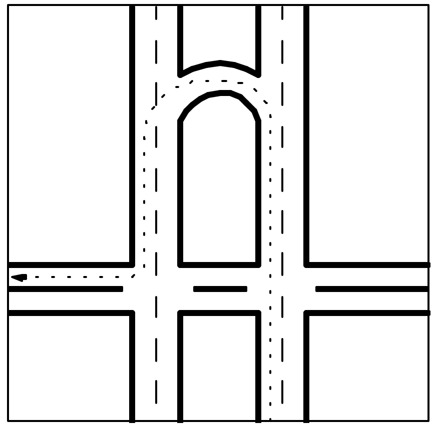
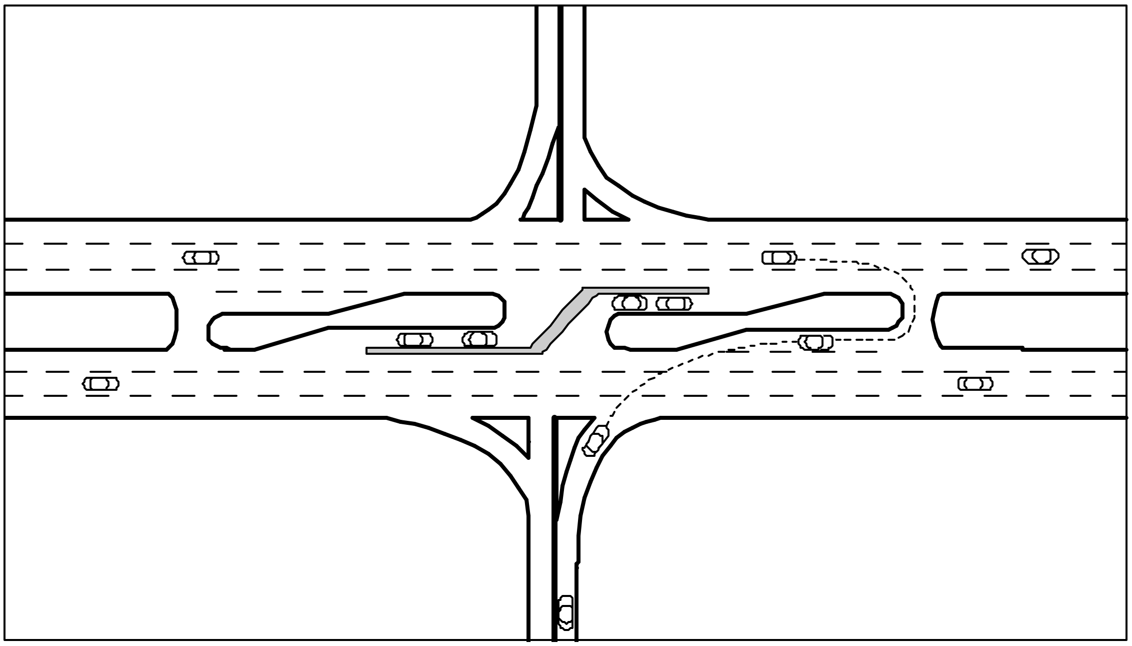


Figure 2.7. Indirect left-turn median U-turn (31)

Under low traffic volume conditions, indirect left-turn U-turns increase delay. Although not entirely analogous, Gluck, Lenvinson, and Stover found that when investigating left-turns from driveways onto multi-lane facilities through median crossovers, indirect left-turn U-turns can reduce delay when compared to direct lefts when the major roadway volume is more than 2,000 vehicles per hour and the minor roadway volume is more than 50 vehicles per hour (34). This holds true even when the U-turn median crossover is as much as a half-mile away. Admittedly, a volume of 2,000 vehicles per hour is rarely experienced on rural expressways in the Midwest. However, this finding does suggest that indirect left U-turns may be appropriate on those routes that experience high peak period volumes and also suggests that drivers making direct lefts during high volumes are experiencing long delays, which may result in aggressive driving and the acceptance of unsafe gaps in traffic.

In a study of median crossovers at driveway intersections, Zhou, et al., suggest a directional median opening, as shown in Figure 2.8 (35). This type of opening allows the traffic on the main line to continue to make left-turns but traffic on the minor road must use the indirect left-turn U-turn to make left-turns and through movements. This eliminates some the disadvantages of a complete median closure at the intersection and



eliminates the conflicts between left-turning vehicles on the mainline and left-turning vehicle on the minor roadway.

Figure 2.8. Directional median opening

Offset T-Intersection

In comparison to a four-legged intersection, a T-intersection has fewer conflicts points and generally has lower crash rates. When comparing 2x2 three-legged and four-legged intersections, Hanna, et al., found crash rates were about 40% lower for T-intersections (36) because maneuvers are eliminated in a T-intersection crossing. Therefore, if a four-legged intersection can be converted into two offset T-intersections, safety benefits are improved for both minor roadway approaches. An offset T-intersection is shown in Figure 2.9. In a 4x2 intersection, there are 40 conflict points, while there are 30 conflict points in an offset T-intersection (37).

Bared and Kaisar used intersection safety performance function models to estimate the safety benefits of converting a 4x2 intersection to an offset T-intersection. The percentage reduction in crashes benefit is greatest for very low volume 4x2 intersections, but generally, Bared and Kaisar estimate that conversion of a 4x2 intersection to an offset T-intersection should reduce crashes by 40% to 60% (34).

In Figure 2-9 is shown an off-set T-intersection with the minor road leg on the bottom of the intersection on the left and minor leg above the intersection on the right. This is known as R-L configuration because a vehicle traveling from the bottom to the top would have first make a right turn (R) and then left turn (L). Of course the position of the legs could be reversed and we would still have an off-set T-intersection but this would be a L-R configuration. The R-L configuration is preferred because it causes slightly less delay and provides higher capacity.

Bared and Kaisar also show that interference between the major roadway traffic with slow moving or accelerating vehicles from the minor roadway. For high speed expressways (65 mph) interference is minimized when the intersections are off-set by a maximum of 141 feet for a R-L configuration and by a maximum of 235 feet for a L-R configuration. The disadvantages of an offset T-intersection include increased travel time and travel distances for minor road through movements, potential confusion for drivers making a through movement on the minor roadway, and the increased acquisition of right-of-way.

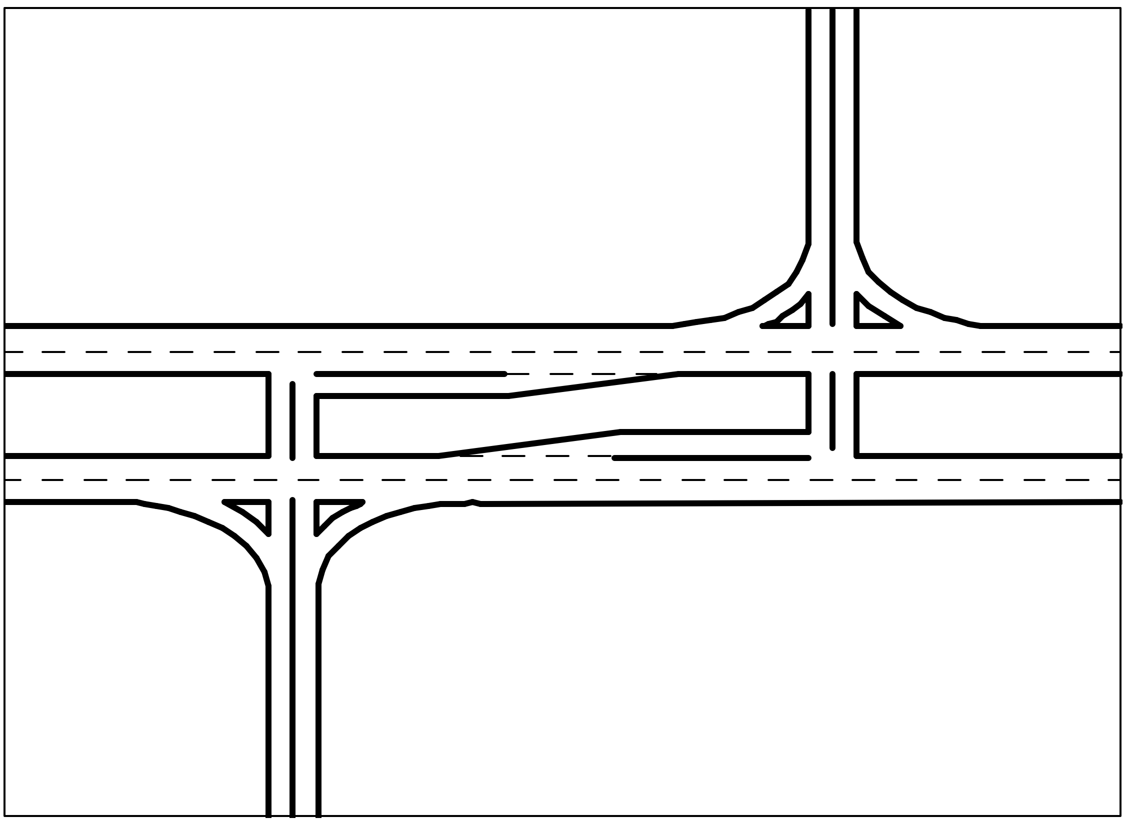


Figure 2.9. Offset T-intersection

Unconventional Intersection Designs

There are several innovative designs that range in acceptance from being used in practice to the field testing stage to the conceptual stage. These innovative designs include those that are growing in acceptance but are still uncommon, like roundabouts and more unusual designs like the bowtie and superstreet, shown in Figures 2.10 and 2.11, respectively.

In the Bowtie all left turns are eliminated. Drivers wishing to turn left off of the major road must first turn right and travel through the roundabout on the minor and then through the intersection. Drivers on the minor road wishing to turn left go through the intersection, go through the roundabout returning to the intersection, and make a right turn. By using the two roundabouts all left turns are eliminated. The Superstreet is similar to the directed median, requiring that all lefts from the minor road must turn right and make a U-turn thought the median crossover.

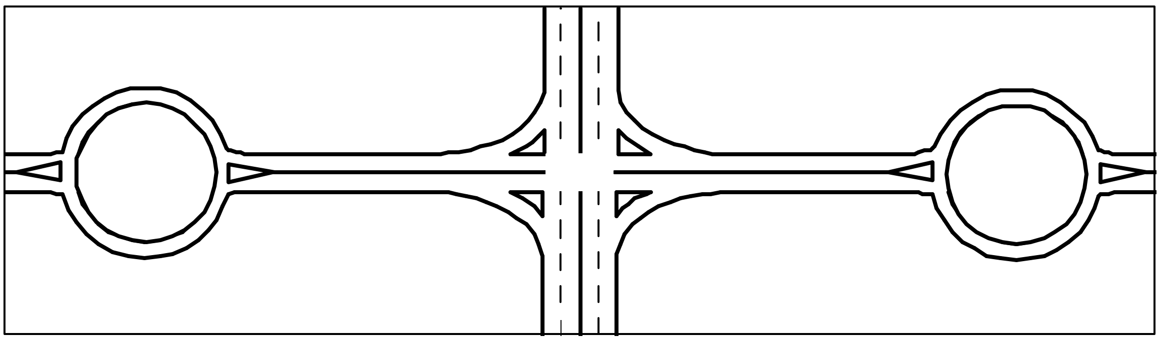


Figure 2.10. Bowtie intersection (38)

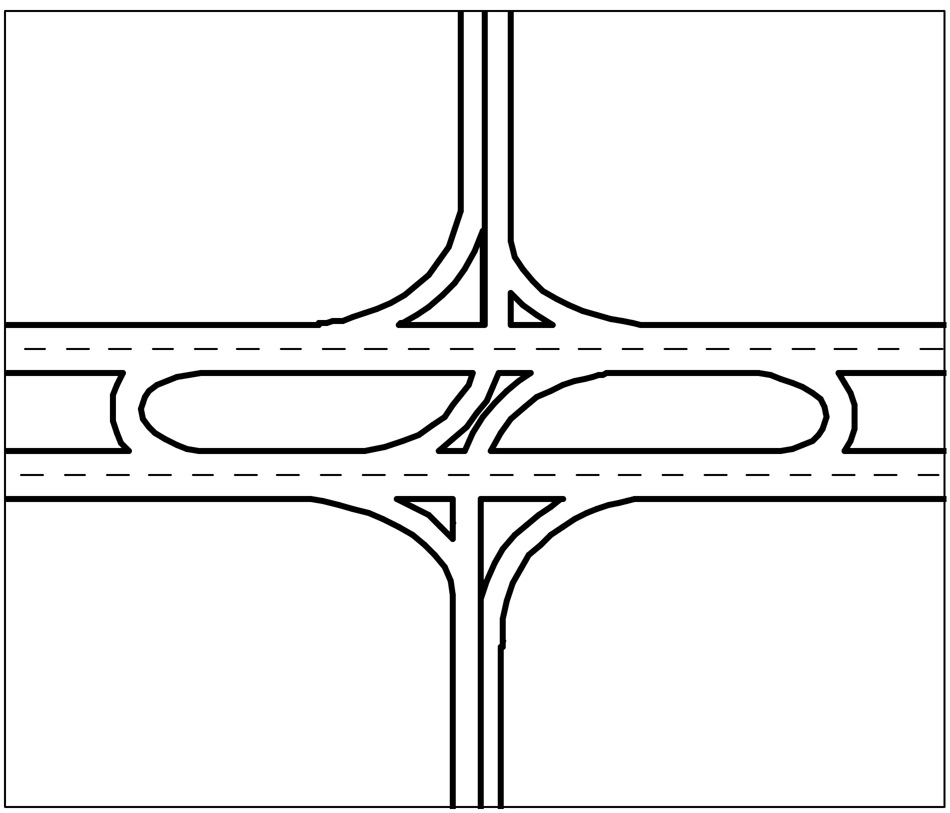


Figure 2.11. Superstreet intersection (35)

Semi-Roundabout Intersection

The semi-roundabout intersection is a new design being proposed by Edwin Lagergren of the Washington Department of Transportation (39). The purpose of the semi-roundabout is to provide an interim measure between a conventional stop-controlled intersection and a diamond interchange. This intersection design is projected to reduce the factors contributing to crashes and crash severity at high speed at-grade intersections. The semi-roundabout intersection incorporates a modern roundabout to correct the narrow median issues and reduce the number of conflict points as well as reducing the speed of vehicles on the expressway. Specifically, speeds within the roundabout are reduced to 35 to 40 mph while allowing reasonable queuing of vehicles on the crossroad. The purpose of the intersection is to perform all of these operations while also functioning as a logical interim step in the staged construction of a diamond interchange.

The semi-roundabout intersection is shown in Figure 2.12. It is built around a center roundabout. The roundabout is large enough to accommodate a large truck and a bridge will be constructed when the roundabout is converted to an interchange. The mainline follows the path of future ramps for the interchange, thus reducing some of the need for grading and paving when the diamond is built. The bowing of the mainline alignment slows down through traffic.

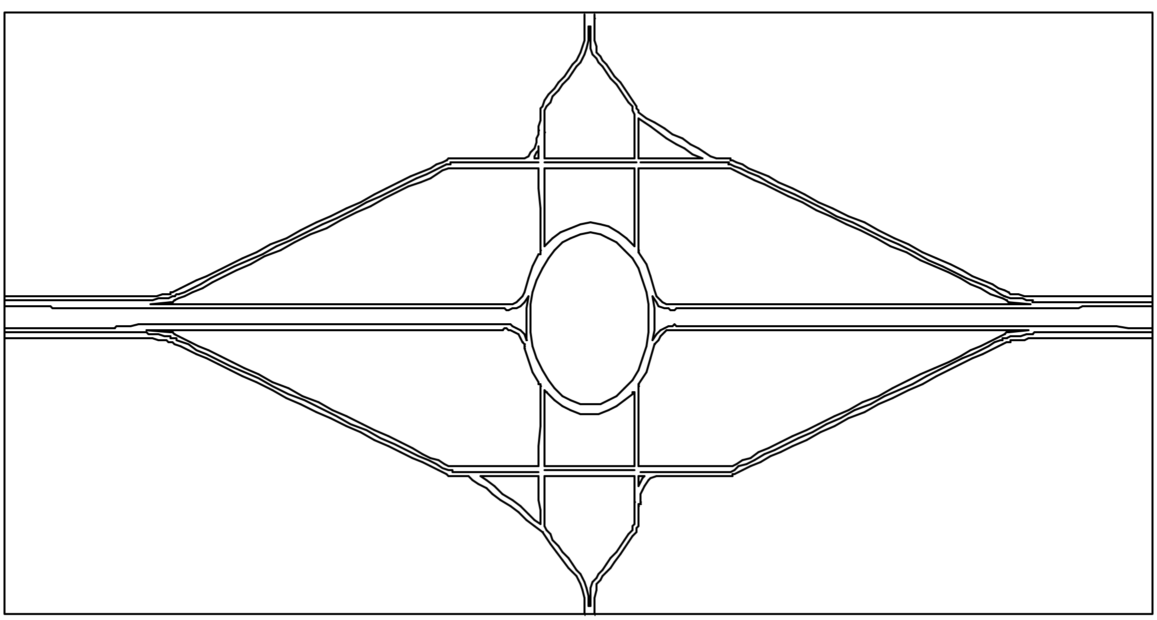


Figure 2.12. Expressway semi-roundabout intersection

Lagergren projects that two semi-roundabout intersections could be built for about the same cost as one interchange. The semi-roundabout intersection is a safer design for an expressway intersection than a typical intersection design.

2.6 Technology to Assist in Intersection Safety

Infrastructure-based intersection collision avoidance systems have been developed, tested, and deployed. The purpose of these systems is to provide the driver with information about the relative safety of making a through or turning movement at the intersection. Information is provided through roadside informational or warning signs. Typically, these systems have roadside sensors and processors that communicate to the driver that the gap in traffic intersection is or is not sufficient for one or more maneuvers (usually a turn or crossing from the minor roadway). To date, all the systems that have been field tested are intended to assist drivers in safely navigating an intersection with inadequate intersection sight distance. A system to help drivers determine the adequacy of gaps at TWSC intersections on expressways is being developed in Minnesota during the summer of 2004 and will probably be field tested in 2005. The Minnesota system's initial test will involve assisting drivers in selecting safe gaps in an intersection with adequate sight distance.

Prince William County, Virginia

A system to help drivers at an intersection with limited sight distance was implemented at the intersection of two two-lane roads in Prince William County, Virginia. The intersection of Aden Road (major) and Fleetwood Drive (minor) is located on the plateau of a hill and has limited intersection sight distance. Previous to implementation of this system, drivers on the minor road had difficulty identifying an adequate gap in the major traffic stream. Figure 2.13 shows the layout of the system and the system is shown in Figures 2.14 and 2.15. On the minor approach, approaching vehicles are detected with a loop detector 215 feet upstream and on the major approach at 950 and 350 feet upstream from the intersection. The processor activates two signs when vehicles on both legs approach the intersection. The sign in Figure 2.14 is activated at the intersection on the opposite side of the minor roadway from the stop sign and the sign in Figure 2.15 is activated at 540 feet and 150 feet upstream from the intersection on the major approach.

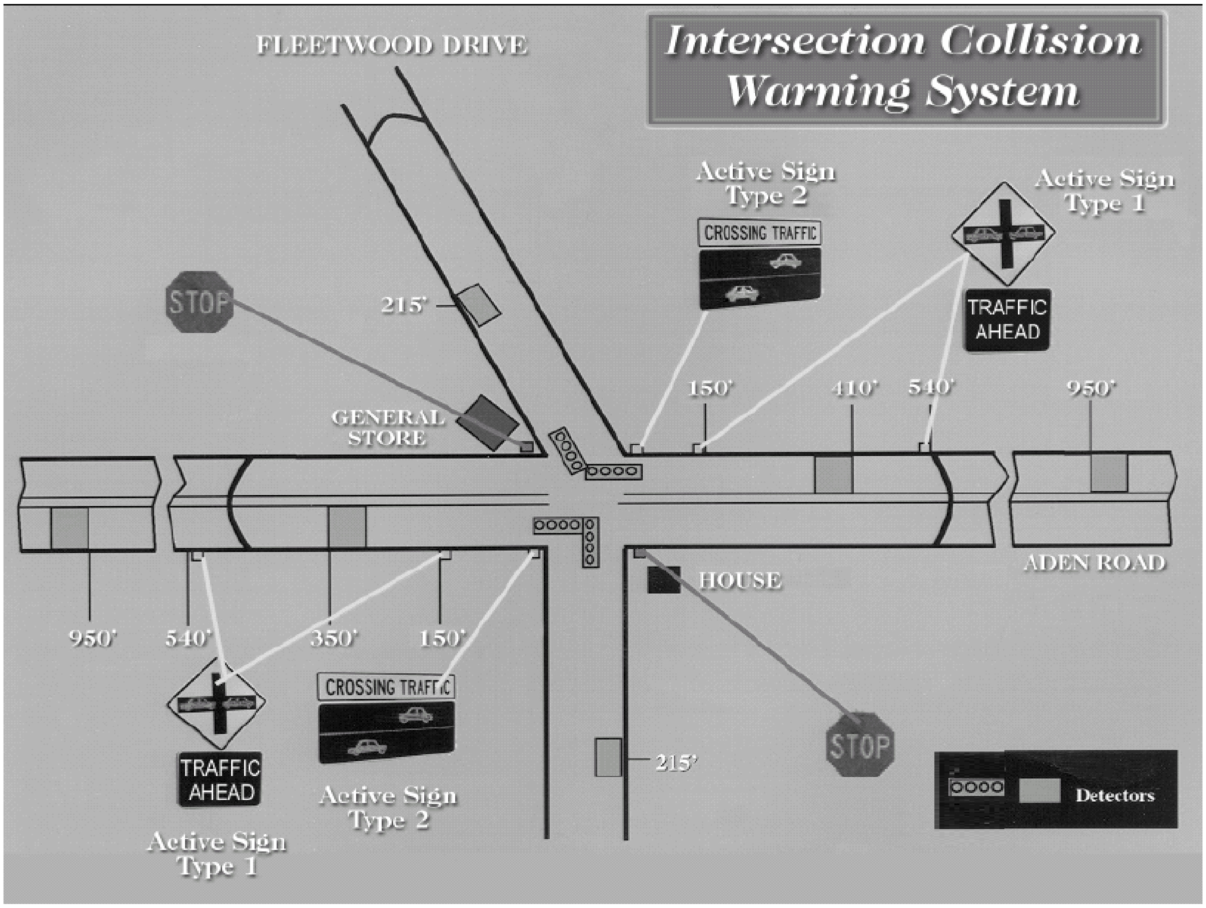


Figure 2.13. Layout of Virginia intersection collision warning system (40)

Figure 2.14. Intersection collision warning system minor approach (36)

Figure 2.15. Intersection collision warning system major approach (36)

The intersection collision warning system was in operation from April 1998 to March 2000. The post-operation evaluation found that vehicles approaching the intersection reduced their speed when a vehicle was present on the minor approach. The crash rate at this intersection also seemed to decline. Prior to installation of the system, the intersection averaged 2.6 crashes per year and following the installation, there were no crashes over the two-year test period (41).

Norridgewock, Maine

Another system, similar to the Virginia system, was implemented by the Maine Department of Transportation in Norridgewock, Maine (42). The system layout is shown in Figure 2.16. The major roadway is US 201A and the subject intersection is immediately north of the touchdown point of a bridge over the Kennebec River. The bridge is an arch concrete bridge with large structural concrete columns and railings that limit sight distances. To the south of the intersection, a dynamic flasher sign is mounted on one of the bridge's cross-members to let northbound drivers on US 201A know that a vehicle is on the cross-street and approaching the intersection. On the minor roadway, dynamic signs indicate that a vehicle is approaching and its direction. These signs are triggered by loop detectors on the major road approach.

The Maine system was evaluated by conducting a conflict analysis before and after the installation of the system and by surveying drivers. Two types of observational conflict analyses were conducted; the method outlined in the FHWA's report, "Traffic Conflict Techniques for Safety and Operations," and a method developed by Per Gårder of the Swedish Royal Institute of Technology (43, 44). The FHWA technique estimated that conflicts were reduced by 35%. The Swedish method estimated that conflicts were reduced by 40%. The evaluators also distributed 1,464 surveys to drivers and 541 were completed and returned. Of the drivers who responded, 67% felt that the signs could prevent crashes and 64% recommended the signs for use in other intersections.

Figure 2.16. Layout of the conflicting traffic warning system used in Maine (10)

Intersection Decision Support System

The third infrastructure system being tested was developed by the Intelligent Transportation Systems Institute at the University of Minnesota (45). Although not specifically designed for expressway intersections, its first implementation and field test will be on an expressway linking Rochester and St. Paul, Minnesota (Trunk Highway 52). The Intersection Decision Support (IDS) system is much more sophisticated than the Virginia or the Maine systems. The IDS includes radar devices directed along the expressway in both directions, sending information about the location and speed of approaching vehicles back to a roadside computer unit, as shown in Figure 2.17. A computer controls a dynamic message sign on the minor roadway approach. The roadside computer calculates when the conflicting vehicle will arrive at the intersection. Several concepts for the dynamic message sign are being considered. Two proposed designs for the dynamic sign are shown in Figure 2.18. The design on the left shows the driver the speed of the approaching vehicle from each direction and the speed indicators turns red when the gap is no longer safe. The sign on the right is similar but shows the time until vehicle arrival instead of the speed. On the second sign, the time indication turns red when the gap is too small to turn with traffic or cross the expressway.

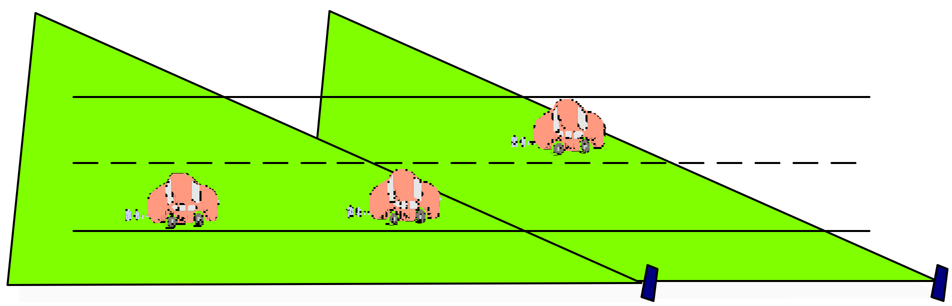


Figure 2.17. Radar directed upstream from the intersection
(Source: ITS Institute, University of Minnesota)

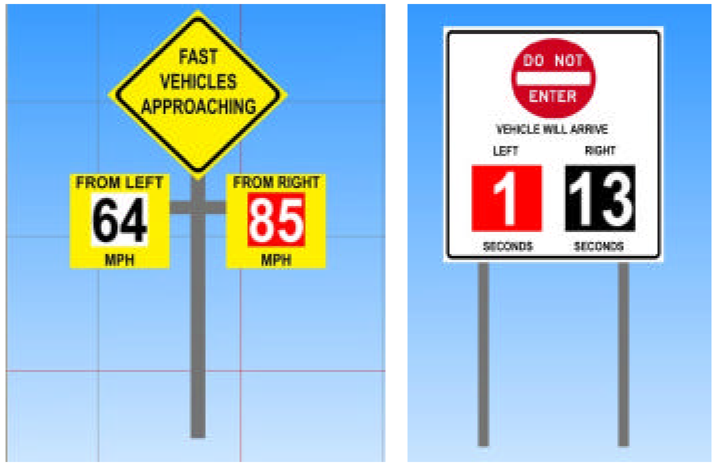


Figure 2.18. Proposed designs for dynamic signs
(Source: ITS Institute, University of Minnesota)

Summary Remarks

Safety improvements are possible at expressway intersections through modifications to intersection geometry and application of ITS technology. In this section, the survey of state transportation agencies revealed that some states are attempting to improve expressway intersections through geometric improvements. The use of ITS technology is promising, but still in its infancy.

3. EXPRESSWAY INTERSECTION SURVEY

A survey focusing on the safety performance of at-grade multi-lane (expressway) intersections was conducted to understand the policies and alternatives that states are implementing or evaluating. This survey was conducted through interviews and the interview outline can be found in Appendix A.

3.1 Methodology

Our team of researchers began the survey process by sending an electronic copy of the interview outline to state traffic engineers. Sometimes the questions were answered by the individual that received the interview outline, but most of the time, our questions were given to a subordinate or someone else within the state transportation agency (STA). Once the survey response was received and a short report was developed from the findings, our team sent the report to the respondent to ensure that the conditions at that STA had been correctly characterized. If the respondent indicated any changes, they were incorporated into the individual STA write-ups in this chapter. We did not survey all STAs; we selected the 35 STAs that operated the most miles of expressways according the list in Table 2.1.

This survey defined an expressway roadway as "a high-speed, multi-lane, non-interstate, divided facility with either partial or no access control. An expressway may have intersections that are at-grade, grade separated, or signal controlled." In Figure 3.1, the 27 STAs that responded to our survey are highlighted in blue. Of those who were initially contacted, 8 STAs declined to respond to our request for information.

Typical survey replies were short comments and an explanation of what data were and were not available. A few STAs were able to give us valuable intersection layouts along with comments on the effectiveness of the intersections. Unfortunately, of the STAs that provided this type of data, none had quantified the safety impacts of the improved intersection. Each STA that responded is discussed individually in the following pages.

The first survey question asked the respondent to tell us exactly how many miles of expressway their state operated, using the above definition. Responses to this question are listed in Table 3.1. In most cases, reported expressway mileage was similar to the mileage reported in Table 2.1 of the literature review in Section 2. Table 2.1 used the Federal Highway Administration data to estimate the number of miles of expressway per state. However, in some cases, the mileage reported by the state was quite different. For example, in Table 2.1, the Federal Highway Administration data indicates that Minnesota has 633 miles of expressways, but our Minnesota respondent reported that the Minnesota Department of Transportation operates 1,010 miles of expressways. It is unclear to us why such large discrepancies in the reported mileages might exist.

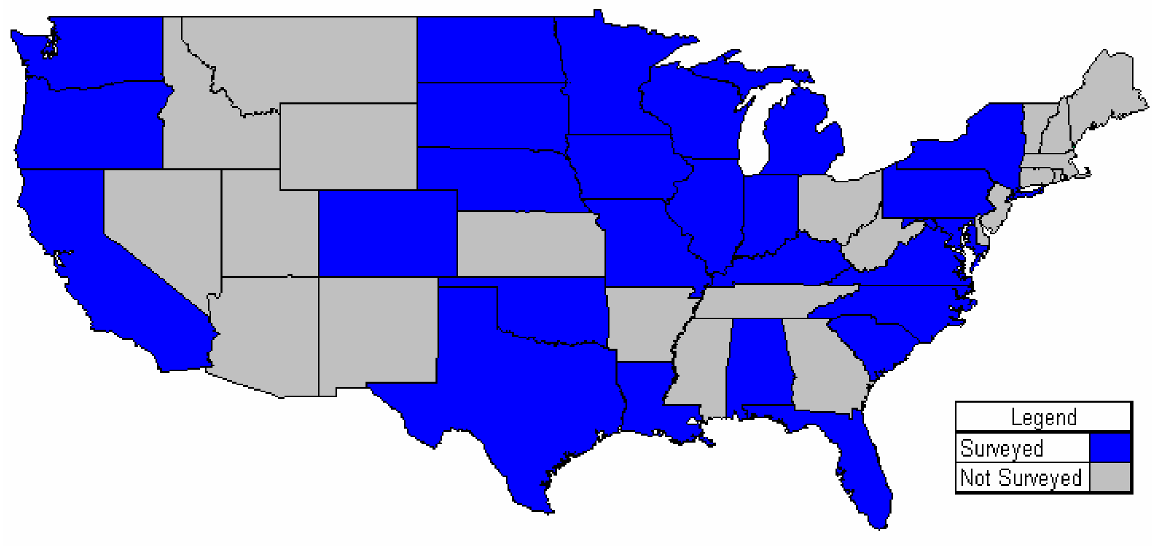


Figure 3.1. Surveyed states

Table 3.1. Reported expressway miles by state

State	Miles of expressway	State	Miles of expressway
Alabama	623	Missouri	1,400
Arizona	151	Nebraska	410
California	584	New York	382
Colorado	488	North Carolina	567
Florida	771	North Dakota	450
Illinois	247	Oklahoma	1,204
Indiana	541	Oregon	104
Iowa	350	Pennsylvania	503
Kentucky	525	South Carolina	943
Louisiana	168	South Dakota	209
Maryland	481	Texas	1,983
Michigan	113	Virginia	2,876
Minnesota	1,010	Washington	219
Mississippi	801	Wisconsin	511

3.2 Survey Responses by State Transportation Agencies

Alabama Department of Transportation [1]

The Alabama DOT currently has 623 miles of expressway, with plans to expand its expressway system over the next 10 years. The state has acquired right-of-way and plans to upgrade several facilities to expressways rather than to interstate standards because of the reduced cost of constructing expressways as compared to the cost of a full access-controlled facility. The Alabama DOT tries to find alternative solutions to converting existing expressways to full access-controlled facilities because of the cost.

The Alabama DOT explained that a traffic analysis involving volume projections and safety concerns are the main factors taken into account when considering conversion of expressway segments to full access control, but rarely do they do more than one or two intersections at a time. Historical capacity and safety have been the main factors used for deciding when to upgrade an intersection to full access control, and these decisions are made on a case-by-case basis. The state does not have a formal policy on when to convert expressway segments to full access control. All traffic control on Alabama expressways complies with the "Manual on Uniform Traffic Control Devices (MUTCD)" guidelines.

Currently, the average crash rate at expressway intersections is 1.7 per million entering vehicles per year. Typical expressway crashes tend to be right angle, lane change, or rear-end crashes. In addition, the Alabama DOT observed that most wrong way maneuvers on new facilities tend to dissipate with time. The Alabama DOT is discussing the use of public relation efforts in reducing the number of times drivers turn onto the wrong lane of new expressways.

The typical speed limit for Alabama's expressway facilities is 55 miles per hour (mph) or below in urban areas and 65 mph in rural areas. Most of Alabama's at-grade intersections are rural T-intersections. The Alabama DOT prefers to minimize the number of four-legged high-speed expressway intersections. Currently, frontage roads are not mandated and not widely used. However, the Alabama DOT has constructed a number of expressway intersections with jug handles for making left-hand turns, placement of stop bars in the median crossovers, rumble strips, and signage improvements, including cautionary warnings on minor approaches. The Alabama DOT has not evaluated these alternatives to determine how they impact safety performance; however, they are currently collecting data to conduct a before and after analysis of these alternatives. The Alabama DOT is also planning on adding an offset left lane improvement on an upcoming construction project.

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[1] Respondent: Tim Taylor, Assistant Maintenance Engineer/Traffic Operations, Alabama Department of Transportation, Maintenance Bureau, Montgomery, AL

Arizona Department of Transportation [2]

The Arizona DOT currently has 151 miles of expressway, with plans to expand their expressway system over the next 10 years with 65 new miles of expressway. Arizona expressways are non-interstate, urban freeways with full access control. The Arizona DOT prefers this type of facility for the Phoenix metro area because as the metropolitan area sprawls, trip lengths become longer, making mobility increasingly important. Currently, the Arizona DOT does not have plans to convert any existing highway intersections to full access control.

California Department of Transportation [3]

The California DOT currently has 584 miles of expressway, with plans to expand its expressway system over the next 10 years. Motivating factors for expanding the system include reduced cost of expressway as compared to freeway design facilities, better safety performance as compared to two-lane highways, relief for the problem of volume peaking on recreational highways, and increased passing on rural highways. Historically, the California DOT has upgraded selected expressways to a full access control facility. Evaluation of route volume, including minor roadways, accident history, and land use changes resulting in changes to highways use (more local trips) serves as criteria used for determining if full-access control is needed.

The California DOT has produced guidelines for access along expressway route. Specifically, Topic 104.3(1)(c) of the California Highway Design Manual indicates that direct access to the through lanes is allowable on expressways. However, when the number of access openings on one side of the expressway exceeds 3 in 500m (1640ft), then a frontage road should be constructed. Also, Topic 205.1(1) states that access openings should not be spaced closer than 800m (2625ft) to an adjacent public road intersection or to another private access opening that is wider than 10m (33ft).

On California expressways, high-speed broadside collisions tend to be over represented in the distribution of crash types. Recently, the California DOT has not noticed any wrong-way maneuvers on sections of new expressways; however, they did notice an overrepresentation of elderly or intoxicated drivers in expressway accidents. The typical geometry of the intersections in California follows the California DOT's Highway Design Manual which is similar to AASHTO's "Policy on Geometric Design of Highways and Street." The speed limit in most areas is 65 mph for personal vehicles and 55 mph for trucks and vehicles with trailers.

The California DOT has constructed offset left-turn lanes, indirect lefts, offset right-turn lanes, jug handles, median stop bars, signals, signage, and rumble strips on minor roadway approaches with mixed results. Specifically, the California DOT stated that at-grade

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[2] Respondent, Kathleen Deisch, EIT, Arizona Department of Transportation, Traffic Engineering/HES Section, Phoenix, AZ

[3] Respondent, Janice Benton, California Department of Transportation, Sacramento, CA

unsignalized expressway intersections tend to have higher speed injury/fatal type collisions than signalized intersections. Signalized intersections have been used as an interim solution until grade-separated intersections can be built. However, signalization has resulted in a high number of high-speed rear-end collisions instead of high-speed broadside collisions. Also, large trucks stopped in median crossovers have been problematic because they project out into oncoming traffic in narrow medians. Widening the median has been attempted with varied results. Wider medians tend to result in increased crashes in the median crossover. These intersection strategies have not been fully analyzed due to their recent completion. Figure 3.2 shows a California expressway intersection with markings for offset right- and left-turning lanes on the mainline, left-turn lanes, and offset right-turn lanes on the minor roadway and wider medians so that a combination tractor-trailer can be sheltered in the median.

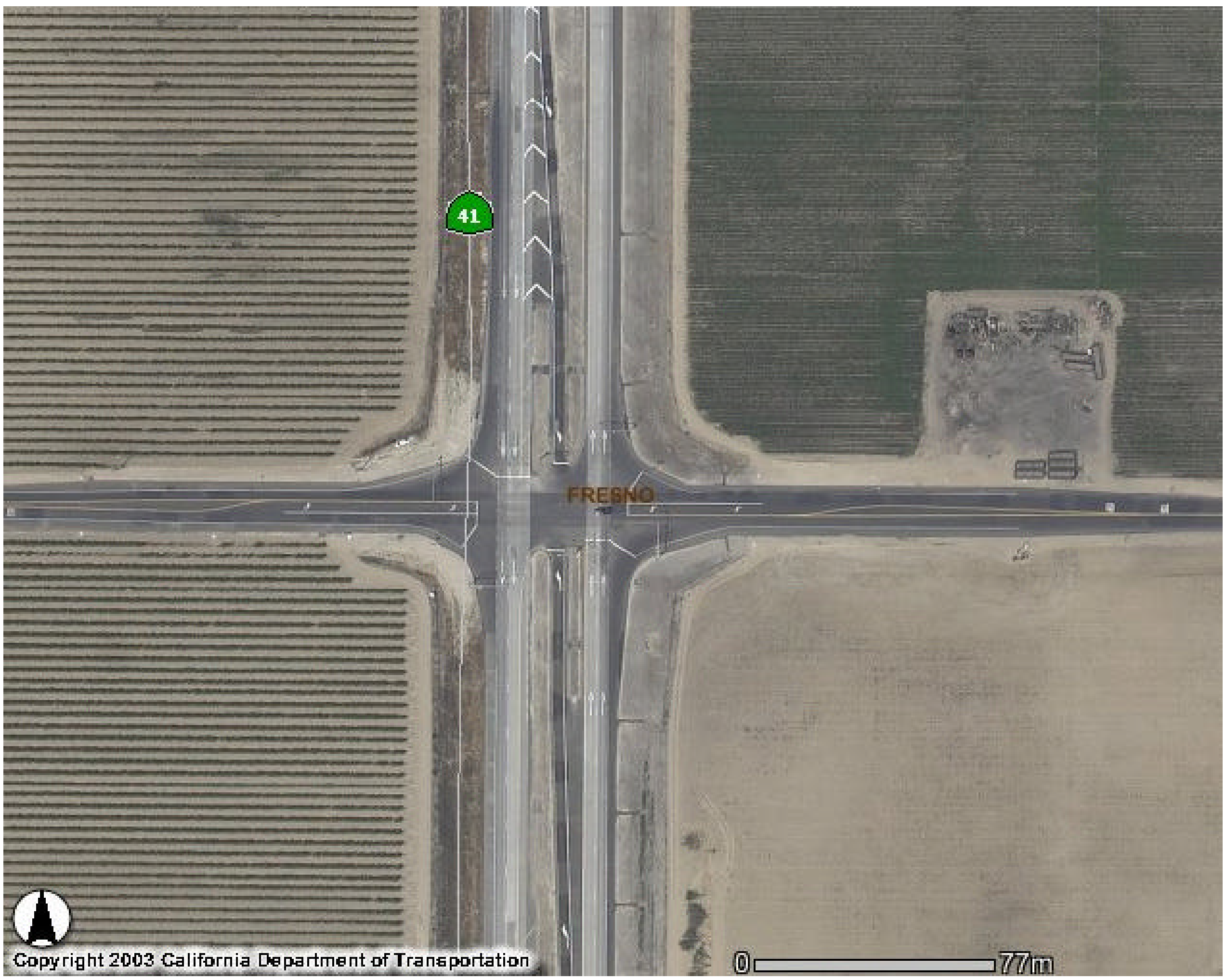

Figure 3.2. Photograph of a California DOT improved intersection
(Source: California DOT)

Colorado Department of Transportation [4]

Currently, the Colorado DOT has 488 miles of expressway. The DOT has no current plans to expand expressway miles; however, they assume that two-lane highways will be upgraded to expressways in the next five years due to safety, access, or land use decisions. The state has not outlined any specific criteria for upgrading expressway at-grade intersections to full access control but operational and safety performance tend to be the driving factors for initiating an upgrade.

The access control policy for the Colorado DOT states that all access points must be spaced a mile apart. In urban areas, access point spacing may be decreased to a half-mile, but the use of frontage roads to limit the number of access points is suggested. The state follows the MUTCD guidelines regarding design of traffic control on expressways, while their geometry features follow typical interstate requirements for medians, lane width, etc. The typical speed limit is 65 mph in rural areas and 45 to 55 mph in urban areas.

The Colorado DOT noticed a high percentage of rear end, broadside, and approach turn collisions on expressway at-grade intersections. Colorado also found that wrong-way maneuvers were extremely rare on new facilities, however they have noticed that pavement markings (arrows) inside the expressway lanes that indicate the direction of traffic to drivers entering from the minor approaches have been very effective in preventing these maneuvers.

Over the last few years, the state has been analyzing the over-representation of specific age groups, as well as considering alternatives to intersection construction. The Colorado DOT has not conducted a crash study specifically for expressways; however, they have built a roundabout on an urban segment of an expressway and preliminary information indicates that roundabouts could reduce crashes by up to 60%. The Colorado DOT also suggested that at unsignalized intersections, auxiliary lanes on the expressway are vital, and painted or even raised channelizing islands should be used to reduce the crossing distance for side road traffic to the through lanes only (stop bar 2–4 feet from edge of through lane) to prevent slowing and turning traffic from obstructing the line-of-sight of the driver at the stop line. The Colorado DOT has also tested offset lefts and median stops, but has not received enough safety performance information to quantify benefits of these strategies.

Florida Department of Transportation [5]

The Florida DOT operates 771 miles of expressway and plans to expand the expressway system over the next 10 years. The principal motivation for expanding the expressway system is the cost advantage when compared to a full grade separated facility. The decision to improve existing expressway to full access control is based on the route's level of service. Typically, the Florida DOT will upgrade to a full access-controlled facility in order

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[4] Respondent: Richard G. Sarchet, P.E., Safety Engineering and Analysis Group, Colorado Department of Transportation Denver, CO

[5] Respondent: Patrick A. Brady, P. E., Transportation Safety Engineer, Florida Department of Transportation, Tallahassee FL

to maintain higher speeds and improve traffic flow. Table 3.2 shows the current crash rates on Florida expressway intersections in 2003. The crash rates show that 3 leg intersection (t-intersections) have a lower crash rate when compared to 4 leg intersections.

Table 3.2 Florida Crash Rates per Million Entering Vehicles (MEV)

	Urban	**Suburban***	**Rural**
4 lane/3 leg	0.304	0.228	0.162
4 lane/4 leg	0.481	0.414	0.365
6 lane/3 leg	0.376	0.261	0.295**
6 lane/4 leg	0.648	0.494	0.528**

* Rural open drainage inside urban boundaries, not curb and gutter
** Limited number of locations, small sample size

The Florida DOT has observed that the safety improvements that have been most effective in reducing the crash rates at expressway intersections include the following: signal timing, visibility improvements, turning bay storage improvements, and protected left-turns. The Florida DOT has also constructed offset left-turn lanes and rumble strips on the minor roadway approaches, but has not had the opportunity to evaluate safety performance of these strategies.

Illinois Department of Transportation [6]

The Illinois DOT operates 247 miles of expressway and plans to expand its expressway system over the next 10 years. The Illinois DOT observed that expressways could serve higher volumes than two-lane facilities and provide an intermediate step for improvement to a full-access control facility. In Illinois, the cross-sections of all expressways are designed to meet interstate geometric requirements. Each intersection is analyzed for type of control. Any intersection that is projected to need a signal in the next 9 years will be programmed for conversion into an interchange. Any intersection that is projected to need a signal in the next 20 years will trigger the purchase of access rights for a future interchange. The speed limit on expressways is 65 mph, but decreases as the expressway enters city limits or populated areas.

The Illinois DOT has constructed offset left-turns, but no evaluation of the safety performance of offset left-turns has been completed. However, the state recently completed an analysis of a major downstate suburban signalized intersection. This analysis demonstrated an over-representation of rear-end crashes versus statewide averages. Auxiliary lanes were added and existing auxiliary lanes were augmented in order to mitigate the occurrence of rear-end crashes.

[6] Respondent: Martha A. Schartz, P.E., Safety Programs Engineer, Illinois Department of Transportation, Bureau of Operations, Springfield, IL

Indiana Department of Transportation [7]

Currently, the Indiana DOT operates 541 miles of expressway with plans to expand its expressway system over the next 10 years to relieve congestion. The Indiana DOT would prefer not to upgrade existing expressways to full access control unless it is a part of a phase plan to upgrade the entire corridor. They have found that safety benefits are decreased when only portions of an expressway are upgraded due to driver expectations. For example, if some intersections are grade-separated, drivers expect that all intersections will be grade separated.

Given the Indiana DOT's access control policy, they have found that an expressway design is more consistent with rural areas and not consistent with urbanized areas. Since cities in Indiana govern access once the route reaches the city limits, in urban areas, access control becomes problematic. The Indiana DOT also follows the guidance in the MUTCD for design of traffic control. They generally use protected left-turn signal phasing on the main line for expressways with grass and barrier medians. Also, if the posted speed limit is above 50 mph, they always use a protected left-turn signal, regardless of the median type. Typically, rural Indiana DOT expressways have a 55 mph speed limit. Currently, the Indiana DOT has not used any unique or innovative strategies as countermeasures to poor intersection safety performance. The Indiana DOT is looking into some strategies and expects to add them to some of their new construction in the next 5 years.

Iowa Department of Transportation[8]

The Iowa DOT currently operates 350 miles of expressway and plans on a limited expansion of this system over the next 5 years. Almost all of the rural expressways have posted speed limits of 65 mph. Iowa's expressways experience an average crash rate of 0.91 crashes per million vehicle miles and the intersections experience an average crash rate of 0.15 crashes per million entering vehicles. Numerous at-grade expressway intersections became problematic soon after construction of the expressway. Some of the most problematic intersections are located on horizontal and vertical curves even though sight distance meets all design standards. Most of these are along urban bypasses or are located along high volume commuter routes near state's largest job centers.

To address these concerns, the Iowa DOT includes more full access-controlled bypasses (access at interchanges only) along the proposed expressways. In addition, selected portions of some expressways were built with a 100 foot median (distance measured pavement edge to pavement edge). While the full access-controlled bypasses are very effective, the wider medians only have limited safety benefits. The Iowa DOT observed that the wide medians do accommodate semi-trucks, agriculture vehicles,

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[7] Respondent: Todd Shields, Field Engineer, Indiana Department of Transportation, Operations Support Division, Indianapolis, IN

[8] Respondent: Thomas M. Welch P.E., State Transportation Safety Engineer, Iowa Department of Transportation, Ames, IA

and school busses, but do not appear to reduced left-turning and cross-traffic crashes. The DOT notes that almost all of these crashes are directly related to a “failure to yield” from the stop sign or median.

On stop-controlled primary highways that intersect with an expressway, the Iowa DOT has in-pavement rumble strips in advance of the stop sign. Intersection lighting is also provided at these intersections. Many, but not all, paved county road expressway intersections include advance stop sign rumble strips and some lighting. The Iowa DOT Office of Traffic and Safety discourages the installation of traffic signals along expressways. However, about 15 traffic signals have been installed at expressway intersections. The Iowa DOT notes that crash patterns changed following the installation of the signals, but major injury and fatal crashes continue to occur at many of these traffic signal-controlled expressway intersections.

Iowa has experienced a considerable number of wrong way maneuvers at expressway intersections. These maneuvers are more prevalent soon after the opening of the new expressway. The DOT explained that Iowa’s high population of older drivers is a contributing factor to this issue.

Iowa has also implemented a number of other strategies in an attempt to mitigate crashes at problematic expressway intersections. The following is a list, discussion, and evaluation of each:

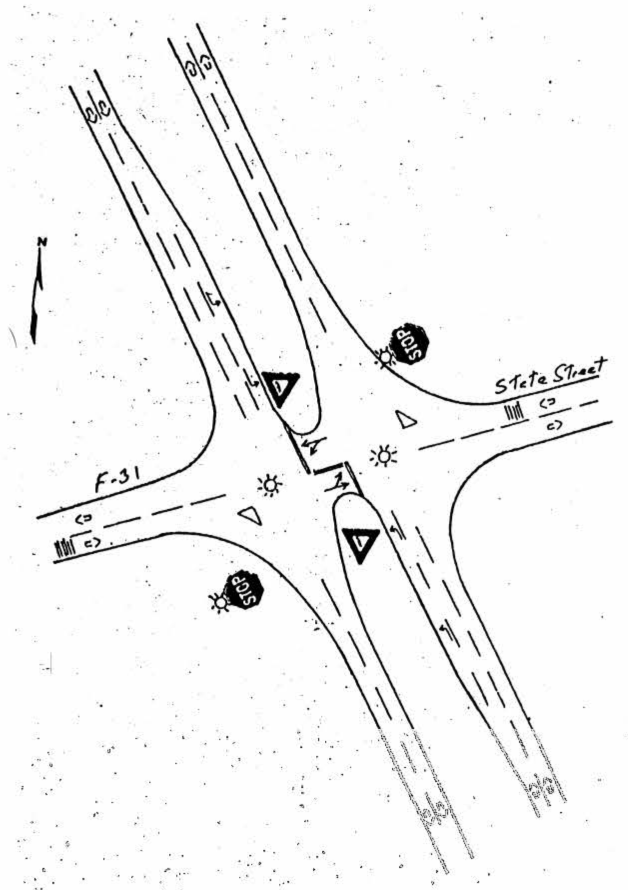
1. As shown in Figure 3.3, a double yellow centerline has been installed in many expressway intersection medians. This strategy has been shown to reduce the number of vehicles that try to queue up in the median. The centerline pavement marking reduces the decision-making process of drivers stopped at the intersection or in the median. It also provides a measure of depth perception to illustrate that the median is wide enough to offer refuge to a car. Limited before and after crash analyses have shown a reduction in intersection-related crashes following the installation of the median centerline. After the pavement markings wore off, the crash rate increased. As a result, the Iowa DOT traffic safety staff have proposed using milled-in tape pavement markings at these locations.

Figure 3.3. Delineation of median storage

2. Stop/yield bars have been painted in the median to encourage motorist to stop in the median before proceeding across the far expressway lanes.

3. News stories have been published in local newspapers to explain to motorists how they should enter and cross an expressway. Figure 3.4 is an example of one such article. These articles encourage the motorist to treat the expressway as two independent roadways.

4. At the request of local residents, increased speed enforcement has been implemented at several intersections. Local enforcement officers state this has not had any long-term effect on running speeds near the intersections.



The above illustration is from Thomas Welch of the IDOT and it shows the proper way to enter or cross IA-141. Motorists in vehicles less than 60 feet in length should cross IA-141 as if they are crossing two separate intersections.

1. Motorists should come to a complete stop at the stop sign.

2. The driver should focus on IA-141 traffic approaching the intersection from their left and the traffic in the median. Motorists on the side road should yield to vehicles in the median which are signaling to turn left onto IA-141, or left off of IA-141.

3. When an acceptable gap in the IA-141 traffic approaching from the left is available they should drive into the median staying right of the double yellow center line and stopping at the far side of the median. Do NOT angle to the left of the center of the median if you are going to turn left. Stay perpendicular to IA-141.

4. The driver should now focus on the IA-141 traffic approaching from the right and enter or cross IA-141 when an acceptable gap in the traffic is available.

In addition to the other interim improvements we will be adding flashing red lights above the stop signs, flashing beacons above the intersection and the county will cut rumble strips on Co. RD F-31 prior to the stop signs.

Figure 3.4. Printed article explaining how to use a newly constructed intersection

5. As demonstrated in Figure 3.5 and Figure 3.6, an advisory speed limit, 10 mph below the posted speed limit, has been posted on both sides of the expressway roadway in advance of an intersection. Before and after speed studies show no or little decrease in speeds during off-peak hours. However, a noticeable reduction in speeds was noted during the peak hours, which are generally the most problematic times for expressway intersection crashes.

6. Recently, at one expressway intersection, a side road approach was relocated to create an offset T-intersection. A before/after crash analysis to determine the benefits of this strategy has not been completed yet.

7. Corridor Access Management agreements have been developed with local governments which identify future sites of traffic signals and call for other median openings to be converted for restricted access points (prohibiting cross traffic and left-turns out of side roads and access points) if they become problematic.

8. At three locations, near the beginning of the four-lane expressway, a lane in each direction was painted out to provide only one through lane in each direction. This provided a traffic calming effect near the intersection.

9. A grade separated intersection have been proposed to replace two paved county road expressway at-grade intersections. Figure 3.7 illustrates one such proposed project.

10. Finally, additional and longer right- and left-turn lanes are being installed at existing expressway intersections to reduce the conflicts between through and decelerating vehicles. Offset left-turn lanes are used at expressway intersections controlled by a traffic signal. Iowa discourages the use of offset lefts at other high-speed expressway intersections not controlled by a traffic signal. Offset right-turn lanes are also being installed at several expressway intersections to improve sight distance for motorists stopped at the side road. The offset can be as little as 4–6 feet.

Figure 3.5. Advisory speed beacon, US 65, Bondurant, Iowa

Figure 3.6. Full view of advisory speed beacon, US 65, Bondurant, Iowa

Figure 3.7. Proposed US 61 highway conversion, Muscatine County

Kentucky Transportation Cabinet[9]

The Kentucky Transportation Cabinet (KYTC) currently operates 909 miles of expressway and plans to expand the number of expressway miles over the next 10 years. The KYTC projected that they will need to build new facilities because of safety and access concerns and insufficient funds to build a full grade-separated facility. Conversion from expressway to full access control is rarely an option for the KYTC, but if conversion is needed, capacity and safety would be the driving factors in the project. Access management is currently done on a case-by-case basis; however, a statewide access management plan is awaiting approval. Also, traffic control in the state is designed to follow the MUTCD guidelines and professional judgment. The maximum speed limit for expressways is 55 mph, but the speed limit is typically reduced to 45 MPH in urban areas.

In 2003, the KYTC observed an average crash rate of 1.24 per million vehicle miles on rural expressways and an average crash rate of 2.95 per million vehicle miles on urban expressways. They also observed an overrepresentation of younger drivers in crashes statewide. The KYTC has not attempted any innovative geometric or traffic control strategies at expressway intersections. Most of the KYTC's at-grade expressway intersections have signal operation, flashing beacons, or advanced warning flashers.

[9] Respondent: Duane Thomas, Kentucky Transportation Cabinet, Frankfort, KY

Louisiana Department of Transportation and Development[10]

The Louisiana Department of Transportation and Development (DOTD) currently operates 168 miles of expressway with plans to expand its expressway system in the next 10 years. The state began upgrading the US 90 expressway from Lafayette to New Orleans into a full access-controlled interstate. This section of road is 180 miles long and 65 miles have already been upgraded. The conversion was undertaken to reduce the number of fatalities at various intersections along the route, local pressure to improve the safety, and growing traffic congestion. The Louisiana DOTD follows AASHTO guidelines for geometric design on expressways and intersections throughout the state. Most speed limits on expressways are 65 mph in rural areas or 45 mph in urbanized areas.

The state observed an average expressway crash rate of 0.75 per million vehicle miles in 2003. Most of the crashes involved a sideswipe, rear-end, or right angle crash. The Louisiana DOTD also noticed a higher frequency of elderly drivers and drunk drivers involved in expressway crashes. They have not attempted any innovative geometric designs; however, they are interested in new crash countermeasures and may modify their standard designs to include safety improvements in the future.

Maryland Department of Transportation[11]

The Maryland DOT operates 481 miles of expressway and plans to expand its expressway system over the next 10 years. Safety and rising volumes have resulted in the addition of improvements to at-grade expressway intersections with additional turning lanes, wider medians, and intersection reconstructions in the 10-year plan. The Maryland DOT has observed the need to convert some expressway intersections to interchanges due to the rising volumes that result in capacity problems for at-grade intersections. The Maryland DOT has not completed a specific crash analysis on its expressway system, but they have observed a higher frequency of younger and older driver with problems judging the speeds of oncoming traffic while making left-turns and making turn at intersections with wide medians. The Maryland DOT follows AASHTO guidelines for geometric design. The speed limits on Maryland's routes are 45 to 55 mph, depending on conditions such as sight distance and design.

The Maryland DOT has attempted a number of new intersection designs and traffic control strategies to improve safety including continuous flow intersections, offset left-turn lanes, median stop bars, signals, warning signs at minor approaches, and "indirect minor road left-turn" (shown in Figure 3.8). In Figure 3.8, the minor road traffic must make a right-turn due to the directional median barrier even though the rest of the traffic can make left-turns. Maryland has not yet evaluated the safety performance improvement of any of these strategies.

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[10] Respondent: Hadi H. Shirazi, P.E., Traffic Safety Engineer, Louisiana Department of Transportation and Development, Baton Rouge, LA

[11] Respondent: Eric Tabacek, Maryland Department of Transportation, Hanover, MD

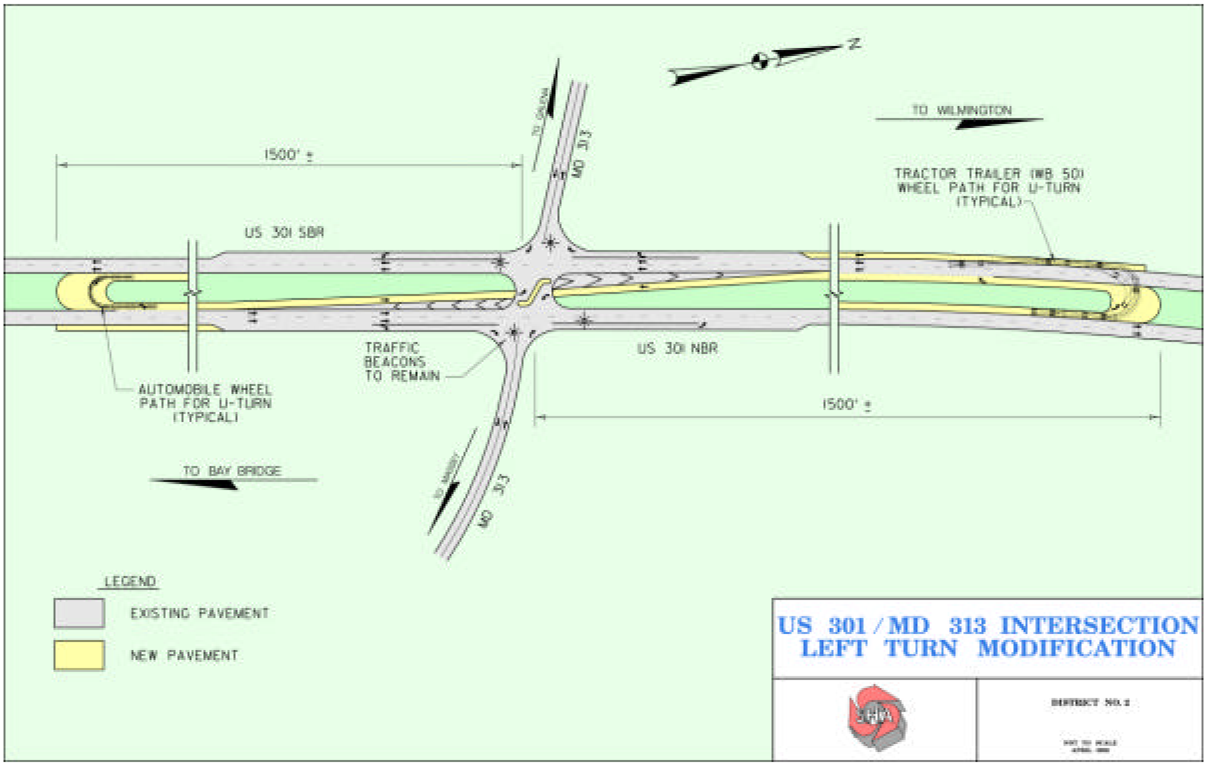

Figure 3.8. Directional median with indirect minor road left-turns (Source: Maryland DOT)

Michigan Department of Transportation [12]

The Michigan DOT operates 113 miles of expressway and plans to expand its system over the next 10 years because of the low cost to construct additional miles of expressway when compared to a full grade separated facility. Currently, a half mile is the minimum distance for access points. The Michigan DOT also follows the MUTCD for the design of traffic control. The speed limit for Michigan's expressways is 65 mph in rural areas and 55 mph in urban areas.

The Michigan DOT has not researched specific crash rates for expressways; however, they have attempted a few improvements. Michigan improved the street lighting at a number of intersections with some success in reducing crashes. Also, the Michigan DOT attempted offsetting some left-turn lanes and from their experience, they would not recommend this strategy. The Michigan DOT plans to try other designs and traffic control strategies, such as roundabouts, over the next 10 years.

[12] Respondent: Imad Gedaoun, Michigan Department of Transportation, Lansing, MI

Minnesota Department of Transportation[13]

The Minnesota DOT operates 1,010 miles of expressway and plans to expand its system over the next 10 years. The motivating factor for constructing expressways is safety and congestion relief when compared to high volume two-lane highways. The Minnesota DOT has converted a few intersections to interchanges because of high crash rates or severe congestion. The Minnesota DOT also notes that on corridors identified as planned grade-separated facilities, interchanges are occasionally constructed at locations where right-of-way and funding is readily available. They also explained that traffic control is done on a case-by-case basis while following MUTCD guidelines. The Minnesota DOT has established design guidelines similar to those of the AASHTO policy on geometric highway design. The speed limit for rural expressways is 65 mph.

The Minnesota DOT has an average crash rate of 0.4 per million entering vehicles (MEV) for at-grade unsignalized intersections on its expressways. They have not done a formal investigation of older or younger drivers, but their perception is that there is an over-representation of older drivers involved in right angle crashes. Minnesota has constructed offset turn lanes, indirect lefts, median left-turn acceleration lanes, longer deceleration lanes, and rumble strips on the minor road approach, but not enough evaluation has been conducted to determine the safety benefits attributable to these countermeasures. Minnesota has installed signals at expressway intersections with varying success and has improved expressway intersections to interchanges. The Minnesota DOT is also testing an ITS Decision Support System (an infrastructure-based system to assist drivers to accept safety gaps). Figure 3.9 below presents a typical Minnesota at-grade intersection.

[13] Respondent: Loren Hill, Minnesota Department of Transportation, Saint Paul, MN

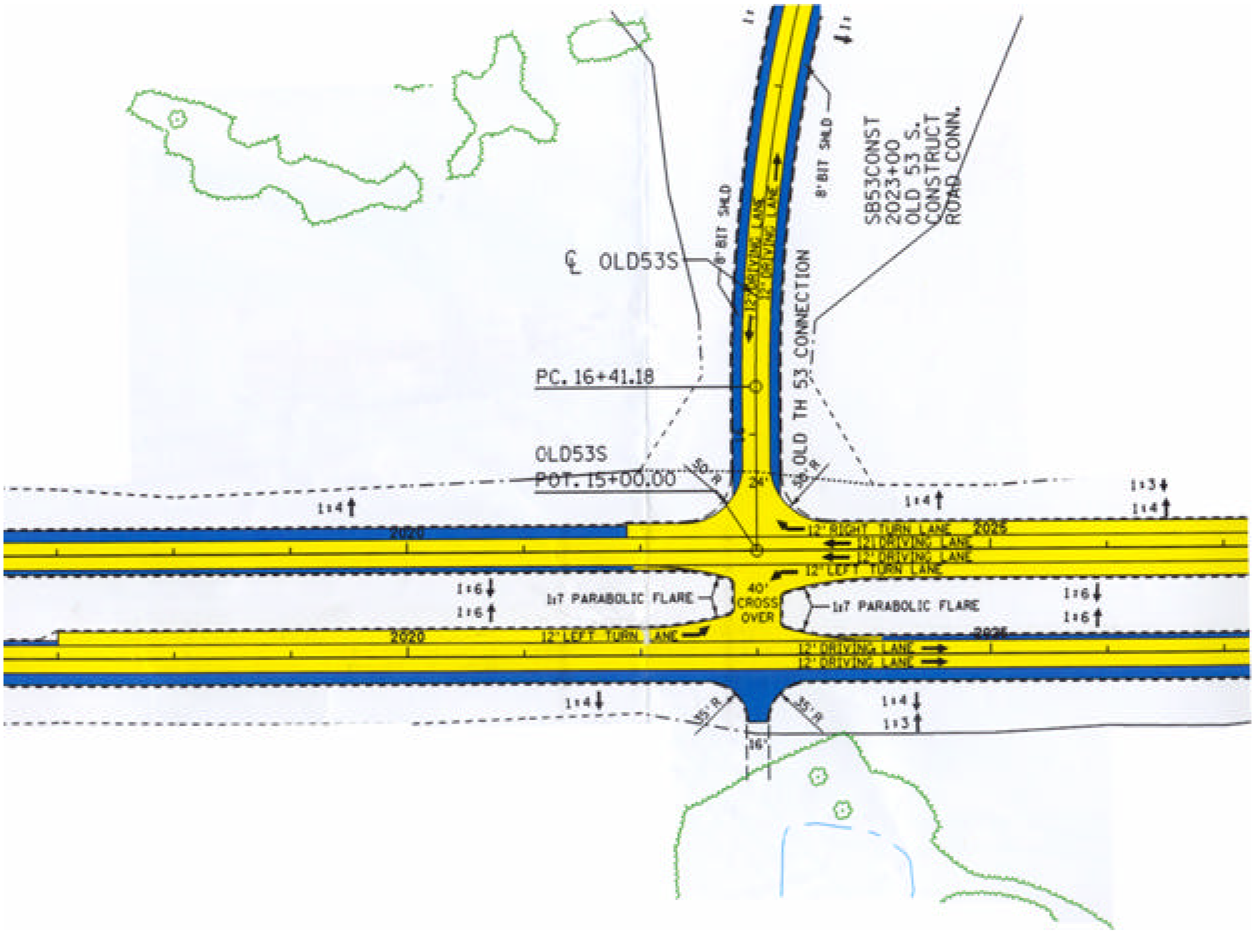

Figure 3.9. Typical Minnesota at-grade intersection
(Source: Minnesota DOT)

Mississippi Department of Transportation [14]

The Mississippi DOT currently operates 801 miles of expressway and plans to expand this number over the next 10 years. The Mississippi legislature has recently passed a bill to give additional funding to create more expressways and to convert some expressways to full access control. Typically, a full conversion of an intersection to an interchange is only completed when the highway is converted to a full access control. This is typically done when an intersection has a high crash rates or has poor operational characteristics due to capacity problems. The speed limit on Mississippi expressways is 65 mph.

The Mississippi DOT has not conducted a crash study of expressways, but they have experienced severe problems with crashes at intersections with narrow medians and also at intersections with very wide medians (more than 100 feet). The Mississippi DOT has attempted to widen several medians in hopes of improving safety performance of the intersection. However, the widening of the medians has created confusion among drivers

[14] Respondent: John Smith, Mississippi Department of Transportation,Traffic Engineering, Jackson, MS

using the median crossover. It seems that most drivers on the minor roadway and using the median crossover do not yield once they have crossed the first set of lanes. Many drivers are attempting to cross the entire intersection in one movement, which results in a high number of crashes. The Mississippi DOT has also converted an expressway intersection to a roundabout and constructed offset left-turn lanes and additional acceleration/deceleration lanes, but the DOT has not evaluated the safety performance of these improvements. For example, they built two roundabout intersections last year and are in the process of constructing a third. The Mississippi DOT believes that roundabouts reduce crash rates, but have not conducted an evaluation yet.

Missouri Department of Transportation [15]

The Missouri DOT currently operates 1,400 miles of expressway and plans to expand its expressway system over the next 10 years. The planned expansion will be minimal due to limited resources and pressure to preserve the highway system they already have. Missouri DOT follows MUTCD guidelines for traffic control devices and the AASHTO policy on geometric highway design. The speed limit on the state facilities is 65 to 70 mph, depending on the location of the route (rural/urban) and the results of speed studies.

The Missouri DOT has not completed any expressway-specific crash studies. However, they have attempted a number of alternative intersection designs with varied success, including median acceleration lanes, jug handles, and flashing lights on approaching signs. Although the Missouri DOT is currently evaluating a number of these alternatives, it is their perception that the median acceleration lanes have offered the most positive results in terms of safety performance for large trucks. In Figures 3.10 through 3.12, three photos demonstrate the design and use of these acceleration lanes.

The survey respondent for the Missouri DOT said that “at-grade intersections along expressways are a concern for Missouri as far as safety and their operation. We currently have a median opening team established, which is made up of traffic and design personnel. This team is evaluating many alternatives to our existing typical crossover design.” The Missouri DOT is a supporting state of the NCHRP 17-18(3) study for unsignalized intersections. When performing the data analysis to provide information to support the development of “A Guide for Addressing Unsignalized Intersection Collisions,” the Missouri DOT found that expressways were overrepresented in the total fatality counts (46). Around 35% of the fatalities at unsignalized intersections were on expressways. Within these fatalities on expressways, older drivers are over-represented in crashes that involve a fatality. Although the Missouri DOT is in the process of evaluating and possibly implementing crash countermeasures at at-grade intersections on expressways, they are still searching for solutions to improve safety and the efficient operation of median crossovers.

[15] Respondent: Grahm Zieba, Traffic Studies Engineer, Missouri Department of Transportation, Jefferson City, MO

Figure 3.10. Missouri acceleration lane

Figure 3.11. Missouri acceleration lane

Figure 3.12. Missouri acceleration lane in use

Nebraska Department of Roads [16]

The Nebraska Department of Roads (NDOR) operates 410 miles of expressway and plans to add 190 miles to its expressway over the next 10 years. The NDOR uses the MUTCD to support its design of traffic control devices and the AASHTO policy on geometric design to guide the design of expressways. The speed limit on expressways in Nebraska is 65 mph. The NDOR uses frontage roads in a number of areas to control access along expressways.

Although the NDOR did not include a crash rate on expressways in their response, they did note that the crash rates on rural expressways are lower than on two-lane highways. The NDOR has not evaluated the involvement of elderly drivers in expressway intersection crashes, but they have observed a number of intersections where elderly drivers appear to have problems finding acceptable gaps for crossing and turning movements. NDOR is contemplating the use of a few alternatives intersection designs to reduce crash rates, but they have not yet implemented any. The NDOR respondent projected that over the next 5 to 10 years, a number of improvements to the expressway system will be necessary, due to congestion and safety.

[16] Respondent: Randy Peters, Nebraska Department of Roads, Lincoln, NE

New York State Department of Transportation [17]

The New York State DOT operates 382 miles of expressway. The accident mitigation measure at expressway intersections employed most often by the New York State DOT is the replacement of at-grade intersections with interchanges. For example, intersections are being replaced by interchanges on a 204 mile segment of rural expressway Route 17 as it is being converted to an interstate highway. In a few locations, a median guardrail has been installed to eliminate crossover movement of traffic and only allow one-way entrance to the expressway. Historically, the New York State DOT has completed a number of conversions from expressway to full access control. Typically, these conversions are completed in response to capacity or safety concerns. The New York State DOT has created a "Roundabout Design Guide." This guide includes standards for high volume facilities, although it is not expressway-specific. The speed limit for expressways in New York is 55 mph.

The New York State DOT has not conducted an overall evaluation of the safety performance of expressways, but it has recently conducted a study of a 17.2 mile-long section of expressway (the Taconic State Parkway) with average daily traffic of 21,500 vehicles. They observed the percentage of crash by type, shown in Table 3.3. The percentages total to more than 100% since some of the crashes may have been involved in more than one type.

Table 3.3. New York collision percentages

Collision Type	Percent of Crashes
Animal Crashes	17%
Fixed Object	71%
Left-turn	0%
Overtaking	13%
Rear End	15%
Right Angle	8%
Side Swipe	0%

As a result of this study, the New York State DOT closed a number of access points and median crossovers along the route. On this segment of Highway 18, at-grade intersections have been closed with the installation of barriers. Case studies were done to consider the impact of these closures on emergency service response time, but the results are not yet available. The New York State DOT is currently investigating the use of "Intersection Approaching" signs with flashing signals, jug handles, and offset left-turns. The New York State DOT has not collected safety performance data from these intersections, but they believe that each alternative has provided some benefit. Furthermore, they do not use traffic signals at expressway intersections.

[17] Bruce Smith, New York State Department of Transportation, Albany, NY

North Carolina Department of Transportation [18]

The North Carolina DOT operates 567 miles of expressway and plans to expand its expressway system over the next 10 years. The North Carolina DOT will construct additional lanes of expressway in the 2006–2012 Transportation Improvement Program (TIP). Expressways have been a popular option for upgrading two-lane facilities without access control to four-lane divided facilities with partial access control. Access occurs at intersecting roads and driveways for larger tracts of land. The functional purpose of these facilities is high mobility and low access. The DOT's expressways are in rural areas of the state. Providing expensive interchanges and grade separations makes improvement projects difficult to fund and program. The expressways are generally posted with a speed limit of 55 mph.

The conversion of an expressway from partial to full access control is completed after a statewide corridor study identified high-risk segments of roadway. The conversion is the last phase of a 25-year, long-range program. Safety concerns or the corridor study may dictate earlier implementation of interchanges. North Carolina's interchanges are added when traffic volumes exceed the capacity of an at-grade signalized intersection. All state projects are designed using 20-year traffic projections from the date of the projects.

Recent North Carolina DOT research has shown an over-representation of the following groups in expressway accidents when compared to the statewide averages:

- Young drivers (ages 16-20): 40% of all crashes, 21% of fatalities, 32% of injuries.
- Older Drivers (older than 65): 19% of all crashes, 19% of fatalities, and 14% of injuries.

The North Carolina DOT has used several intersection strategies, including offset left-turn lanes, rumble strips on the minor roadway approach, and a roundabout on an urban segment. However, the North Carolina DOT has not yet evaluated any of the alternatives, with the exception of rumble strips. Based on the positive performance of edge line rumble strips on freeways, the North Carolina DOT has recently added flexibility to allow for the use of rumble strips on expressways on the edge line and on minor roadway intersection approaches. In Figures 3.13 and 3.14, the North Carolina DOT has provided samples of their design manual. Figure 3.13 is a typical design for a T-intersection. Figure 3.14 illustrates North Carolina DOT's standard for an offset left-turn design.

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[18] Respondent, Cliff Braam, North Carolina Department of Transportation, Raleigh NC

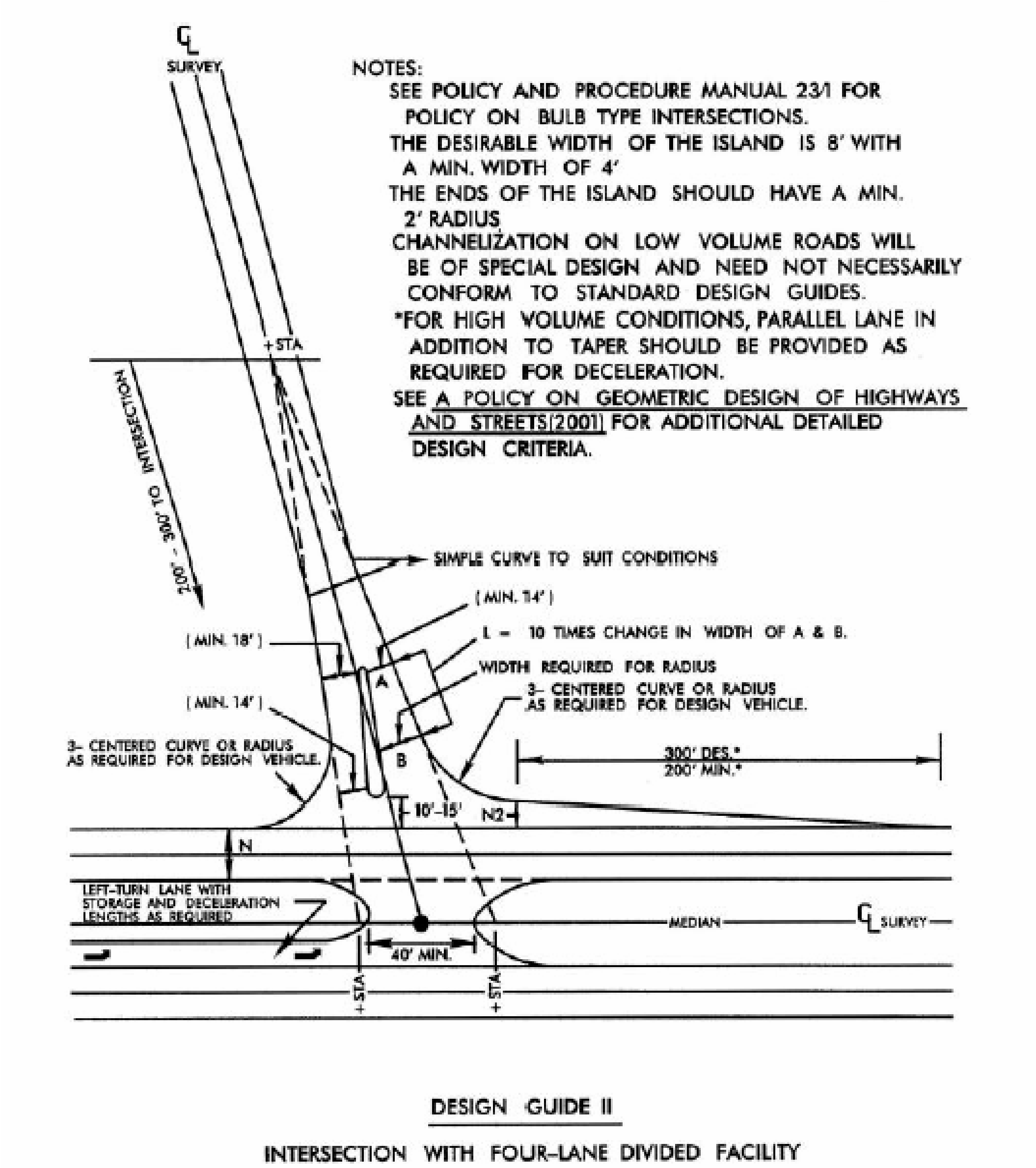

Figure 3.13. North Carolina DOT T-Intersection Design
(Source: North Carolina DOT)

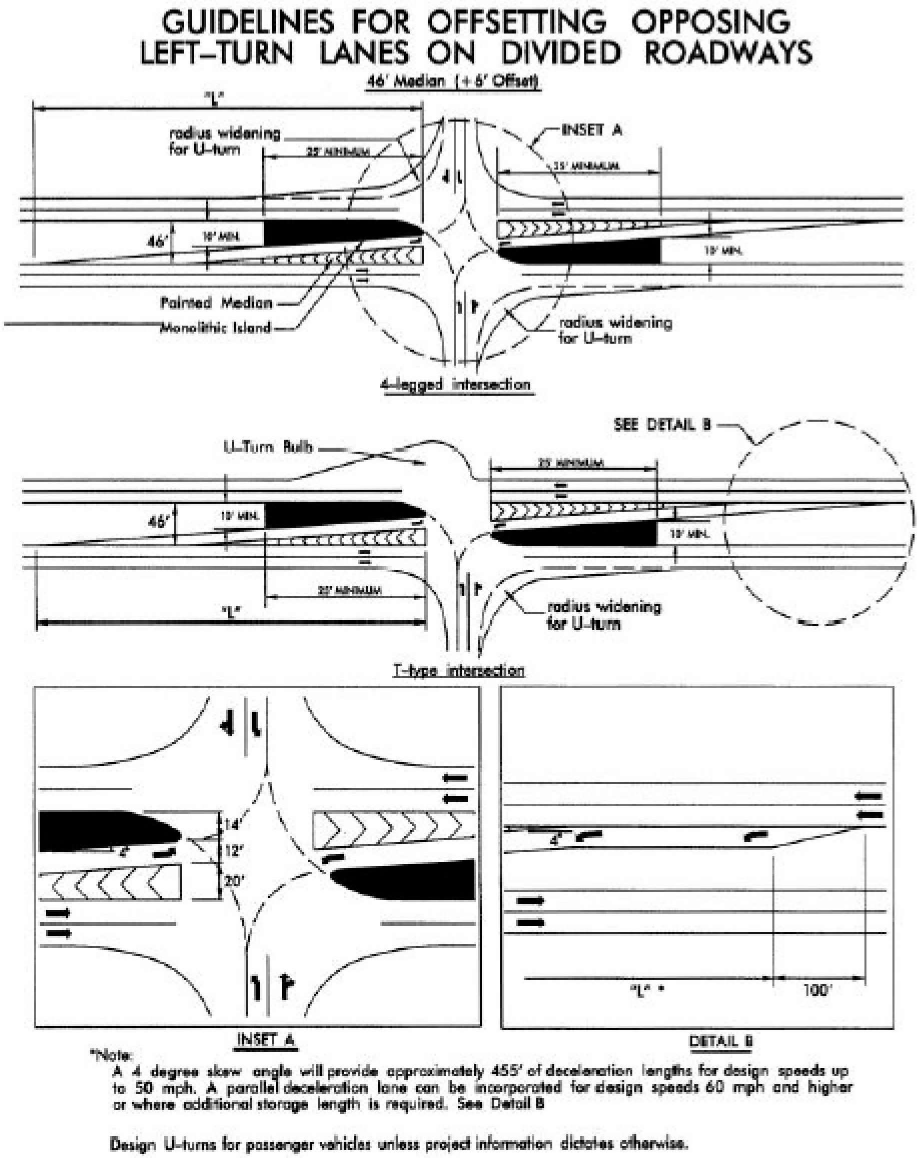

Figure 3.14. Offset left-turn design
(Source: North Carolina DOT)

North Dakota Department of Transportation [19]

The North Dakota DOT operates 450 miles of expressways and plans to expand its expressway system over the next 10 years. For example, in the next 4 years, the North Dakota DOT plans on upgrading US 2 between Williston and Minot to an expressway by constructing two additional lanes. The primary factor driving the development of expressways has been the potential for economic development in the corridor as a result of the improvement. The North Dakota DOT has also converted some expressways to full

[19] Respondent, Allan Covlin, North Dakota Department of Transportation, Bismarck, ND

access control because of safety and capacity concerns. The speed limit for North Dakota DOT expressways is 70 miles per hour.

The North Dakota DOT has not conducted a safety study of expressway intersection crashes; however, the respondent believed that right angle crashes constitute a majority of crashes. The North Dakota DOT has modified its standard intersection design so that the left-turn lanes are at least opposing each other, regardless of the width of the median. At signalized intersections on expressways with a speed limit of 35 miles per hour or greater, the North Dakota DOT provides a protected left-turn phase. If the crash history indicates right angle crashes are caused by vehicles on the minor roadway failing to stop, the North Dakota DOT may install rumble strips on the minor approach and/or flashing beacons. Rumble strips and offset lefts are the only special strategies that have been attempted, but they seem to have resulted in improved safety performance.

Oklahoma Department of Transportation [20]

The Oklahoma DOT currently operates 1,204 miles of expressway and plans to expand its expressway system over the next 10 years. The speed limit on Oklahoma expressways is 45 to 55 miles per hour. The Oklahoma DOT uses frontage roads in urban areas to control access.

Recent crash data analysis has shown that Oklahoma DOT expressways experience 1.20 to 1.30 crashes per million vehicle miles. The state has not observed any over-representation of any driver age groups, although right angle, sideswipe and rear end crashes collision types are over-represented. To reduce crash rates, the Oklahoma DOT has installed signals and turn lanes with mixed results. The Oklahoma DOT respondent believed that the use of signals and turn lanes have reduced the crash severity at intersections; however, no analysis has been conducted to confirm that safety performance was improved, but a study on this issue is planned in the upcoming year.

Oregon Department of Transportation [21]

The Oregon DOT operates 104 miles of expressway and plans to expand its system over the next 10 years. Due to safety and capacity concerns, the Oregon DOT is considering a number of two-lane routes as candidates for conversion to expressways. The Oregon DOT respondent speculated that they might add up to 30 additional miles of expressway in the next 5 years. The Oregon DOT follows MUTCD guidance for design of traffic control and uses AASHTO's policy for geometric highway design when designing expressways. The design speed for expressway varies from 45 miles per hour to the more typical 70 miles per hour; however, the posted speed for these faculties is 55 miles per hour.

The Oregon DOT has not conducted an analysis of expressway crashes, but the Oregon DOT respondent did speculate that younger and older drivers are over-represented in

[20] Respondent: Alan Stevenson, Oklahoma Department of Transportation, Oklahoma City, OK

[21] Respondent: Robin Ness, Program Coordinator, Transportation Data Section, Oregon Department of Transportation, Salem, OR

expressway crashes. The Oregon DOT has constructed intersections that include offset left-turns, indirect lefts, jug handles, median stop bars, rumble strips on the minor approach lanes, and rumble strips in the median crossover at the approach to the second lane in very wide medians. These design modifications were recently made to a new section of expressway and there is not enough information to determine their effect on safety.

Pennsylvania Department of Transportation [22]

The Pennsylvania DOT operates 503 miles of expressway and plans to expand its expressway system over the next 10 years. The Pennsylvania DOT respondent stated that lower costs when compared to the costs of constructing full access-controlled facilities, better safety performance than two-lane highways, the ability to control access, and positive environmental impacts were all motivating factors for constructing new expressways.

The Pennsylvania DOT has not conducted a safety study of expressways, but they did observe that "wrong-way maneuvers" account for 1% of all crashes at intersections along expressways. Specifically, from 1997 to 2001, the Pennsylvania DOT experienced 768 wrong-way crashes on expressways. To improve safety at expressway intersections, the Pennsylvania DOT is constructing jug handles, offset left-turns, improved signage, and the installation of left- and right-turn/deceleration lanes. Although a technical evaluation of these improvements has not been conducted, the Pennsylvania DOT believes that the left- and right-turn/deceleration lanes are effective in reducing crashes at high volume intersections.

South Carolina Department of Transportation [23]

The South Carolina DOT operates 943 miles of expressway and plans to expand its expressway system over the next 10 years. The South Carolina DOT has converted a number of expressway intersections to interchanges. Intersections are selected for conversion on a case-by-case basis. Turning an intersection into an interchange is done because of high volume, poor safety performance, terrain and other restricting geometric features. The South Carolina DOT does not have an explicit access management policy, but, by state law, the South Carolina DOT can define the type of access (access spacing) for a roadway.

The South Carolina DOT has not conducted a study of crash rates on expressways. To improve safety at expressway intersections, the South Carolina DOT has used offset left-turn lanes, indirect lefts, rumble strips on the minor roadway approach, and deceleration lanes to encourage left-turn median U-turns. Figure 3.15 illustrates a channelized turn lane intersection, which is typically used at high volume intersections. Figure 3.16 shows an alternative design for offset left-turning lanes.

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[22] Respondent: Michael A. Baglio, P.E., Manager, Highway Safety Engineering Section Pennsylvania Department of Transportation, Bureau of Highway Safety and Traffic Engineering, Harrisburg, PA

[23] Respondent: Richard Werts, Director of Traffic Engineering, South Carolina Department of Transportation, Columbia, SC

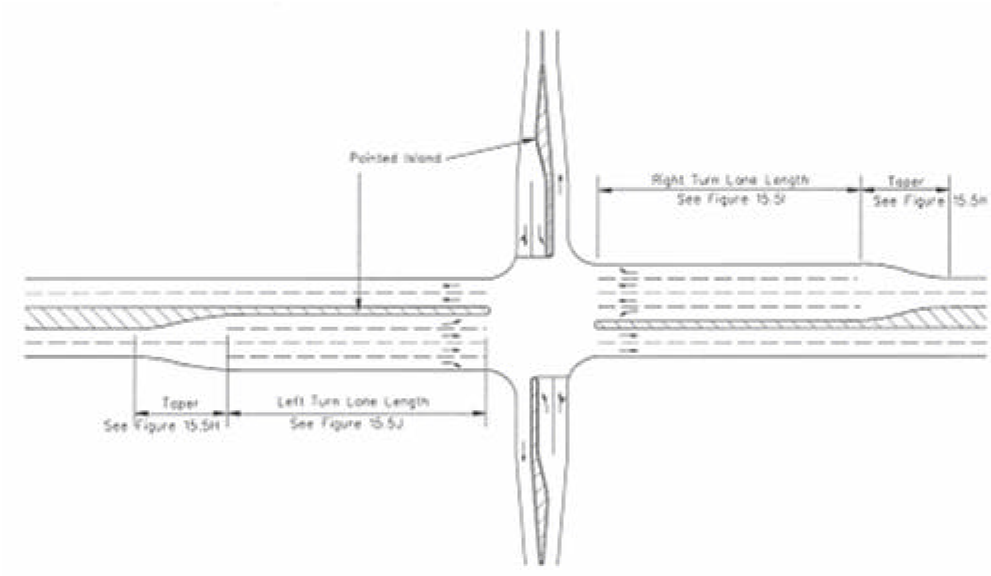

Figure 3.15. South Carolina DOT Channelized Turn Lanes
(Source: South Carolina DOT)

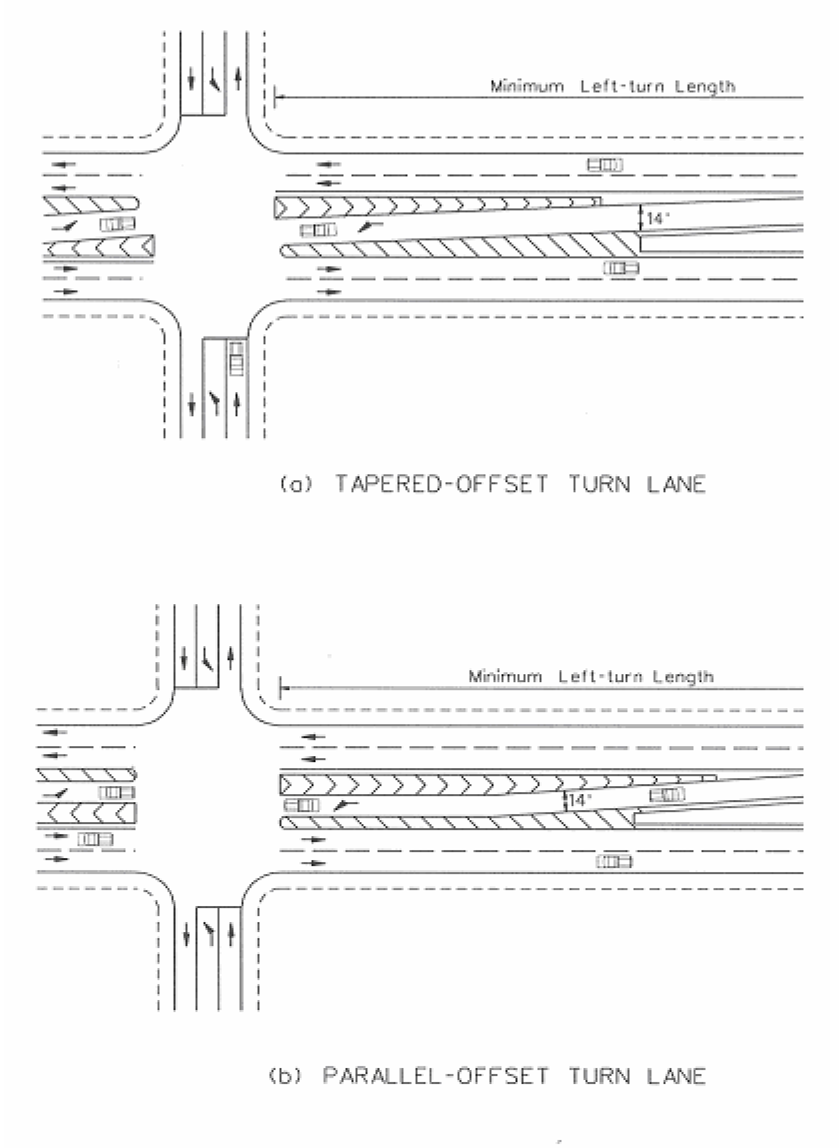

Figure 3.16. South Carolina DOT offset left-turn lanes design
(Source: South Carolina DOT)

South Dakota Department of Transportation [24]

The South Dakota DOT operates 209 miles of expressways and plans to expand its expressway system over the next 10 years. The primary motivation for construction of expressways is to improve safety performance and capacity as compared to two-lane highways. For selected locations, the South Dakota DOT is converting expressway intersections to interchanges. The decision to convert to an interchange is made on a case-

[24] Respondent: Joel Gengler, South Dakota Department of Transportation, Pierre, SD

by-case basis and usually involves intersections with high volume, poor safety performance, and existing or potential congestion. The speed limit on expressways is 65 mph.

The South Dakota DOT has not done a study of crash rates on expressways and many of the expressways may have not been in operation long enough to have a crash history sufficient for statistical analysis. The South Dakota DOT has constructed a few offset left-turn intersections that appear to have improved safety performance. However, the South Dakota DOT respondent emphasized that most of their facilities are very rural and have much lower volumes than most states would observe.

Texas Department of Transportation [25]

The Texas DOT operates 1,983 miles of expressways and plans to expand its expressway system over the next 10 years[26]. Currently, the Texas DOT has various projects at different stages to convert or construct expressway to freeway standard facilities. The main factors for determining the design type of a new facility are safety and level of traffic flow performance. When converting an intersection or route segment to full access control, the Texas DOT relies heavily on the current or projected traffic volumes to decide if conversion is appropriate. Another factor is the level of service classification of an existing location. In other words, if the existing level of service is below the level intended for the existing design, then the location is considered for grade-separated and full controlled access design.

The Texas DOT did not provide us with any information on crash rates for expressways. The Texas DOT has used rumble strips to help decrease crashes at highway intersections and is now looking at new research on additional rumble strip applications.

Virginia Department of Transportation [27]

The Virginia DOT operates 2,876 miles of expressways and plans to expand its expressway system over the next 10 years. Expressway designs are selected for reasons of safety, access, political pressure, and lower costs when compared to grade separated facilities. The Virginia DOT uses AASHTO's policy on geometric design of highway to guide their design of expressways and the MUTCD to guide the design of traffic control at expressway intersections.

The Virginia DOT has not conducted any studies of crash rates on expressways and therefore, they provided no safety performance assessment for expressways. The Virginia DOT has constructed offset left-turn lanes in unique urban situations and placed shoulder rumble strips on expressway highways and other principle roadways with significant

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[25] Respondent: Charles Koonce, P.E., Traffic Operations Division, Texas Department of Transportation, Austin, TX

[26] Miles of Texas Expressway are based on mileage reported to FHWA (shown in Table 2.1) and were not confirmed by the Texas DOT

[27] Repondent: Mena Lockwood, P.E., Systems Analysis Program Manager, Mobility Management Division, Virginia Department of Transportation, Richmond, VA

accident occurrence. Travel lane rumble strips have been installed at 56 sites, mostly at stop conditions in non-residential areas, with some limited use at toll plazas, severe curves, lane drops, work zones and reduced speed zones. No research has been completed to evaluate safety performance after implementation of these safety countermeasures.

Washington Department of Transportation [28]

The Washington DOT operates 219 miles of expressways and plans to expand their expressway system over the next 10 years. Most of the Washington DOT's expressway expansion is conversion of two-lane highways. Conversions are undertaken to increase the capacity in a corridor with the addition of a second parallel roadway at a cost that is much less than a comparable interstate design standard facility. Most expressways have a speed limit of 60 mph.

The Washington DOT has not completed a safety study for expressways and crash rate information is not available. The Washington DOT has attempted to improve the safety of expressway intersections by constructing offset right-turns, median stop bars, offset left-turns, and traffic signals. No evaluation of the safety performance of these improved intersections has been completed.

Wisconsin Department of Transportation [29]

The Wisconsin DOT operates 511 miles of expressway and plans to expand its expressway system over the next 10 years. The majority of the new construction will be done as part of Major Highway Projects. The Wisconsin DOT prefers expressways over two-lane roadways because expressways offer superior safety performance when compared to two-lane highways and expressway can carry higher volumes at a higher level of service then two-lane highways. The Wisconsin DOT's standard expressway speed limit is 65 mph.

The Wisconsin DOT has found that crash rates and types seem to vary by location and the geometry leading up to the intersection. It appears that some problem intersections have been located on or near a horizontal curve and although all the design standards were met. Drivers seem to have more trouble judging the correct gaps in traffic because people have a difficult time judging the speeds of approaching vehicles on horizontal curves. Most of these crashes occur in the far lane. Another fairly typical scenario for a problematic intersection is one where the land use at rural intersections change and a service station that sells diesel fuel is constructed on one corner. Then, as trucks make left-turns or cross the road to purchase fuel, they may stop in the median while they wait for a gap. Unfortunately, the storage space in many medians is not wide enough to shelter a modern truck (possibly more than 63 feet in length) leaving a portion of the rear end of the truck trailer in the travel lane and resulting in an extreme traffic hazard.

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[28] Respondent: Ed Lagergren, P.E., Signals, Illumination and Pavement Marking Engineer, Washington Department of Transportation, Traffic Operations Office, Olympia, WA

[29] Respondent: Richard Lange, Wisconsin Department of Transportation, Madison, WI

A Wisconsin DOT counter-measure to expressway intersection crashes is to widen medians on or near curves. Left- and right-turn auxiliary lane length depends on side road traffic volume. Intersections with minor road average daily traffic (ADT) over 1,000 vehicles per day are designed with turn bays 450 feet-long plus a 150 foot taper. Low volume ADT intersections are designed with turning bays as short as 100 feet. These standards were developed after studying existing expressways and their safety concerns. Milled-in edge rumble strips are required on all rural divided highways/expressways, but not at turn bays or tapers. Urban areas may get rumble strips, depending on noise considerations. In problematic cases, the Wisconsin DOT has improved intersections to interchanges. As a measure preceding an intersection improvement (in the interim), the Wisconsin DOT has placed lower advisory speed limits at the intersection.

At a few intersections, the Wisconsin DOT recently installed yield signs in the median, new yield markings, and flashers on the stop signs. The medians were only 60 feet-wide, so stop signs could not be used. In their design guide, the Wisconsin DOT does state that stop control and double yellow pavement markings are required in wider medians designed to accommodate long trucks or combination farm equipment.

Survey Conclusions

Rural expressway intersection safety is an issue for the STAs interviewed. Most of the STAs surveyed are experimenting with or using some kind of special strategy for at-grade intersections. The types of improvements are listed by state in Table 3.4. In some cases, the special strategy being applied is a recent experiment and no positive or negative experience is available yet. For several special strategies, the respondent from the STA could only offer their personal opinions about the strategy's safety performance. Although some STAs are planning scientific studies on the impact of the improvement on safety performance, no study results were reported.

Most STAs reported making decisions about upgrading intersections to full access-controlled facilities on a case-by-case basis based on the safety and delay performance of the intersection. However, four states make decisions regarding upgrading to full access control on a corridor basis rather than one intersection at a time. The respondent from Indiana believed corridor-wide conversion was justified because the alternative, improving only some intersections, tends to be safety problem because drivers' expectations are violated when mixed conditions (grade separated and at-grade intersections) exist. Only the Illinois DOT had systematic thresholds for upgrading of intersections.

Table 3.4. STA Experience with special strategies at at-grade expressway intersections

State	Strategies used	Experience
Alabama	Public relations to reduce wrong ways on new highways	Considering
	Encourage use of T-intersections	Positive
	Jug handles	Unknown
	Rumble strips on minor approach	Positive
	Signage	Positive
	Median stop bars	Positive
	Offset left-turns	Unknown
Arizona	Full access control in metro area	Unknown
California	Conversion to full access control	Positive
	Limits driveways to 3 per 500m	Positive
	No driveways within 800m of an intersection	Positive
	Wider medians	Positive/negative
	Offset left-turns and right-turns	Positive/negative
	Jug handles	Positive/negative
	Indirect lefts	Positive/negative
	Rumble strips on minor approaches	Positive/negative
	Stop signs in wider medians	Positive
	Median detector loops at signalized intersections	Unknown
Colorado	One mile access spacing on rural segments	Positive
	One-half mile access spacing on urban segments	Positive
	Turning/deceleration lanes	Positive
	Offset left-turns	Unknown
	Protected left-turns	Unknown
	Offset rights	Unknown
	Median stop bars	Positive
	Signage	Positive
Florida	Left-turn lanes	Positive
	Protected left-turns	Positive
	Offset lefts	Unknown
	Rumble strips on minor approach	Unknown
Illinois	Channelized offset left-turn lanes	Positive
	When signal is warranted, start interchange programming	Positive
	When signal is planned in next 20 yrs, start purchase of access rights for an interchange	Positive
Indiana	Convert entire expressway to full access control at one time	Positive
	Always use protected left when above 50 mph	Positive

Table 3.4. Continued		
State	**Strategies used**	**Experience**
Iowa	Wider medians	Positive
	Off-set left and right turn lanes	Positive
	Public relations to educate drivers on use of intersection	Positive
	Longer deceleration/turning lanes	Positive
	Intersection lighting	Positive
	Double yellow in median cross over and stop bar	Positive
	Reduced advisory speed limit at intersection	Positive
	Off-set T-intersections	Positive
	Longer turning lanes	Positive
	Stop ahead sign and rumble strips on minor approach	Positive
	Increased speed enforcement	No impact
	Corridor access agreements identifying future signal sites and restricted median crossovers for future access	Unknown
	Grade separated intersections	Positive
	Closing a lane to so that only one lane of the expressway continues through the intersection	Positive
Kentucky	Developing access management/control policy	Unknown
	Most signalized intersections have a flashing beacon or advanced warning flashers	Unknown
Louisiana	Improve to full access control	Unknown
Maryland	Continuous flow intersections	Negative
	Offset left-turns	Unknown
	Median stop bars	Unknown
Michigan	Offset left-turns	Negative
Minnesota	Offset left-turns	Negative
	Median left-turn acceleration lanes	Positive
	Longer deceleration lanes	Proposed
	ITS gap advisory	Testing
	Indirect left	Unknown
	Signalization	Negative/positive
	Rumble strips on minor approach	Negative
Mississippi	Offset left-turns	Positive
	Lengthen acceleration and deceleration lanes	Positive
	Roundabout on an urban expressway	Unknown
	Widen median	Positive/negative
Missouri	Median acceleration lanes	Unknown
	Jug handles	Unknown
	Flashing beacon on advance warning signs	Positive
	Offset left-turns	Unknown
	Indirect lefts	Unknown
Nebraska	Frontage roads to control accesses	Positive
New York	Jug handles	Positive
	Restricted access openings	Positive
	Offset left-turns	Positive
	Convert entire expressway to full access control at one time	Positive

Table 3.4. Continued

North Carolina	Offset left-turns	Positive
	Rumble strips on minor approach	Unknown
	Roundabouts on an urban expressway	Unknown
	Planning process for conversion to full access control	Positive
North Dakota	Offset left-turn lanes	Positive
	Rumble strips on minor approach	Positive
	Intersection flashing beacons	Positive
	Protected phase at signalized intersection with gt 35mph	Positive
	Conversion to full access control	Positive
Oklahoma	Installation of traffic signals	Unknown
	Longer deceleration/turning lanes	Unknown
Oregon	Offset left-turns	Unknown
	Indirect lefts	Unknown
	Offset rights	Unknown
	Jug handles	Unknown
	Median stop bars	Positive
	Rumble strips in very wide medians	Positive
	Rumble strips on minor approach	Positive
Pennsylvania	Jug handles	Unknown
	Offset left-turns	Unknown
	Signage	Positive
	Installation of left- and right-turn lanes	Positive
	Signalized right-turn movements	Positive
South Carolina	Offset left-turn lanes	Positive
	Indirect lefts	Unknown
	Jug handles	Unknown
	Conversion of intersection to interchanges	Positive
	Installation of deceleration lanes in advance of median u-turns	Positive
	Rumble strips on minor approach	Positive
South Dakota	Offset left-turn lanes	Positive
	Conversion of intersections to interchanges	Positive
Texas	Rumble strips on minor approach	Unknown
	Ongoing research on additional rumble strip applications	Unknown
	Conversion of intersections to interchanges	Positive
	Conversion of entire corridor to full access control	Positive
Virginia	Offset left-turn	Positive
	Rumble strips on minor approach and shoulders	Positive

Table 3.4. Continued		
Washington	Offset left-turn lanes	Unknown
	Indirect lefts	Unknown
	Offset rights	Unknown
	Jug handles	Unknown
	Median stop bars	Unknown
	Rumble strips on minor approach	Unknown
	Signals	Unknown
Wisconsin	Yield signs in medians	Positive
	Double yellow strips in median	Positive
	Low advisory speed limits in advance of intersection	Unknown
	Installation of traffic signal	Unknown
	Conversions of intersections to interchanges	Positive
	Mainline left and right turn lanes	Positive
	Milled in edge line rumble strips	Unknown

Only one of the STAs surveyed, the New York State DOT, did not have plans to expand its expressway system. Between 1996 and 2002, expressway mileage in the U.S. grew at a rate of almost 4% per year (see Table 2.1) and our findings indicated that expressway growth will continue while the mileage of the remaining types of highways in the national inventory will remain relatively constant. The continued growth in expressway mileage only elevates the need to further understand expressway safety performance.

Rural Expressway Intersections Strategies

Several special strategies have been attempted to improve safety at expressway intersections. To provide the reader with guidance on the use of these strategies, Table 3.5 is synthesis of the information gathered from the literature and surveyed states. Through our survey, we found that several states are experimenting with strategies to reduce the frequency and number of crashes at high-speed expressway intersections, but few have empirical data available to quantify the safety benefits of these strategies. Therefore, the guidance we provide in this report is largely based on the experience of a limited number of case studies and should be treated as such. Determining the appropriateness of any of these strategies in any particular application is the responsibility of the design professional.

Table 3.5 lists strategies for improving the safety performance of existing expressway intersections, organized from lowest to highest cost. The relative costs are based on the experience of the Iowa Department of Transportation engineers in the Office of Traffic and Safety. Of course, depending on conditions, actual relative costs could be different.

Table 3.5. Potential safety strategies for expressway intersections

Strategy description	Requires/applies to	Safety benefits
Adding stop bars or yield signs in the median for minor roadway vehicles	Sufficient median width to store design vehicle in the median	Encourages drivers on the minor roadway to make their maneuvers in two stages. Stage 1: crossing the expressway in the near side mainline lanes. Stage 2: pausing in the median to select a gap in far side mainline lanes. Believed to reduce right angle crashes.
Adding a double yellow line in the median for minor roadway vehicles	Sufficient median width to store design vehicle(s) and median opening width restricted to the width of the two minor roadway lanes with flaring of the median openings to meet turning radius requirements.	Better defines the storage area for vehicles stopped in the median and reduces associated conflicts. It also encourages two-stage maneuvers. Beneficial in all medians, but benefits increase with increasing median width and median opening width. Clarifies the lane assignments and paths for minor roadway vehicles. Reduces crashes in the median and in combination with stop bar/yield also reduces right angle crashes.
Adding advanced in-lane rumble strips for minor roadway traffic in advance of the stop location	Hard surfaced minor roadway with PCC requiring less maintenance than ACC	Provides a tactile warning of approaching stop-condition. Believed to reduce ran stop sign right angle crashes
Adding offset right- and left-turn lanes at unsignalized intersections (see Figure 2.4)	Sufficient area for paved right- or left-turn lane	Reduces the visual obstruction of turning vehicles approaching on the expressway. Reduces right angle crashes due to failure to accept an adequate gap.
Adding longer turning/deceleration lanes (as long as 500 feet plus taper)	High-speed (55+ mph) major roadways with moderate to heavy turning volumes	Improves major roadway capacity and reduces rear-end and side-swipe crashes. Improves gap selection for minor roadway drivers due to major roadway vehicles being organized into turn lanes in advance of the intersection.

Table 3.5. Continued

Strategy description	Requires/applies to	Safety benefits
Adding left-turn median acceleration lanes (see Figure 2.2)	Main line roadways with sufficient median width to accommodate acceleration lane width and length.	Allows minor roadway left-turn vehicles to accelerate prior to weaving into the major roadway through lanes. Reduces the consequences of minor roadway poor gap selection, thereby reducing right angle crashes. Eliminates the need for median storage for left-tuning traffic. Reduces number of trucks stopping in the median with trailer blocking through lanes on major roadway.
Adding indirect left-turns from the expressway to the minor roadway through jug handles and loops (see Figures 2.5 and 2.6)	Sufficient right-of-way for indirect left lanes. Unconventional maneuver and added delay for left-turning vehicles.	Beneficial where there is inadequate median or deceleration lane storage for left-turning mainline vehicles or where sight distance or traffic volumes makes left-turns from the mainline problematic. Commonly used in European countries, limited U.S. experience.
Adding indirect left-turn and median U-turn, prohibiting minor road left-turns and downstream median U-turns (see Figure 2.7)	Major roadways with sufficient median width to accommodate the downstream turn lane and U-turn area.	Beneficial at intersections with relatively high volumes or highly peaked traffic volumes on the minor roadway. Can reduce delay at intersections with high volume expressways. Reduces crashes and conflicts between through expressway traffic and left-turning traffic from the minor roadway. Implementation results mixed.

Table 3.5. Continued

Strategy description	Requires/applies to	Safety benefits
Adding a directional median barrier and adding downstream median U-turns for minor roadway through and left-turn movements. (see Figures 2.8 and 3.8)	Major roadways with sufficient median width to accommodate the downstream turn lane and U-turn area.	Beneficial at intersections with relatively high volumes or highly peaked traffic volumes on the minor roadway. Can reduce delay at intersections with high volume expressways. Reduces crashes and conflicts between through expressway traffic and minor roadway through and left-turning traffic from the minor roadway. Results from implementation are not yet available.
Widen median	Applicable at intersections where the median is not wide enough to store the design vehicle (school bus or tractor trailer combination truck) and where right-of-way is available.	Wider medians provide refuge for longer vehicles and allow the driver of the longer vehicle to move through the intersection in two steps. However, when medians are wider than the design vehicle, the added width may increase the number of crashes in the median or contribute to wrong way movements from the side road.
Infrastructure Decision Support Systems (see Figures 2.13–2.18) are automated systems that help drivers make gap selection decisions.	Applicable at intersections with limited sight distance and/or high number of right angle crashes.	Very beneficial at intersections with limited intersection sight distance. Advanced technology version (Figures 2.17 and 2.18) will assist drivers in selecting an acceptable gap at intersections without sight distance issues. Low-technology systems have reduced right angle crashes and the high-technology system is being tested by the Minnesota DOT and the University of Minnesota and is expected to reduce right angle crashes.

Table 3.5. Continued

Strategy description	Requires/applies to	Safety benefits
Build or covert four leg intersection into two T intersections (See Figure 2.9)	Adequate right-of-way to offset each minor approach by a sufficient distance to separate the intersections and permit efficient operation.	An offset T-intersection has 25% fewer conflict points than a normal four-leg expressway intersection. Offsetting the intersection is believed to reduce right angle crashes in the far major roadway lanes (traffic flowing right to left).
Conversion from stop-controlled to signal-controlled	Intersection volumes or crash history and conditions which warrant traffic signal control per the MUTCD.	An interim step to grade separation and for locations with problematic right angle crashes. Traffic signals provide a specific allocation of right-of-way between conflicting movements. The results of installing traffic signals have been mixed. Right angle crashes are often replaced by more frequent rear-end crashes and red light running right angle crashes. In some cases, conversion to signal control has actually increased crashes.
Adding protected left-turn phasing for the major roadway	Signalized intersection with sufficient left-turn lane storage	Primarily benefits older and younger drivers who have difficulty making left-turns at high-speed intersections. Reduced crashes involving left-turning vehicles from the major roadway. May increase rear-end collisions on major highway and will increase delay.
Grade separated intersections (see Figures 3.8, 4.19 and 4.20)	Sufficient right-of-way and existing alignment to accommodate the interchange layout.	Beneficial at lower-volume, problematic crash locations where minor roadway traffic does not warrant a full diamond or parclo interchange. May be used as an interim measure and converted to standard interchange at a later date. Very positive experience at Iowa's two low-cost interchanges.

Table 3.5. Continued

Strategy description	Requires/applies to	Safety benefits
Isolated conversion of intersections to interchanges	Locations having adequate right-of-way, alignment, and funding.	When safety and/or intersection delays warrant construction of an interchange. Reduces crashes and delays. When mixed with at-grade intersections on the same facility, isolated intersection conversions have the potential to violate driver expectations.
Conversion of expressway to fully access-controlled highway	Locations having adequate right-of-way, alignment, and funding.	Minimizes crashes and delay. Permanent preservation of corridor access control. Provides consistent geometry and is consistent with driver expectations.

4. RURAL EXPRESSWAY CRASH ANALYSIS

This chapter is divided into eight sections. The first section describes the development of the database used to study rural expressway intersections. Next, several descriptive statistical analyses are presented and the findings illustrated. After that, statistical models are estimated to further understand the how traffic volumes, intersection geometry, and driver characteristics impact crash frequency. The final section presents an identification of the ten intersections in Iowa with the worst and best safety performance and an overview of two intersections with unique designs that have experienced superior safety performance.

4.1 Database Development

A GIS-based Iowa Expressway Intersection Crash Database was created to assist in the research of rural expressway intersection safety. Specifically, records from four databases were integrated to produce our expressway intersection database, which include the following:

- Iowa DOT Roadway Inventory Database (GIMS)
- Iowa Video Log imagery
- Iowa Department of Natural Resources color infrared imagery
- Iowa DOT Crash Record Database (Accident Location and Analysis System—ALAS)

The Iowa Expressway Intersection Crash Database includes 644 rural two-way, stop-controlled intersections, which were selected using the following intersection characteristics:

- Located on a multi-lane, non-interstate divided facility
- Not access-controlled
- Two-way stop-controlled
- Outside of an incorporated city limit

The Iowa DOT 2003 Roadway Inventory (GIMS) was used to select the roadway segments of interest. These segments were used to insert attributes including traffic volume, median width, and the presence and length of turning bays. Next, the Iowa DOT Accident Location and Analysis System was used to add historic intersection location points (nodes). The intersection selection was completed following a visual inspection of the 2002–2003 Iowa Video Log imagery and the 2002 Iowa Department of Natural Resources color infrared imagery to verify intersection locations. Once the intersections of interest were identified, the Iowa DOT Crash Record Database was used to examine collision attributes. Due to the accuracy of the cartography, crashes were selected using a 150 foot buffer area around each intersection. These crashes were then visually inspected using the attributes found inside each crash record to add or remove inaccurate queries (e.g. crash location=intersection). Overall, the database includes over 100 different attributes for the use by the investigator.

To minimize the impacts of random spikes in crash activity or inactivity that may occur during a single year, we used data for five consecutive years. The most recent crash data available to us through the Iowa DOT were for the year 2000 (even though this work is being conducted in 2004). Therefore, the first year of our analysis period is 1996 (eight years ago).

4.2 Descriptive Analysis of Crash Rate of Rural Expressway Intersections

We have observed that crash rates on expressways increase with increasing volumes (an upward sloping safety performance function). Therefore, as a first step in the analysis of the crashes at expressway intersections, we calculated crash rates per million entering vehicles for increasing volumes. Since the majority of these intersections are rural intersections with very low volumes, many experienced extremely low crash frequencies. The mean crash rate is 0.15 crashes per million entering vehicles (MEV) for all 644 intersections and the median crash rate is 0.068 crashes per MEV. For comparison purposes, a Minnesota study estimated the crash rate at rural and urban two-way stop-controlled intersections in Minnesota and found a crash rate closer to 0.4 crashes per MEV (47). The low median crash rate in our rural expressway intersection database indicates the skew of the data towards low volume intersections.

Figure 4.1 is a graph of average crash rate, crash severity index rate (a system where the crash severity index for the intersection is divided by MEV per year), and fatal crash rates for all intersections and summarized by increasing minor roadway volume. For comparison purposes, we used the simple severity index used in a companion study for the Minnesota DOT, which applies a weight of 5 for a fatal crash, major injury crashes have a weight of 4, minor injury crashes have a weight of 3, possible injury/unknown crashes have a weight of 2, and property damage-only crashes have a weight of 1 (48).

We expected the average crash rate and the crash severity index to increase as the minor roadway volume increases. In other words, as crossing traffic volumes increase, the crash rate increases and crashes become more severe. The fatality rate is calculated by hundred million entering vehicles (HMEV) and also increases as minor roadway volume increases. Because each of these rates increases across increasing minor roadway volumes, the safety performance of the intersection declines as traffic volumes increase. The Iowa pattern of increasing crash severity rate is similar to what was found in a companion analysis of Minnesota rural, two-way stop-controlled intersections. In Minnesota, they also found higher volume intersections had more severe crashes (2).

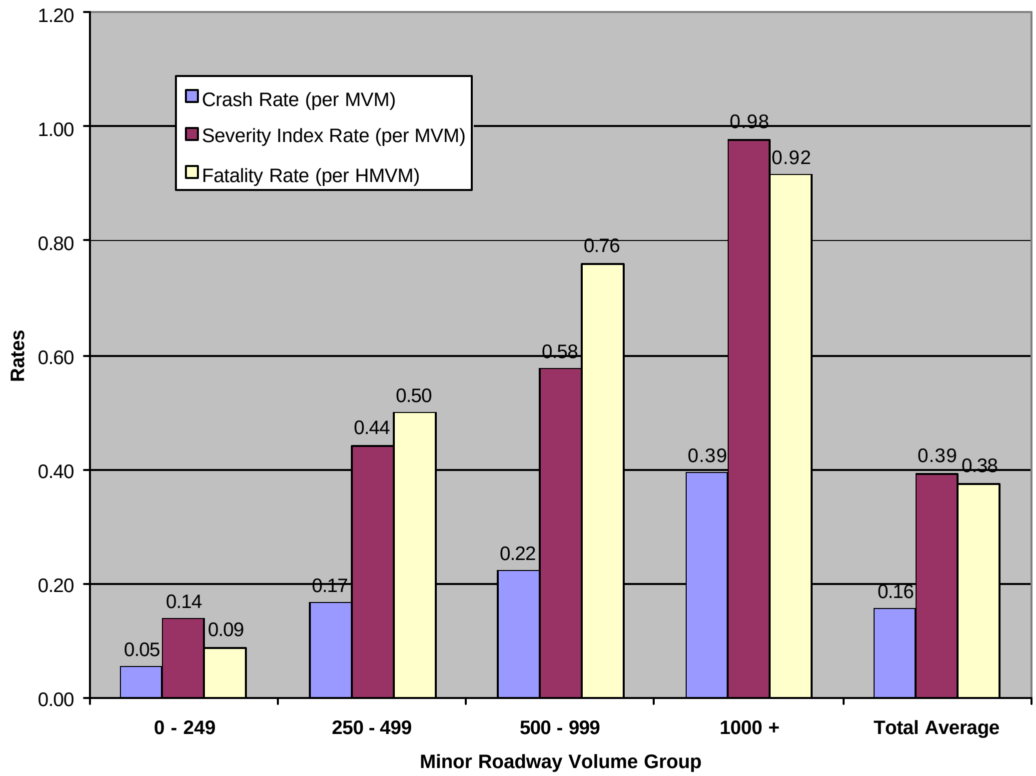

Figure 4.1. Crash, severity index, and fatality rates of Iowa rural expressways by minor roadway volume

* Data represents averages for the five-year period from 1996–2000. Minor roadway volume represents the average ADT volume of all entering minor routes.

Crash Type

The Iowa crash reports used by reporting officers during the period of our data collection provide 16 types of multi-vehicle intersection crash types. In addition, the officer could decide not to check a crash type and the type became unknown. For our purposes, disaggregating crash types to 16 types was too fine and we reduced crashes to four crash types. We combined the original crash types into four crash types: head on, right angle, rear-end, and sideswipe, as defined in Table 4.1.

Table 4.1. Conversion to reduced crash types

Original Crash Type	Aggregated Crash Type
Head on	Head on
Sideswipe/right-turn	Sideswipe
Sideswipe/left-turn	Sideswipe
Sideswipe/dual left-turn	Sideswipe
Sideswipe/dual right-turn	Sideswipe
Sideswipe/both left-turning	Sideswipe
Sideswipe/opposite direction	Sideswipe
Sideswipe/same direction	Sideswipe
Broadside/right angle	Right angle
Broadside/right entering	Right angle
Broadside/left entering	Right angle
Broadside/left-turn	Right angle
Rear end	Rear end
Rear end/right-turn	Rear end
Rear end/left-turn	Rear end
Other	Other

Figures 4.2–4.5 present graphs of the frequency of crash types grouped by increasing minor and major roadway volumes. Figure 4.2 illustrates crash rates stratified by minor roadway volume and Figure 4.3 stratifies crash rates by major roadway volume. Figure 4.4 stratifies crash rates by minor roadway volume and excludes all property damage-only crashes, while Figure 4.5 stratifies crash rates by major roadway volume and excludes all property damage-only crashes.

We had expected that as volumes increased, we would see increasing right angle crashes. Right angle crashes are generally the result of a driver on the minor roadway approach failing to select an appropriate gap. In the companion study, Minnesota researchers found that increasing intersection volumes resulted in more right angle crashes (2).

From our observations, we found that right angle crashes increase as minor roadway volumes increase, as seen in Figure 4.2. When we remove the property damage only (PDO) crashes and only consider injury and fatal crash data, this trend becomes even more apparent. However, increasing major roadway traffic volumes does not correlate with an increase in right angle crashes, as seen in Figures 4.3 and 4.5. Because right angle crashes are likely to be more severe, we believe that increasing minor roadway volumes results in increased crash severity, as seen in Figure 4.1.

In Figure 4.2, as the minor roadway volume increases, the relative involvement in rear-end crashes decreases. This decrease is a result of the redistribution of crash types and relative increase in right angle crashes as crossing volumes increase.

From these observations, it seems two phenomena are causing right angle crashes. One is increased opportunity for right angle crashes to occur as minor roadway volume increases.

The second is driver selection of unsafe gaps when there is more traffic (and maybe even congestion) on minor roadway approaches.

In prior work, we have shown that increasing major road volumes result in increased crash frequency (49). The analysis here shows (Figures 4.1, 4.2, and 4.4) that increasing minor roadway volumes result in increasing crash severity and increasing crash rates. More specifically, crash frequency seems to be related to major roadway volumes and crash rate and crash severity seems to be related to minor roadway volumes (3).

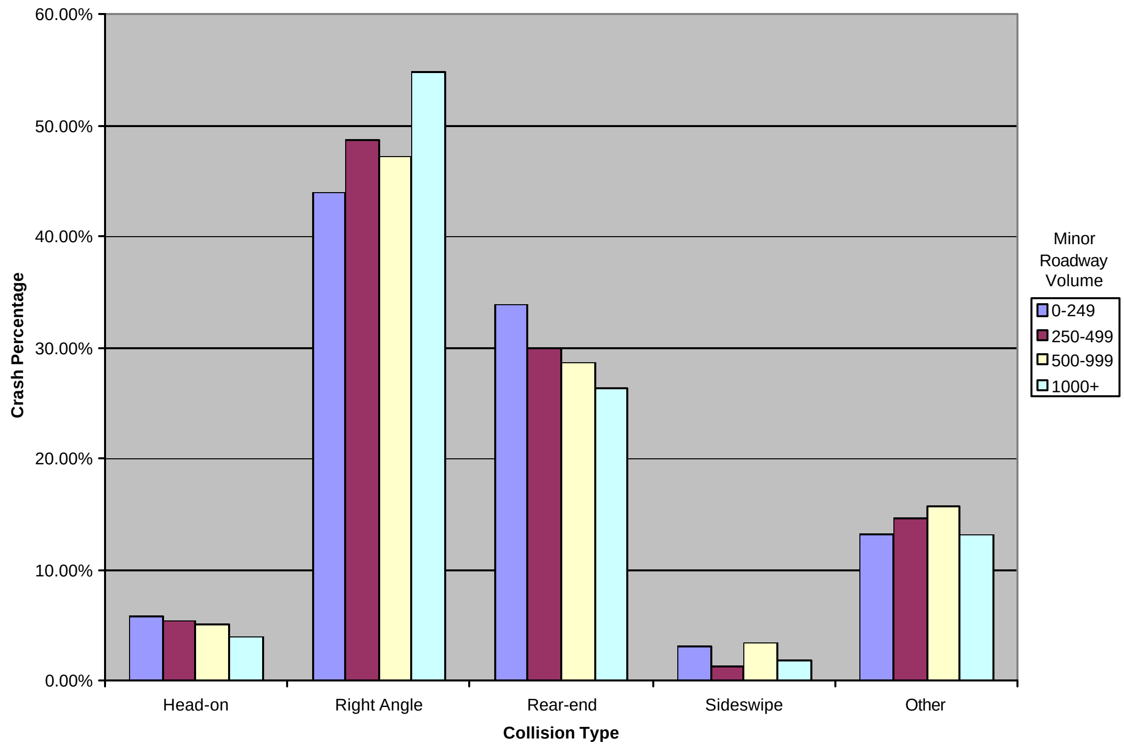

Figure 4.2 Crash type by minor roadway volume

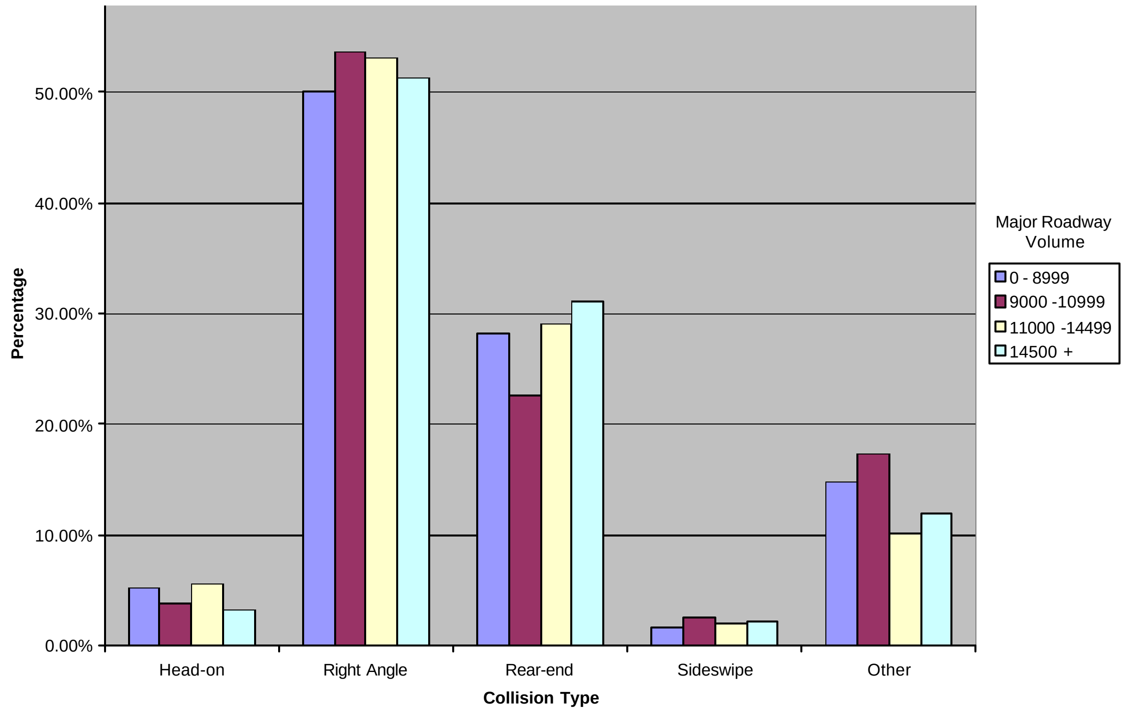

Figure 4.3. Crash type by major roadway volume

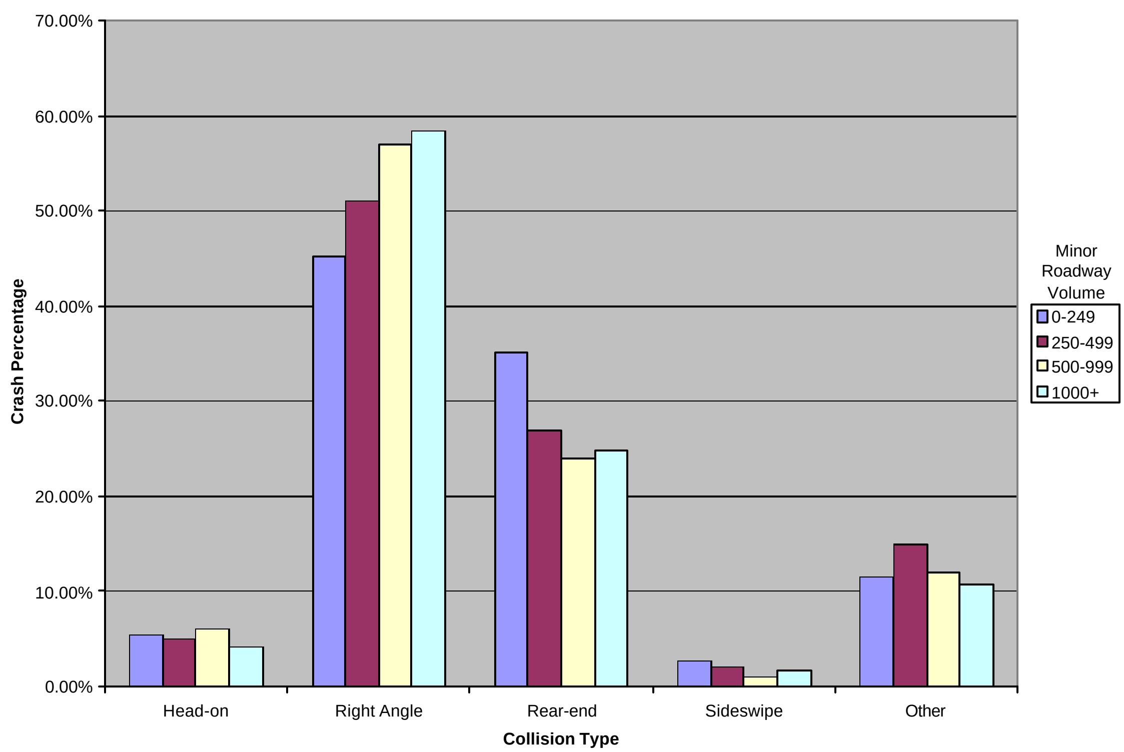

Figure 4.4 Crash type by minor roadway volume without PDO

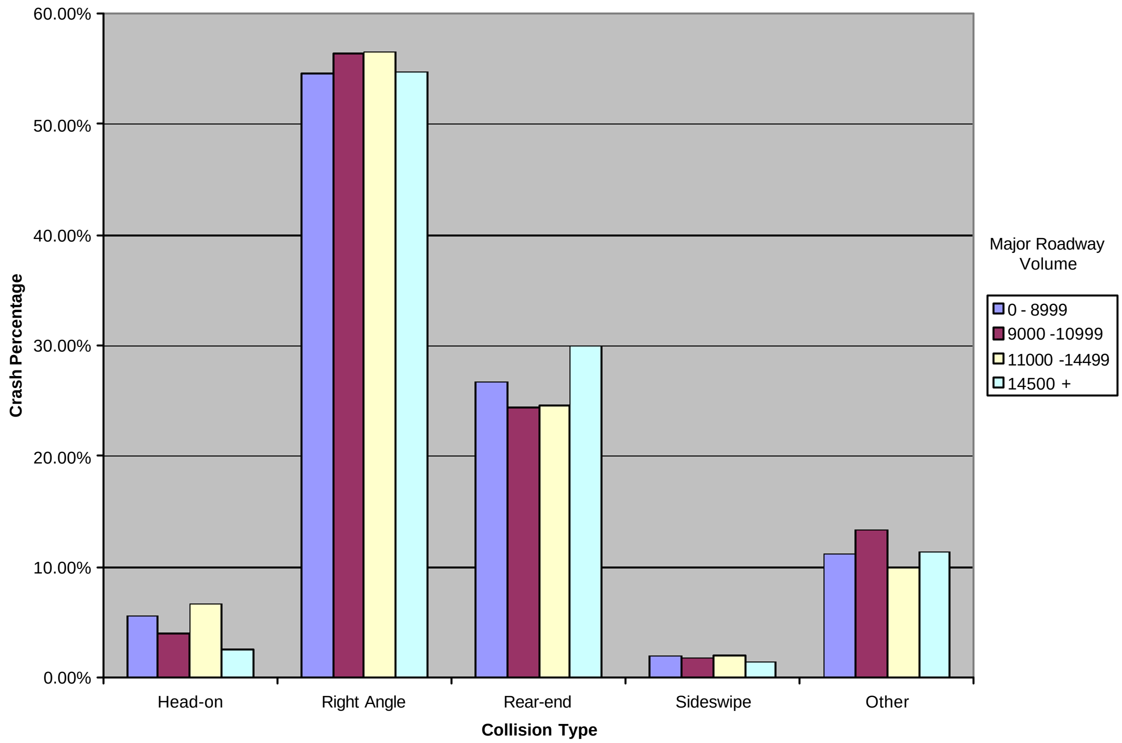

Figure 4.5 Crash type by major roadway volume without PDO

Intersection Crash Type Distribution

Figure 4.6 examines rural expressway intersections in comparison to all rural two-way stop-controlled intersections on rural primary highways (all primary roads including expressways). These data are derived from five years of crash records (1996 to 2000) and are grouped into the five crash types described in Table 4.1. In Figure 4.6, the distribution of crash types at expressway intersections and rural primary highway intersections is similar. At all types of highway intersections, right angle crashes are the most common crash type and right angle crashes are only slightly more common at expressway intersections than at other two-way stop-controlled intersections.

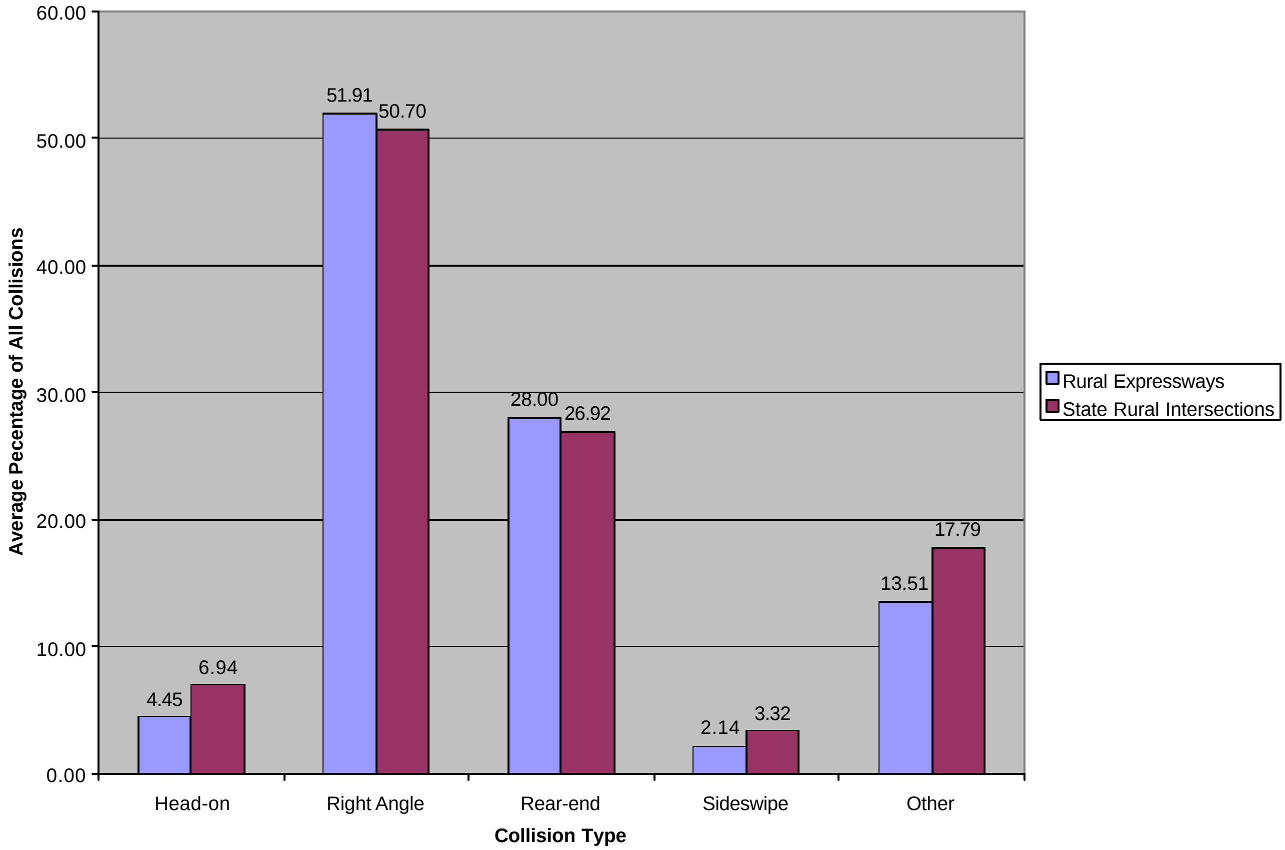

Figure 4.6. Comparison of crash type at rural expressway intersections to all intersections on primary roadways

Crash Severity at Rural Expressways

An analysis was completed involving the crash severity of rural expressways versus the statewide averages for rural two-way stop-controlled intersections. For this analysis, 5 years of rural expressway crash data (1996 to 2000) was compiled and each crash was identified by its most severe injury. Crashes within 150 feet of an intersection were included and the data collection included visual inspection for the 2000 data. For the 1996–1999 data, intersection nodes were used to query crashes within one 150 feet of the intersection. These data were then used to compare rural expressways to the statewide average for two-way stop-controlled intersections.

Figure 4.7 illustrates that injuries on rural expressways are marginally more severe than injury crashes at rural intersections and the fatality rates are about the same.

Before analyzing the data, we thought expressway intersection crashes would be more severe than crashes at rural intersections because cars are traveling at higher speeds on expressways. After analyzing the data, we found that expressway intersection crashes are not more severe; they have about the same severity as crashes at all rural intersections.

Even though at-grade expressway intersections have significantly higher design standards, crash severity is approximately the same at stop-controlled rural intersections.

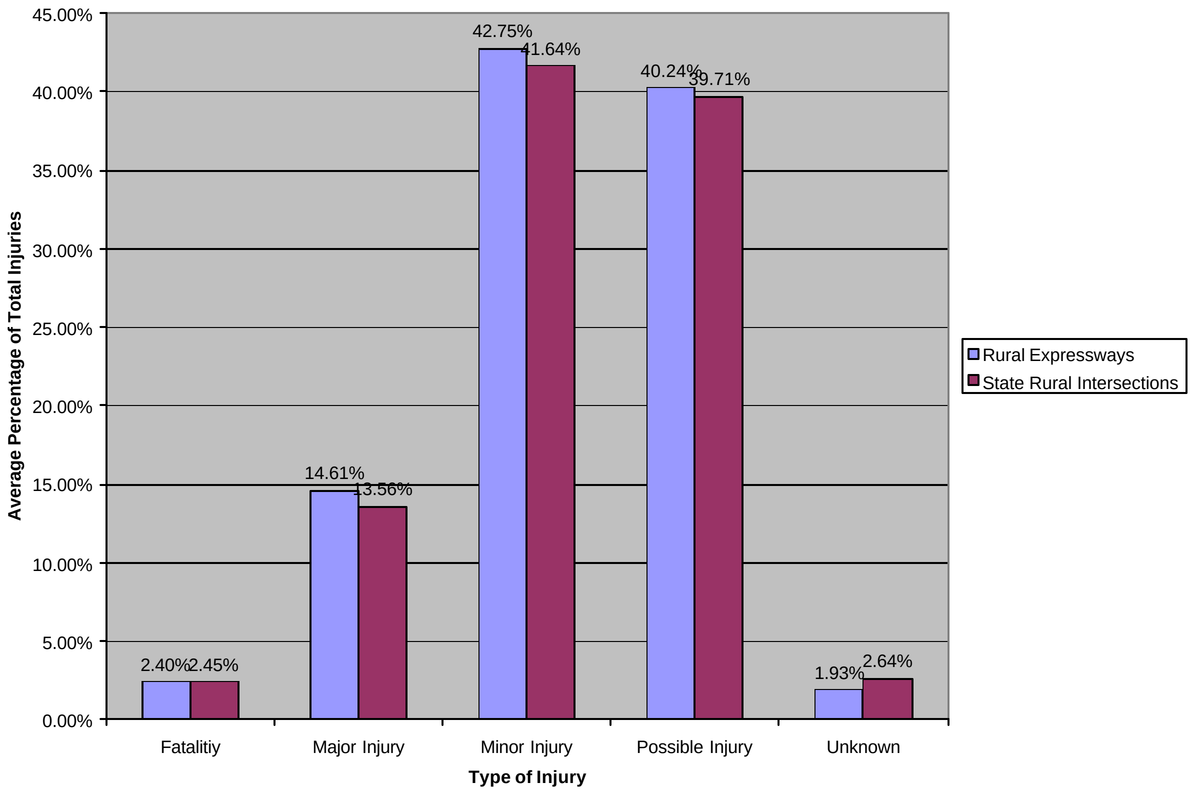

Figure 4.7. Comparison of crash severity at rural expressway intersections to those at all intersections on rural primary highways

Unpaved and Paved Minor Roads

To determine if there are differences in crash characteristics of expressway intersections with paved and unpaved (gravel) roads, we compared the crash rates and crash types at paved and gravel road intersections. Table 4.2 shows the average ADT (average daily traffic) on the minor and major roadway approaches. Roughly one-quarter of the expressway intersections involve an unpaved minor roadway. As we would expect, the minor roadway ADTs are much lower on the minor road approach at intersections with unpaved roadways. The major roadway approach average ADT is very close for paved and unpaved roadways.

Table 4.2. Average approach ADTs on paved and unpaved minor roadway intersections

Average Approach ADT	Unpaved	Paved
Major Road	9,976	10,222
Minor Road	125	1040
Number of Intersections	155	487

Figure 4.8 illustrates the crash rate, the severity rate index, and the fatality rate for expressway intersections with paved and unpaved minor roadways. Figure 4.8 illustrates that because paved minor roadways carry a higher volume, the crash rate, severity rate, and fatal crash rate is higher than lower volume, unpaved roads. This is consistent with the trends illustrated in Figure 4.1.

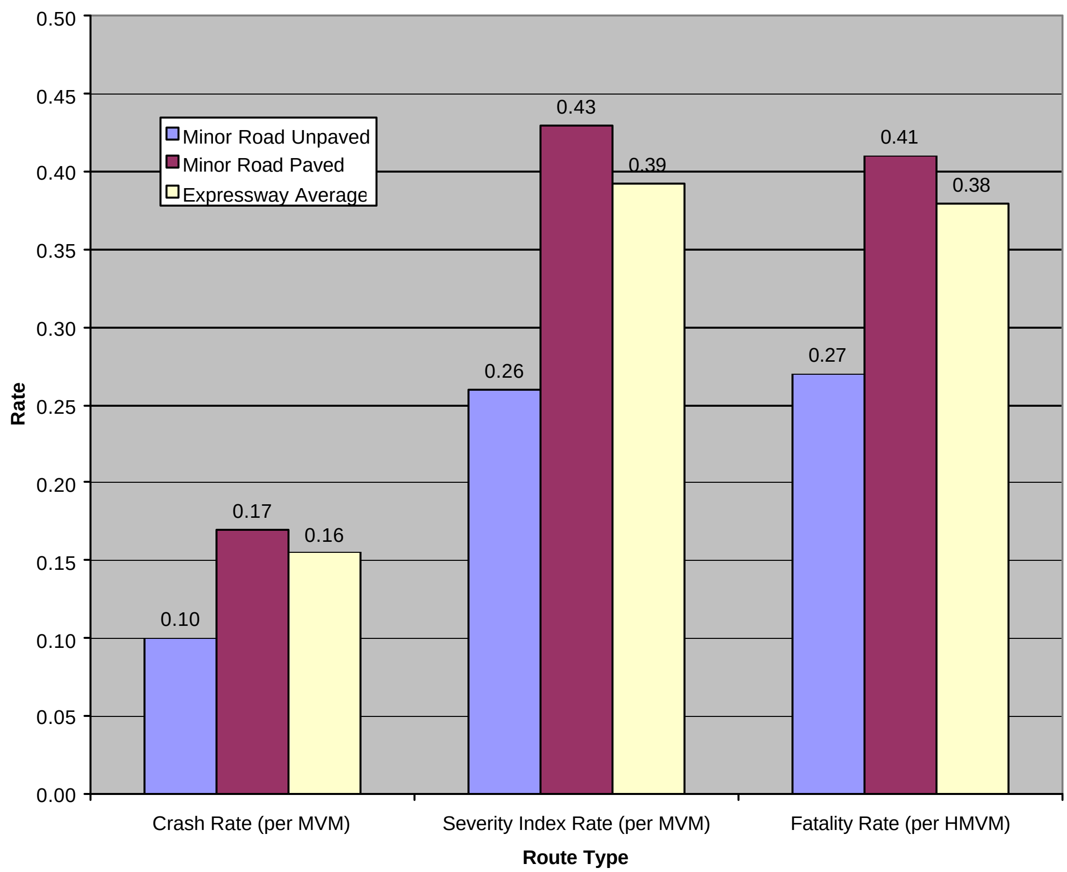

Figure 4.8. Crash, severity index, and fatality rate comparison of minor unpaved roads, minor paved roads, and rural expressways averages

Figure 4.9 is a comparison of the crash type distribution for paved and unpaved minor roadways at expressway intersections. The most frequent crash type at higher volume, paved minor roadway approach intersections is right angle crashes. This is consistent with the findings in Figures 4.2 and 4.4.

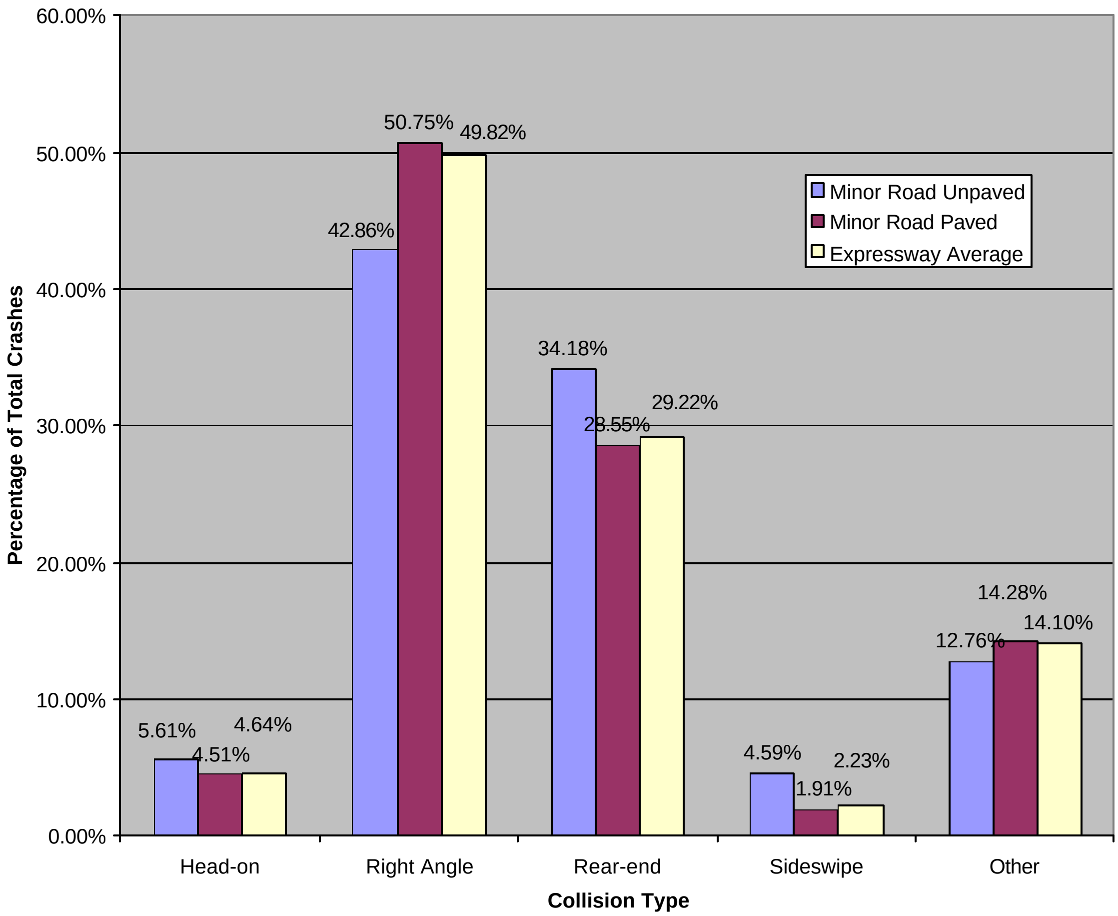

Figure 4.9. Collision type comparisons of minor unpaved roads, minor paved roads, and rural expressways averages

4.3 Crash Frequency Statistical Models

This section describes analysis of the intersection database using maximum likelihood to estimate parameters for a negative binomial model. All regressions were performed using the software package *LIMDEP Version 7.0*. Given that we were modeling count data (crash frequency), both Poison and negative binomial models were considered. Generally, crash data suffer from over-dispersion, a problem for the Poisson model, but not for the negative binomial model. Therefore, we chose the negative binomial model.

Major and Minor Volume

Our regression analysis included all 644 rural expressway intersections and crash frequencies for a 5 year period (1996-2000). The dataset includes the minor and major roadway volumes at 644 expressway intersections. The traffic volumes are the independent variables and the crash frequency is our dependent variable.

We performed several regressions using a negative binomial model. Our work with the model was done to help us to obtain a general understanding of the relationships between the volumes and crashes. For the models within this report, we used a Rho-squared value to demonstrate the goodness-of-fit of the model. Like R-squared, the Rho-squared value varies from 0.0 to 1.0 and measures the model's ability to account for variance in the dependent variable. The closer this value is to 1, the better the model represents the data set (similar to a R-Square value). Below each equation, the statistical significance of that parameter estimate (P-Value) is given.

Crash frequency increases with both minor and major roadway volume. There is a strong statistical relationship between independent variables and the dependent variable. The relatively low Rho-squared value does indicate that there are important variables that remain unaccounted for, but the Rho-squared value is acceptable for this type of analysis. We also estimated a model where we included the product of minor and major roadway volumes to test the importance of the interaction between minor and major roadways, but the interaction variable did not improve the model and an interaction term was dropped from further analysis.

In Equation 4-1, note that the coefficient for the minor roadway volume is about eight times as large as the major roadway volume, indicating that minor roadway volume has a stronger impact on increasing crash frequency than major roadway volume. Figure 4.10 contains a plot of the model (Equation 4-1) where the minor roadway volume is held constant at 150 vehicles per day and the major roadway volume is increased over a range of volumes we observed in our Iowa database. Figure 4.11 contains a plot of the model (Equation 4-1) where the major roadway volume is held constant at 10,000 vehicles per day and the minor roadway volume is increased over a range of volumes we observed in our database. In comparing the two plots, it is clear that crash frequencies are more sensitive to an increase in minor roadway volumes than an increase in major roadway volumes.

$$\text{Crash Freq} = e^{\,(0.02278 + (0.00005 * \text{Major ADT}) + (0.00042 * \text{Minor ADT}))} \tag{4-1}$$

$$(0.881) \quad (0.0001) \qquad\qquad (0.00001)$$

Rho-squared value = 0.381

To illustrate the impact minor roadway volume has on crash frequency, we can consider the following example. If the volume on the major approach increases by 100 vehicles per day, the crash frequency correspondingly increases by 0.5%. However, when the volume on the minor roadway increases by 100 vehicles per day, the crash frequency correspondingly increases by 4%. The impact of minor and major roadway volumes on crash frequency means that crash frequency increases with increasing major road volume and crash rate and severity rate increase with minor roadway volume.

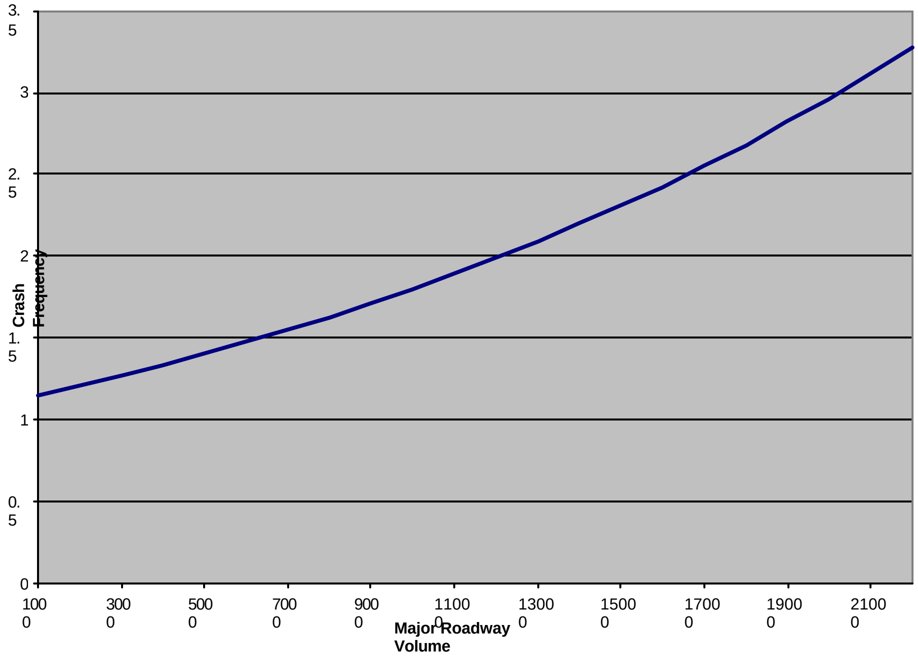

Figure 4.10. Traffic safety function for expressway intersections (major volume)

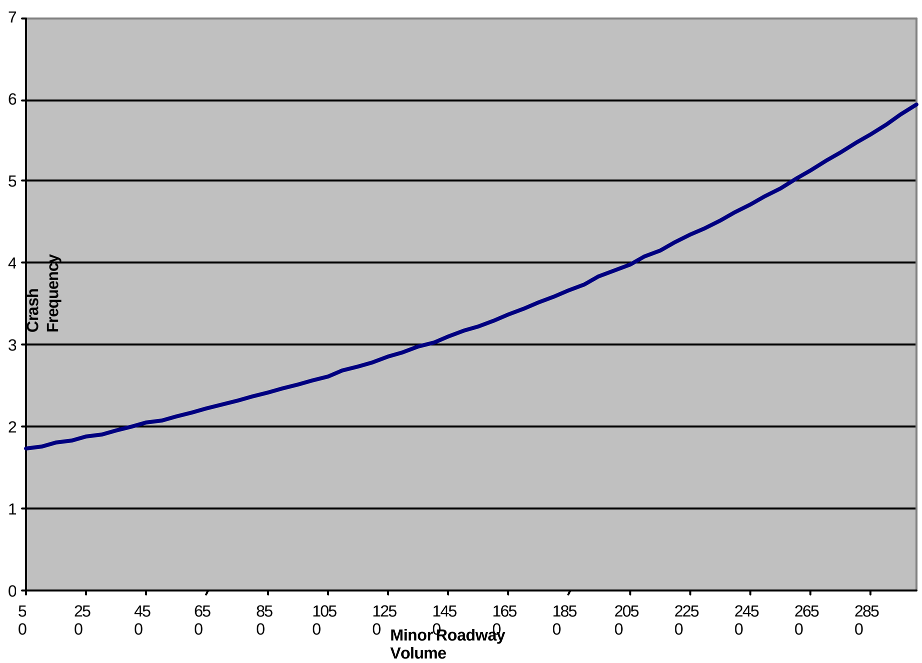

Figure 4.11. Traffic safety function for expressway intersections (minor volume)

To further analyze the impact of the major and minor roadway volumes, we divided the intersections into clusters. Each cluster has an increasing range of major roadway volumes. Each cluster is approximately 107 intersections (one-sixth of our sample) and is adequate to support a regression analysis.

Mainline Volume Interval 0 to 7,099 vehicles per day

$$\text{Crash Freq} = e^{\underset{(0.099)}{(-0.3074}+\underset{(0.00001)}{(0.0011*\text{Minor ADT}))}} \tag{4-2}$$

Rho-squared value = 0.158

Mainline Volume Interval 7,100 to 7,999 vehicles per day

$$\text{Crash Freq} = e^{\underset{(0.0604)}{(0.2546}+\underset{(0.0102)}{(0.0005*\text{Minor ADT}))}} \tag{4-3}$$

Rho-squared value = 0.09

Mainline Volume Interval 8,000 to 9,199 vehicles per day

$$\text{Crash Freq} = e^{\underset{(0.0472)}{(0.3328}+\underset{(0.0001)}{(0.0008*\text{Minor ADT}))}} \tag{4-4}$$

Rho-squared value = 0.331

Mainline Volume Interval 9,200 to 10,799 vehicles per day

$$\text{Crash Freq} = e^{\underset{(0.0001)}{(0.6465}+\underset{(0.0001)}{(0.0004*\text{Minor ADT}))}} \tag{4-5}$$

Rho-squared value = 0.253

Mainline Volume Interval 10,400 to 13,799 vehicles per day

$$\text{Crash Freq} = e^{\underset{(0.0001)}{(0.7640}+\underset{(0.0001)}{(0.0004*\text{Minor ADT}))}} \tag{4-6}$$

Rho-squared value = 0.416

Mainline Volume Interval 13,800 to 17,500 vehicles per day

$$\text{Crash Freq} = e^{\underset{(0.0001)}{(1.1879}+\underset{(0.0001)}{(0.0002*\text{Minor ADT}))}} \tag{4-7}$$

Rho-squared value = 0.453

The parameter estimates for the minor roadway ADT coefficients are highly statistically significant, indicating the strength of the relationship between minor roadway ADT and crash frequency. We notice from these models that crash frequency increases with increasing minor roadway volume. Also notice that our goodness-of-fit statistic (Rho-squared value) increases with mainline volume. This means that as mainline volumes increase, volumes on the minor roads explain more of the variance in crash frequency and other variables become less important. The importance of minor roadway volume in estimating expected crash frequency at higher volumes is not unexpected and further reinforces the observation that crash rates increase as a function of increasing minor roadway volume.

Physical Roadway Features Examination

We used the negative binomial model to examine geometric features of the 644 rural Iowa expressway intersections. This model uses a similar database collected over a five-year period (1996-2000) that was developed from the Geometric Information Management System and the Iowa Crash Record Database. The model includes geometric features, including turning lanes, median width, median type, etc. The geometric features of these intersections were verified through visual inspection of the Iowa DOT Video Log Image Database.

4.4 Median Width

Use of the negative binomial model demonstrated the relationship between crash frequency and median width. The parameter estimates for this model are highly statistically significant and provide a Rho-squared value of 0.3656. Both Equation 4-8 and Figure 4.12 demonstrate how crash frequency decreases as median width increases, which is consistent with other research that has found that median width improves safety performance (28). To illustrate the impact of increased median width, both major and minor volumes are held constant at 10,000 and 150 vehicles per day, respectively and crash frequency is plotted in Figure 4.12 for increasing median width.

$$\text{Crash Freq} = e^{\left(\underset{(0.4147)}{0.2254} + (\underset{(0.0149)}{0.00005}*\text{Major ADT}) + (\underset{(0.00001)}{0.00047}*\text{Minor ADT}) - (\underset{(0.0099)}{0.00745}*\text{Median Width in ft})\right)} \qquad (4\text{-}8)$$

Rho-squared value = 0.3656

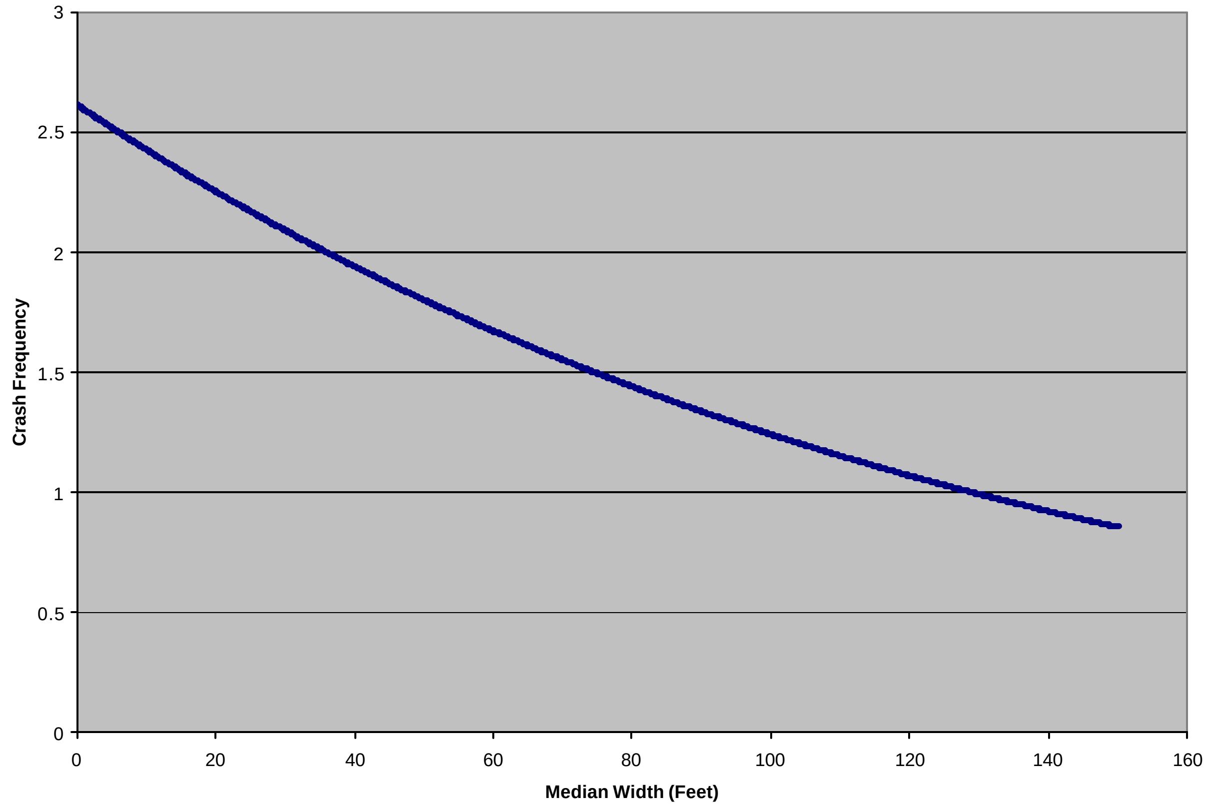

Figure 4.12. Crash frequency versus median width

4.5 Turning Lanes

Using the physical feature database, we determined that the presence of left- and right-turn lanes have an impact on crash frequencies at the 644 intersections in our database. Our model shows that there is a positive statistical relationship between the presence of a paved right-turn lane and crash frequency.

We expected that crash frequency would decrease with the addition of a right-turn lane. To explain this relationship, it's possible that paved right-turn lanes are installed by the Iowa DOT as a countermeasure when high crash rates are observed and, therefore, we are observing the impact of the crash frequency on the presence of right-turn lanes rather than the reverse. Further, only 37 intersections out of 644 expressway intersections had a paved right-turn lane, which is a very small sample. Although statistically significant, the result does not appear to be meaningful.

$$\text{Crash Freq} = e^{(0.2214 + (0.00005*\text{Major ADT}) + (0.00045*\text{Minor ADT}) - (0.00690*\text{MW}) + (0.6589*\text{Right lane}))} \quad (4\text{-}9)$$
$$(0.4107) \quad (0.0266) \qquad\qquad (0.00001) \quad (0.0174) \quad (0.0766)$$

Rho-squared value = 0.405

A similar analysis was completed to examine the presence of left-turn lanes. Our regression model is shown in Equation 4-10. The sign on the parameter estimate is the correct direction but the parameter estimate is not statistically significant. Therefore, the results are not meaningful.

$$\text{Crash Freq} = e^{(0.2556 + (0.00005*\text{MajorADT}) + (0.00047*\text{MinorADT}) - (0.0076*\text{Median Width}) - (0.032*\text{LeftLane})} \quad (4\text{-}10)$$

(0.4297) (0.0189) (0.00001) (0.0107) (0.8299)

Rho-squared value = 0.4201

Crash Severity Index Model

To evaluate the relationship between the variables and crash severity, we separated the intersections that experienced crashes from those that had no crashes. During the 5 year period (1996-2000), 327 intersections experienced at least 1 crash. Almost half the intersections in our dataset had no crashes. Crash severity was calculated over a 5 year period for the 327 remaining intersections. Once again, traffic volumes are the independent variables while the crash severity index over the 5 year period is the dependent variable.

We performed several regressions using a negative binomial model. Our work with the model was done to help us to obtain a general understanding of the relationships between roadway volume and crash severity. Both Equation 4-11 and Figure 4.13 below demonstrate how crash severity increases as major volume increases. Figure 4.13 holds minor volume constant at 150 vehicles and increases major roadway volume.

$$\text{Crash Severity Index} = e^{(2.10612+ (0.0000688*\text{Major ADT})+(.00004*\text{Minor ADT}))} \quad (4\text{-}11)$$

(0.001) (0.00001) (0.00001)

Rho-squared value = 0.53

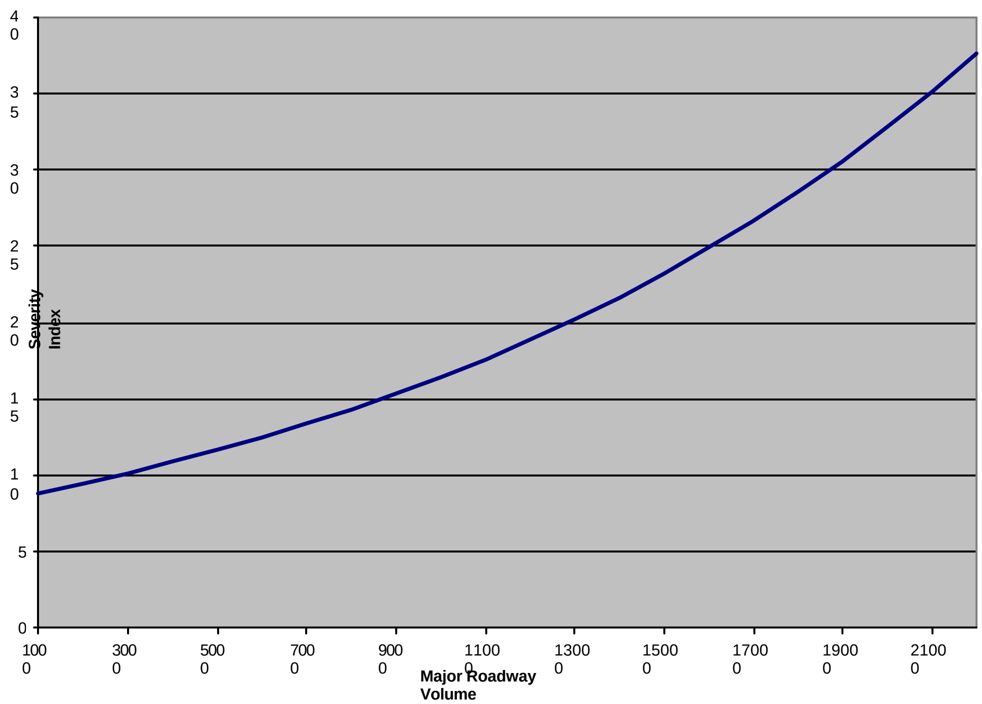

Figure 4.13. Crash severity versus major roadway volume

Equation 4-11 offered the best statistical properties of any statistical model we used. When we added other variables, such as the median width and presence of turning lanes, lower Rho-squared values or parameter estimates that were not statistically significant resulted.

Younger and Older Drivers

An analysis of older and younger driver crash involvement was conducted to understand problems these groups may be having on rural expressways. Tables 4.3 and 4.4 represent a comparison of the total number of crashes occurring on each of the 644 expressway intersections (Table 4.3) versus the total number of crashes occurring at all rural Iowa intersections (Table 4.4) over a 5 year period. The crash column represents the percentage of fatal and injury crashes that include at least one driver in each age category. Also the fatality and injury totals represent any person involved in a crash that included a driver of that age group. The age distribution is about the same for rural expressway intersection as it is for all rural intersections.

Table 4.3. Average rural expressway intersection injury and fatal crashes involvement by age group, 1996-2000

Age	% Crashes	Fatalities	Injuries
		Frequency	
All	100.00%	22	894
0-15	0.59%	3	1
16-24	41.81%	4	230
25-34	32.35%	9	189
35-44	30.57%	3	178
45-54	27.61%	3	218
55-64	17.95%	1	114
65-74	10.85%	2	53
75-84	7.50%	1	34
85-94	1.38%	0	8
95 +	0.00%	0	0

* 1996 and 1999 data derived from node intersection-related definition.

** 2000 data derived from crashes w/in 150 Feet.

*** % Crashes calculated from total crashes at all rural expressway intersections.

Note: Age ranges are inclusive

Table 4.4. Average statewide rural intersection injury and fatal crash involvement by age group, 1996-2000

Age	% Crashes	Fatalities	Injuries
		Frequency	
All	100.00%	492	17970
0-15	1.94%	8	398
16-24	41.77%	191	8268
25-34	27.46%	156	5433
35-44	29.02%	143	5631
45-54	21.48%	105	4069
55-64	15.77%	97	3060
65-74	9.28%	82	1846
75-84	5.99%	61	1354
85-94	1.27%	20	300
95 +	0.04%	2	10

Note: Percentages were calculated by dividing the number of crashes of a certain age group by the total number of crashes. E.g., 7.50% of the crashes at rural expressway intersections involved a driver 75-84 years of age.

* 1996 and 1999 data derived from node intersection-related definition.

** 2000 data derived from crashes w/in 150 Feet.

*** % Crashes calculated from total crashes at all rural expressway intersections.

Note: Age ranges are inclusive

Note: Percentages were calculated by dividing the number of crashes of a certain age group by the total number of crashes. E.g., 5.99% of the crashes at rural intersections involved a driver 75-84 years of age.

Source: Iowa Department of Transportation Traffic and Safety (2004)

Tables 4.5 and 4.6 break down the type of fatal and injury collision for each age group. The data are grouped into the five crash types described in Table 4.1. Most drivers (with the exception of the 25–34 group) appear to be involved with right angle crashes more than any other category at expressway intersections. The involvement in right angle crashes is 45%, 34%, 16%, 36%, and 21% higher at expressway intersections than at all rural intersections for the 0–15, 16–24, 45–54, 55–64, and 75–84 age groups, respectively. However, for all age groups, right angle crash involvement increases by 8% from all rural intersections to rural expressway intersections. Although the younger and older drivers are clearly over-represented in right angle crashes, it seems to be a general trend that right angle crash involvement increases at rural expressway intersections.

Table 4.5. Distribution of rural expressway intersection injury and fatal crashes by type and age, 1996-2000

Collision Type

Age Group	Head-on	Right Angle	Rear-end	Sideswipe	Other
All	4.64%	49.82%	29.22%	2.23%	14.10%
0-15	0.00%	66.67%	0.00%	0.00%	33.33%
16-24	2.04%	59.18%	30.10%	1.02%	7.65%
25-34	2.80%	39.16%	37.76%	4.20%	16.08%
35-44	3.60%	45.32%	28.78%	2.88%	19.42%
45-54	0.00%	54.62%	24.37%	4.20%	16.81%
55-64	1.43%	64.29%	21.43%	2.86%	10.00%
65-74	8.51%	51.06%	25.53%	2.13%	12.77%
75-84	3.23%	64.52%	19.35%	0.00%	12.90%
85-94	0.00%	60.00%	20.00%	0.00%	20.00%
95 +	0.00%	0.00%	0.00%	0.00%	0.00%

* 1996 and 1999 data derived from node intersection-related definition.
** 2000 data derived from crashes within 150 feet.
*** % Crashes calculated from total crashes at all (statewide) rural intersections.
Note: Age ranges are inclusive.
Note: Percentages were calculated by dividing the number of crashes of a certain collision type involving a driver of that age group by the total number of crashes. E.g., 3.23% of the crashes at rural intersections were head-on crashes involving drivers aged 75-84.

Table 4.6. Distribution of rural intersection injury and fatal crashes by type and age, 1996-2000

Collision Type

Age Group	Head-on	Right Angle	Rear-end	Sideswipe	Other
All	6.82%	46.03%	26.43%	3.26%	17.46%
0-15	6.46%	46.01%	25.86%	2.28%	19.39%
16-24	7.34%	44.07%	29.16%	3.48%	15.95%
25-34	6.65%	46.42%	27.57%	3.49%	15.87%
35-44	6.41%	45.80%	27.22%	3.05%	17.52%
45-54	6.42%	46.99%	26.43%	3.46%	16.70%
55-64	6.76%	47.34%	24.39%	3.36%	18.15%
65-74	7.42%	52.42%	21.99%	3.06%	15.11%
75-84	6.81%	53.31%	21.67%	1.92%	16.30%
85-94	9.57%	59.57%	17.39%	2.17%	11.30%
95 +	0.00%	88.89%	0.00%	11.11%	0.00%

* 1996 and 1999 data derived from node intersection-related definition.
** 2000 data derived from crashes w/in 150 feet.
*** % Crashes calculated from total crashes at all (statewide) rural intersections.
Note: Age ranges are inclusive.
Note: Percentages were calculated by dividing the number of crashes of a certain collision type involving a driver of that age group by the total number of crashes. E.g., 6.81% of the crashes at rural intersections were Head-on crashes involving drivers aged 75-84.
Source: Iowa Department of Transportation Traffic and Safety (2004)

Older and Younger Drivers (Crash Model)

We produced a crash frequency model, similar to our previous models, for older and younger drivers. This work was again completed to help us to obtain a general understanding of the relationships between the expressway volumes, crash frequency, and driver age. Only crashes that involved either a younger or older driver were used for this model.

Equation 4-12 outlines the crash frequency of younger (16–24) drivers.

$$\text{Crash Freq} = e^{\underset{(0.0001)}{(-1.9097} + \underset{(0.0001)}{(0.0001}*\text{Minor ADT}) + \underset{(0.00001)}{(0.00014}*\text{Major ADT}))} \qquad (4\text{-}12)$$

Rho-squared value = 0.21

Equation 4-13 demonstrates the crash frequency of older (65+) drivers.

$$\text{Crash Freq} = e^{\underset{(0.00001)}{(-2.5734} + \underset{(0.00001)}{(0.0001}*\text{Minor ADT}) + \underset{(0.00001)}{(0.00014}*\text{Major ADT}))} \qquad (4\text{-}13)$$

Rho-squared value = 0.19

Equations 4-12 and 4-13 produce results similar to roadway volume increases: both older and younger drivers have higher crash frequencies. However, a lower Rho-squared value than we observed in Equation 4-1 (the same model, but data for all drivers were included) indicates that other (unaccounted for) variables are more important in describing the crash frequencies of both younger and older drivers.

Older and Younger Drivers (Median Width)

The negative binomial models demonstrate the relationship between crash frequency and median width for older and younger drivers. Equation 4-14 examines younger (16-24) drivers.

$$\text{Crash Freq} = e^{\underset{(0.00001)}{(-1.596} + \underset{(0.00001)}{(0.00009*\text{Major ADT})} + \underset{(0.00001)}{(0.00013*\text{Minor ADT})} - \underset{(0.0204)}{(0.5056*\text{Median Width in ft}))}} \qquad (4\text{-}14)$$

Rho-squared value = 0.119

The same analysis was completed for older (65+) drivers in Equation 4-15.

$$\text{Crash Freq} = e^{\underset{(0.00001)}{(-2.332} + \underset{(0.00001)}{(0.00011*\text{Major ADT})} + \underset{(0.00001)}{(0.00012*\text{Minor ADT})} - \underset{(0.2519)}{(0.0039*\text{Median Width in ft}))}} \qquad (4\text{-}15)$$

Rho-squared value = 0.326

Both of these equations demonstrate how crash frequency decreases when median width increases. However, the Rho-squared value is much lower for younger drivers than older drivers, although the parameter estimated for median width for the older driver model is not statistically significant, making the results difficult to interpret.

4.6 Highest and Lowest Crash Severity Intersections

We took our severity index model (Equation 4-11) and used it to estimate the expected 5 year crash severity index for the 327 intersections that had experienced at least 1 crash and compared the results to the actual 5 year severity rate. Applying the actual ADT on the minor and major roadways to Equation 4-11 provides an expected severity index value for the intersection. Because of variables not accounted for in the model, some intersections performed worse (higher crash severity index intersections) than expected and some performed better than expected.

Next, we identified the 10 intersections where the expected severity index exceeded the actual by the greatest amount (lowest crash severity intersections) and the 10 intersections where the actual severity index exceeded the expected by the greatest amount (highest crash severity intersections). This set of 20 intersections represented the extremes in our data set. The 10 highest severity index intersections are listed in Table 4.7 starting with the poorest performance and moving to the 10th most poorly performing intersection. Also listed in the table are the expected severity index, the actual severity index, the major roadway volume and the minor roadway volume.

The values for the expected and the actual severity index Table 4.7 are the largest deviations in the data set. From these data, we should next try to determine what variable(s) caused these values to deviate so much.

Table 4.7. Top 10 highest severity index intersections

	Top 10 intersections with the poorest performance	Nearest city	Actual five-year severity index	Expected five-year severity index	Major roadway volume	Minor roadway volume
1	US 30 and T-Ave (Old IA 17)	Boone	90	19.99	12,100	1,420
2	IA 141 and 190th St	Granger	84	16.11	9,100	1,180
3	US 30 and W 4th St.	Nevada	77	20.40	12,300	1,580
4	US 71 and 320 St.	Spencer	70	17.61	10,200	1,510
5	US 218 and Barrick Rd.	Janesville/ Waterloo	75	27.12	15,500	3,190
6	US 218 and Cedar-Wapsi Rd.	Janesville/ Waterloo	76	30.34	17,500	2,560
7	US 30 and L Ave.	Boone	55	13.66	6,800	1,020
8	US 61 and IA 22	Muscatine	66	25.93	12,400	7,400
9	US 61and Hershey Ave.	Muscatine	59	19.21	11,000	2,310
10	US 151 and Springville Rd.	Cedar Rapids	53	14.73	8,000	830
				Average	11,490	2,300

We did a cursory review of these intersections to see if there were any common characteristics, but found none. Aerial photos of the two intersections near Boone on US 30 (intersections 1 and 7) are shown in Figures 4.14. The intersection with the poorest performance, US 30 and T-Ave (Old IA 17), is shown in Figure 4.14. The minor roadway (old IA 17) intersects US 30 while the major roadway is in a horizontal curve. Although the sight distance is more than adequate, crossing traffic may have trouble judging gaps due to curvature in the major roadway. The seventh most poorly performing intersection, US 30 and L Ave., is shown in Figure 4.15. This section of US 30 is very flat and straight with ample sight distance. However, just to the south of the intersection is a recreation area (a ski hill) and further to the south is a rural subdivision. We assume that these two developments result in traffic volume peaking on the minor road approaches and that the peak volumes result in poorer performance than what would be indicated by average daily traffic volumes.

Of the 10 high severity index intersections, 5 are located on or near a horizontal curve on the expressway and because of the horizontal curve, the intersection angle is usually slightly skewed from 90 degrees. Two intersections are located near the base of a vertical curve, and one is a skewed intersection with no expressway horizontal or vertical curve. Of the 2 remaining locations, 1 has a very high minor roadway volume (more than 7,000 VPD). All of the high severity rate intersections are on expressways that are primary rural commuter routes creating peaked intersection volumes, resulting in periods of congestion and delay, and causing aggressive driving.

The best-performing intersections are shown in Table 4.8 and Figure 4.16 presents a map identifying their locations. When comparing the best-performing with the worst-performing intersections, some differences are apparent. For example, the worst-performing intersections have major roadway volumes that average about the same as the average of the entire 327 intersections in our database (the 10 worst intersections average 11,490 vehicles per day and the 327 intersections average 10,840 vehicles per day). However, the minor roadway volumes for the worst intersections were well above the average (the worst intersections averaged 2,300 vehicles per day while all intersections averaged 1,362 vehicles per day). The best-performing intersections all had high volumes on the major roads; in fact, these are some of the highest-volume expressways in Iowa. However, the minor roadway volumes of our best-performing intersections were well below the average. This finding highlights the significance of increasing minor roadway volume on intersection crash severity.

Initially, we believed that the worst-performing intersections would be on high volume routes and were therefore surprised to find the worst-performing intersections on moderate volume routes. We found that in general, the worst-performing intersections are on rural commuter routes with moderate traffic volumes, while the best-performing intersections are on very high volume roadways close to Iowa’s largest urban areas.

Figure 4.14. US 30 and T-Ave

Figure 4.15. US 30 and L Ave.

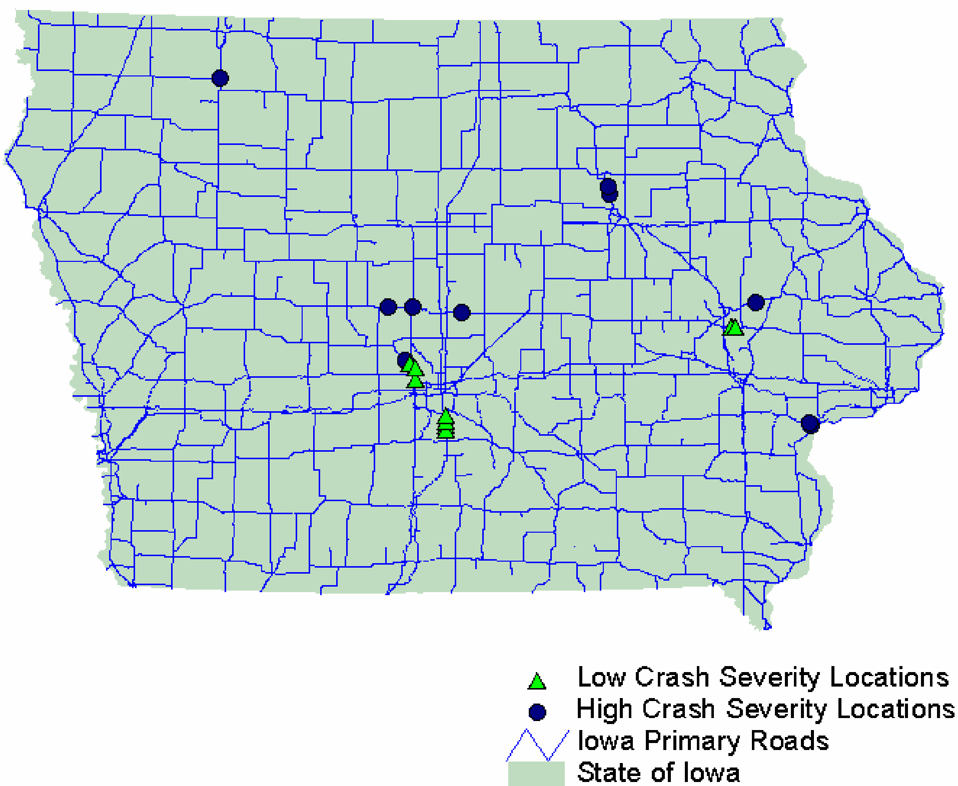

Figure 4.16. Locations of lowest and highest crash severity intersections

Table 4.8. Top 10 lowest severity index intersections

	Top ten intersections with the poorest safety performance	Nearest city	Actual five-year severity index	Expected five-year severity index	Major roadway volume	Minor roadway volume
1	IA 141 and NW 62nd Ave.	Grimes	5	55.92	27,300	990
2	US 30 and Honey Grove	Cedar Rapids	4	40.91	23,100	400
3	US 30 and Jappa Rd.	Cedar Rapids	6	41.09	23,100	510
4	US 30 and Ivanhoe Rd.	Cedar Rapids	8	41.98	23,100	440
5	US 69 and Carpenter St.	Indianola	6	36.70	21,700	90
6	IA 141 and NW Rowe Dr.	Granger	4	29.05	18,300	100
7	US 69 and Geneva St.	Indianola	3	27.24	17,400	40
8	US 69 and Delaware St.	Indianola	3	25.75	16,600	10
9	IA 141 and NW 102nd Ave	Granger	2	24.82	15,600	810
10	US 69 and Summerset Rd.	Indianola	8	28.14	17,400	850
				Average	20,360	424

Figure 4.17 shows the frequency of crashes, broken down by crash type, for both highest and lowest crash severity intersections. For the highest crash severity intersections, a preponderance of crashes are right angle crashes. This indicates that drivers are having difficulty selecting safe gaps in traffic when crossing major roadways or turning into traffic. In contrast, the lowest crash severity intersections have relatively few right angle crashes.

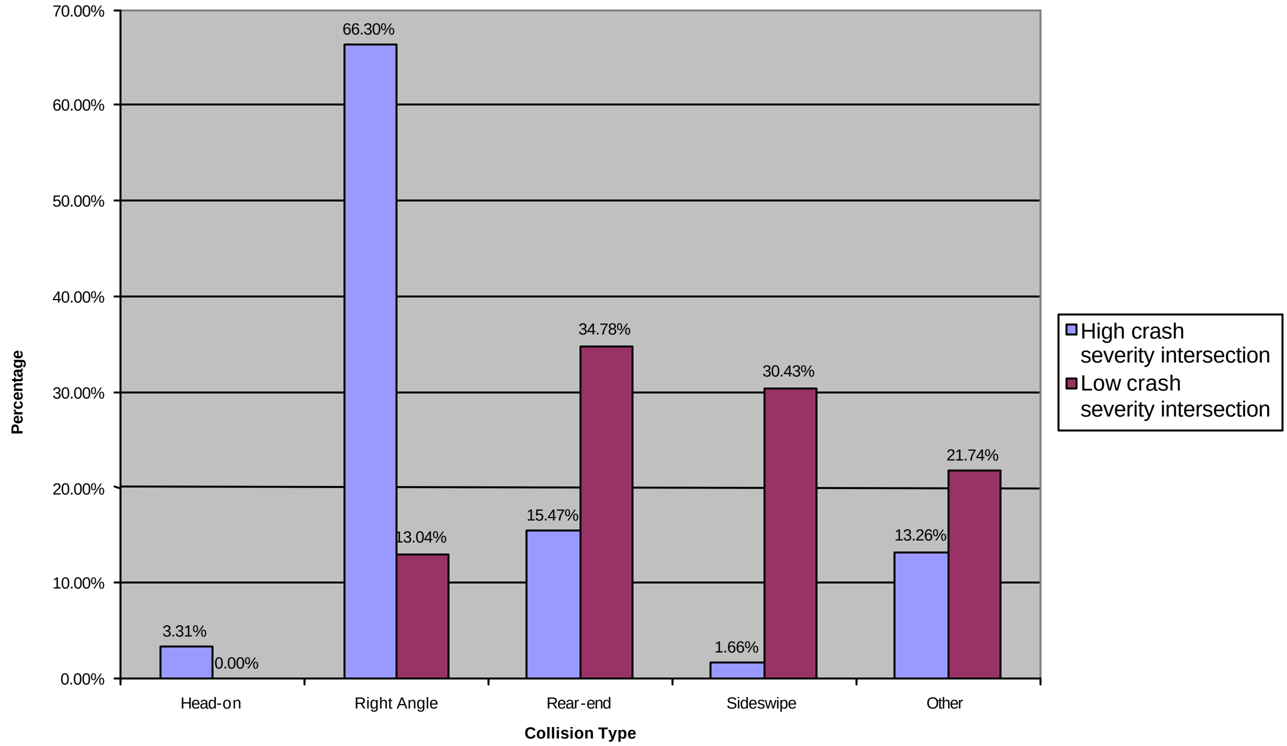

Figure 4.17. Crash type distributions for highest and lowest crash severity intersections

Figure 4.18 illustrates that more field investigation is required to understand the extreme difference in performance and crash type distribution at the lowest and highest crash severity intersections. Future study should examine the demographic and land use characteristics in the area of the intersection, as well as traffic patterns, geometric and alignment features of the roadway and the intersection and investigate individual crashes. Such an investigation would contribute to our understanding of what variables, in addition to minor roadway volume, lead to higher numbers of severe right angle crashes.

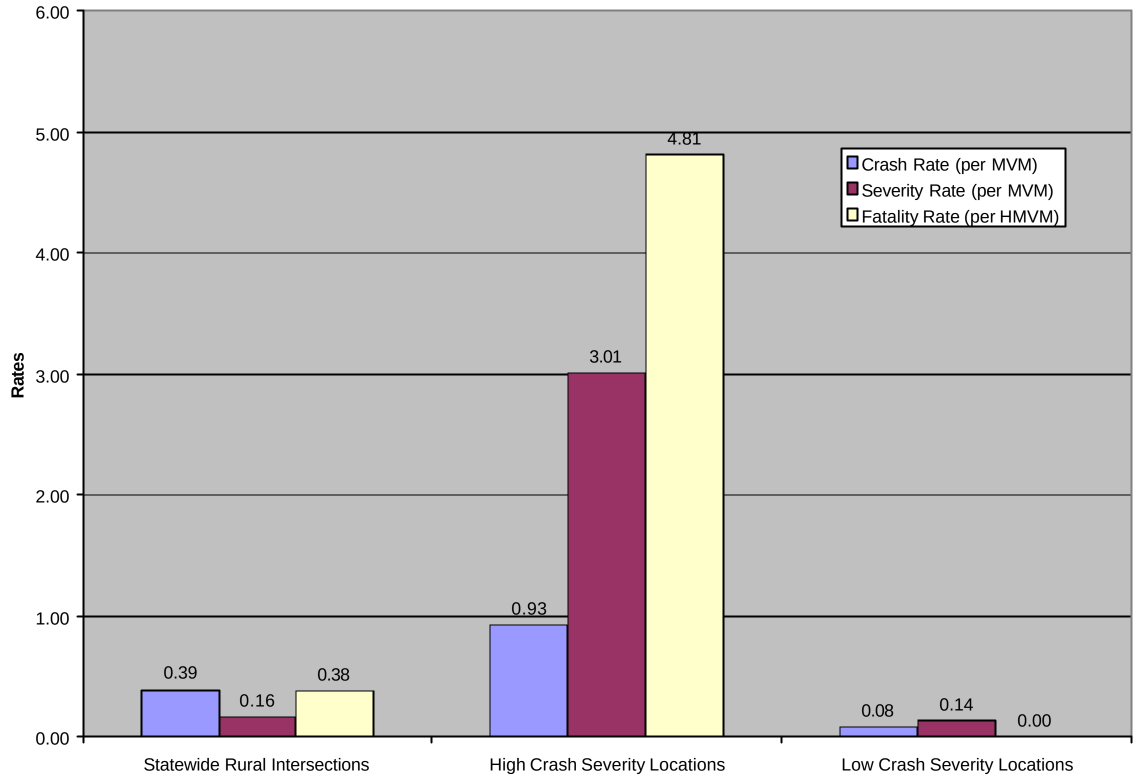

Figure 4.18. Crash, severity, and fatality rates of highest/lowest crash severity locations and statewide rural expressway intersections

4.7 Grade Separated Intersection and Phased Improvement Intersection

Over the past several years, the Iowa DOT has tried to reduce the number of conflict points and crashes at major intersections. To do this, one method implemented at a few locations was to grade separate the roadways with an overhead bridge and build a roadway for turning movements in one or more of the quadrants of the intersection. This configuration reduces conflict points much like an offset-T intersection and provides an interim step between an intersection and an interchange. Two examples of this method are shown in the aerial photographs in Figures 4.19 and 4.20. The intersection in Pottawattamie County near Carson, Iowa (Figure 4.19) eliminates the median crossover conflicts but requires two turning roadways. Crossover conflict still exists on the Mills County example (Figure 4.20), but the conflict points are reduced because the intersection has been converted into two T-intersections.

Figure 4.19. Intersection of US 59 and IA 92 in Pattawattamie County

Figure 4.20. Intersection of US 59 and US 34 in Mills County

These intersections can be completed as a staged improvement to ultimately constructing a full access-controlled intersection. The turning roadways and the bridge can be built and the medians closed in stage one. At this point, the intersection operates as two T-intersections and reduces the total conflict points. At some point in the future, the turning roads can be converted into ramps and the turning radius can be increased at the ramp terminals to allow high-speed operation, which will result in an interchange. The major benefit to this type of intersection is that it provides an intermediate step to an interchange and provides improved safety until volumes become great enough to warrant an interchange. Using the model in Equation 4-11, we would expect a crash severity of 12 for the Pottawattamie intersection, but with this configuration, it observed a crash severity of 5. Similarly, using the model in Equation 4-11, we would expect the Mills County Intersection to have a crash severity of 20, but with this configuration, it observed a crash severity of 7.

4.8 Statistical Analysis Conclusions

In this chapter, we performed descriptive and regression statistical analysis on a special purpose database created from 644 two-way, stop-controlled intersections on rural Iowa expressway highways. This database included five years of crash data and data relating to the approach traffic volumes and a few geometric features at the intersections. Since the data are from rural intersections, the traffic volumes at many of the intersections are very low and over the five-year period, roughly half the intersections experienced no crashes.

Our analysis showed that increasing minor roadway volume results in increasing crash rates and increasing crash severity. Increasing minor volumes also resulted in an increasing involvement of right angle crashes. Although we know that increased major roadway volume increases the frequency of crashes, increases in minor roadway volume appear to be more highly related to crash rate increases and increased crash severity. This is a very significant finding for systematically identifying intersections to improve or construct a new at-grade separated facility. First priority should be given to intersections with high minor roadway volume or where minor roadway volumes are expected to grow quickly.

We estimated several negative binomial regression models where crash frequency at each intersection is modeled with minor and major roadway volume. Our regressions have good statistical properties and show that frequency increases non-linearly with major and minor volume. We also found that with increasing volume, traffic volumes became more important in forecasting crash frequency. This suggests that on high volume roadways, traffic volume becomes a more important factor in identifying safety performance. We attempted to include the presence of right and left-turn lanes in our analysis, but our results were not interpretable, although it was apparent that median width does have a statistically significant impact on decreasing crash frequency.

Our best model (from a goodness-of-fit perspective) is a model of crash severity. For this model, we multiplied all of the crashes that occurred over a five year period by a crash severity index to form our dependent variable and used minor and major roadway volumes as the independent variables. This negative binomial regression model resulted in an extremely good fit. This indicates the strong relationship between crash severity and traffic volumes.

When crash experience at rural expressway intersections is compared to crash experience on all rural intersections with a primary roadway (including expressways), drivers of all age groups are represented in about equal numbers at both types of intersections. When we compared crash types, right angles crashes at expressway intersections are generally over-represented in most age groups. Older drivers are more frequently involved in right angle crashes at all rural intersections, but are particularly over-represented at expressway intersections.

We identified the 10 intersections with the worst safety performance and the 10 intersections with the best safety performance. At the level of detail this study reached, no common characteristics for all of the good or bad intersections were found. In general, the intersections with the worst performance had minor roadway volumes well above the average minor roadway volumes, while the best performing intersections had below-average minor roadway volumes. In addition, we found that worst performing intersections were commonly located on or near to a vertical or horizontal curve. However, more field analysis should be conducted to identify alignment, design, marking, traffic pattern, land use, or demographic characteristics that distinguish the good and worst performing intersections. When we looked at the crash type distribution data of the intersections with good and poor safety performance, more than 60% of the crashes were right angle crashes at the worst intersections while only about 13% were right angle crashes at the best intersections. Having trouble with right angle crashes is symptomatic of drivers having difficulty selecting a safe gap.

We also examined two intersections where conflict points and traffic conflicts are reduced by grade separating the roadways. These are locations where the Iowa DOT has built an overhead bridge for the minor roadway and created one or more turning roads between the two intersecting highways. By doing this, the conflicts are greatly reduced and the crash rates and crash severity is much lower.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Through this research, we found that many states are quickly converting two-lane highways to high-speed (55+ mph) expressways. At low volumes, these facilities allow motorists to travel at nearly the same level of safety and speed as an interstate highway, but expressways can be constructed at a much lower cost than interstate highways. However, as volumes on expressways and volumes on intersecting roadways increase, crash rates and the severity of crashes at intersections increase. As a countermeasure to crashes and crash severity at expressway intersections, there are a number of safety strategies that may be applied. Many State Transportation Agencies (STAs) are testing several of these strategies. Many of these strategies are listed in Table 3.4 and they range from very low cost signing and marking strategies to high cost grade separation strategies.

Three important conclusions can be drawn from this report. First, the safety performance of conventional two-way stop-controlled (TWSC) intersections on expressways declines precipitately as volumes on the minor roadway increase. Second, there are a wide variety of strategies that may be applied at expressway intersections to improve safety. Engineers have many alternatives, including conventional countermeasures like installing offset turning lanes, to improve the safety of problematic intersections. Third, many STAs are beginning to test and experiment with innovative strategies at expressway intersections. As the results of these tests become available, more will be known about the benefits of each intersection safety strategy and when and where the strategy is most appropriate.

5.2 Recommendations

With an understanding that safety issues may occur at high volume intersections, the next step should be to consider programming intersection improvements over the life of an intersection as it reaches specific volume thresholds before safety and/or traffic operations become problematic. In our survey, we found only one STA (the Illinois DOT) that has specific criteria that cause the triggering of steps that move from an at-grade intersection to an interchange.

To be able to identify the intermediate steps between a TWSC intersection and grade separating an entire corridor and when these strategies are most cost-effective, two important research questions must be addressed. The first research question is to quantify the safety performance improvement resulting from each of the intersection safety strategies identified in Table 3.4. As we found in our survey of states, several states are testing geometric, signing, and marking strategies. These tests will provide subjective information on these strategies. Unfortunately, little is being done to measure and document the safety performance improvement resulting from the treatments being tested. Research is required to quantify and document the safety performance improvement from these strategies. The second research question is to understand how intersection environment variables impact the performance of expressway intersections. For example, we believe that peaking of traffic volume at TWSC intersections decreases the safety performance of an intersection. Therefore, land use and commuter patterns may have a great deal of impact on the safety performance of an intersection. Other intersection environment variables believed to have an impact on intersection crash rates include the horizontal and vertical alignment on the expressway approaches, commercial activity on the corners of the intersection, the percentage of light and heavy vehicles making through, right, and left-turns, and violation of the drivers expectation by grade separation at an adjacent intersection. However, little is known about the intersection safety performance impact of these intersection environment variables.

Ideally, corridor planners and highway designers would be armed with several strategies, the expected safety performance improvement of the strategies, and the impacts of intersection environment variables. At low volumes, we know that TWSC intersections can provide very good safety performance and a TWSC intersection may be appropriate at most intersections when a two-lane roadway is first converted to a four-lane expressway. However, if we know that the land use around the intersection is likely to change and result in increased volume on the minor street, when the conversion to an expressway is being planned, the corridor planners could purchase additional right-of-way to allow for such strategies as wider medians, jug handles, offset T-intersections, or low-cost interchanges. Or, if the highway designer knew that in the future the intersection was likely to experience large truck volumes, the intersection could be designed with left-turn median acceleration lanes, long deceleration/turning lanes, and wider medians to safely accommodate future truck volumes.

Once more is known about the safety benefits of intersection safety strategies and the impact of environment features, more systematic plans and designs for intersections can be developed for the life cycle of new and existing expressways. Today, without research-based information on the safety performance implications of treatments and the intersection environment, STAs are applying treatments at problematic intersections to see if a treatment has the desired result or not and are slowly building an experiential database. Further research is needed to arrive at a proactive and systematic approach to planning for expressway intersection safety.

APPENDIX. INTERVIEW OUTLINE

The survey of states was conduct through an open-ended series of questions during a telephone interview. The questions are shown below. We contacted each state traffic engineer by telephone and then sent him or her the list of our questions. The next step was to schedule a time when we could interview them and to obtain answers to our questions. Some agencies choose to provide us with written responses rather then wait to conduct the interview.

February 13, 2004

To:

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I greatly appreciate your help in completing this information. We will be sure to share the results of our study with you. Feel free to add any supplemental information unique to at-grade expressway intersections you or others in your organization feel are relevant to either the safety, performance, or other features of these locations.

When completed, please either email the document or mail it to me as noted above. I look forward to sharing these results with you in the near future!

On behalf of the Iowa Department of Transportation we are conducting research into the safety performance of at-grade multi-lane (expressway) intersections. First we should loosely define the expressway roadway…

"a multi-lane, non-interstate divided facility with either partial or no access control. An expressway may have intersections that are at-grade, grade separated, or signal controlled."

1.0 EXPERIENCE WITH EXPRESSWAY TYPES OF ROADWAYS

1.1 How many miles of expressways does your state have (we had an estimate for of XX miles)?

1.2 Do you expect to construct additional lane miles of expressway roadways in the future (five to ten year plan)? If you anticipate constructing additional mile of expressway what is the motivating factor over other types of roadways (cost, safety, access, standard)?

1.3 Do you have any criteria for determining when to grade separate intersections or to convert an expressway to full access control (basic volume, performance, safety)?

1.4 If you don't have specific criteria what historically has been used when upgrading from at-grade intersection to an interchange?

1.5 Do you have an access control policy for expressway roadways (please provide or reference if available)?

1.6 Do you have any special criteria regarding type of intersection traffic control (other than MUTCD…side street vs main line perhaps may vary due to high main line speeds)?

2.0 SAFETY PERFORMANCE OF AT-GRADE INTERSECTIONS ALONG EXPRESSWAY ROADWAYS IN

2.0 If you have at-grade intersections along expressways, what crash frequency/rates and types of crashes have been experienced?

2.1 Did you observe any higher frequency of wrong-way maneuvers for new facilities versus long term?

2.2 Have you found an over-representation of drivers involved in crashes (young, old, etc)?

2.3 Have you documented the impact of any safety improvements made at at-grade expressway intersections?

2.4 Have you conducted in-depth crash investigations at any at-grade expressway intersections and if so were there any significant conclusions or safety improvement as a result?

3.0 LAYOUT/GEOMETRY OF AT-GRADE INTERSECTIONS ALONG EXPRESSWAY ROADWAYS

3.0 Does have a typical or standard geometry for at-grade expressway intersections? Could you provide a reference or information regarding typical features as listed here…Main-line (lane widths, left turn treatments such as off-set lefts, median widths both at the intersection and typical along the mainline, use of auxiliary lanes, access control or intersection spacing, typical side street treatment geometry, auxiliary lanes, intersection spacing, lighting standards, rumble strips, shoulder treatment)?

3.1 What is the typical main-line roadway speed limit (55mph, 65mph)?

3.2 Are frontage roads common (urban vs rural) or mandated?

3.3 Have you tried any innovative geometric treatments (offset left turn lanes, indirect lefts, offset right lanes, jug handles, median stop bar and signals, signage, rumble strips, etc)?

3.4 Does your state do any special PR work ahead of opening a new facility to alert public on driving issues related to a new expressway?

3.5 Could you provide a photograph or reference for an aerial view of a typical at-grade expressway installation?

4.0 OTHER RELEVANT ISSUES FACED BY REGARDING AT-GRADE INTERSECTIONS ALONG EXPRESSWAY TYPES OF ROADWAYS

4.0 Please take a moment to record or attach any additional information on the safety or performance experience for these at-grade intersections along expressway facilities.

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