3-2006

Intersection Safety

Aemal Khattak
University of Nebraska-Lincoln, khattak@unl.edu

NDOR Research Project Number SPR-1(2) P544-SJ0105

Transportation Research Studies

INTERSECTION SAFETY

F I N A L R E P O R T

Prepared for

Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, NE 68509-4759

By

Aemal J. Khattak

Mid-America Transportation Center
University of Nebraska-Lincoln
W333.2 Nebraska Hall
Lincoln, Nebraska 68588-0530

Telephone: (402) 472-1974
Fax: (402) 472-0859
Website: http://www.matc.unl.edu

March 2006

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EXECUTIVE SUMMARY

The objectives of this project included a study to determine the safety effects of intersection type (unsignalized, signalized, and interchange) on Nebraska expressway intersections, quantification of the safety effects of a Collision Countermeasure System (CCS), and update of the Nebraska Department of Roads (NDOR) expressway intersection guidelines. The CCS is an Intelligent Transportation Systems (ITS) traffic control device to warn drivers of conflicting cross-traffic at rural, non-signalized intersections. The goal was that if found effective, the CCS will become part of the intersection designer's options for expressway intersection design (other options being an interchange, traffic signals, and traffic control signs). Several issues and concerns were identified during research on the CCS including:

- Drivers on the minor road approaches failing to stop if the CCS indicated there was no traffic approaching on the main road,
- Drivers relying on the CCS information and failing to pay attention to the presence of vehicles which may not be indicated by the CCS; thus, perhaps increasing accident potential,
- System failures, maintenance costs, and liability concerns,
- Driver understanding of the CCS signs, and
- CCS complexity and cost.

In view of the above and upon the recommendation of the project Technical Advisory Committee (TAC), the research team decided to study the safety of a bouncing ball beacon (BBB) system. This system alerts drivers approaching an intersection via a bouncing ball beacon. The research team inventoried the multi-lane divided expressway system in Nebraska and found two intersections where a BBB was in operation. However, these two sites were not suitable for a before-and-after safety study. The BBB at the first site was installed when the existing highway was upgraded to expressway standards, thus there were no before installation accident data available for the expressway. The BBB at the second site was installed simultaneously with other safety-related changes so the effects of the BBB could not be effectively separated from the effects of the other safety-related changes. The research team identified two intersections where a BBB system might be installed for this research. However, cost and potential public concerns with the installation and subsequent removal of BBB systems in a relatively short period prohibited the study of BBB systems.

The research team then focused on the study of factors influencing expressway intersection safety in Nebraska including the effects of intersection type (unsignalized, signalized, and interchange). After a review of published literature, the research team identified a number of intersection-related elements that appeared to play a role in intersection safety. As such, information on those intersection elements was collected from various NDOR sources including the NDOR Reference Post Log Book, as-built plans, and photolog records. This was a very time consuming process but resulted in collection of valuable data. A total of 41 intersections were included in the database containing information on intersection-related elements as well as yearly accidents reported between 1988 and 2000 (later than 1988 if the intersection was upgraded to an expressway intersection after 1988) and any changes to those 41 intersections during the study period (1988-2000). This database was subsequently analyzed for expressway intersection safety including the effects of intersection type, i.e., safety of unsignalized versus signalized intersections; no interchanges were available for comparison in the database analyzed.

Analysis results indicated that exposure (measured as total entering traffic) is an important factor affecting expressway intersection safety – expected number of accidents on an intersection approach increase with increasing exposure. While the analysis did not reveal any differences in safety of unsignalized and signalized intersections, the presence of horizontal curves on intersection approaches was found to increase accidents while vertical curves placed through intersections were also found increase accidents on intersection approaches. Expressway approaches with offset left turn lanes were found safer when compared to conventional left turn lanes and expressway approaches with no exclusive left-turn lanes. The above information is recommended for addition to the existing NDOR expressway intersection guidelines to make Nebraska expressway intersections safer. This report also provides directions for future expressway safety investigative research efforts.

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CHAPTER 1 - INTRODUCTION

1.1. Background

At-grade intersections on expressways in Nebraska experience a number of traffic accidents every year. These accidents often tend to be severe compared to accidents at other locations because of relatively higher vehicular speed on expressways. The objectives of this research project included a study to determine the safety effects of intersection type (unsignalized, signalized, and interchange) on Nebraska expressway intersections, quantification of the safety effects of a Collision Countermeasure System (CCS) via a before-and-after study, and update of the Nebraska Department of Roads (NDOR) expressway intersection guidelines. The CCS is an Intelligent Transportation Systems (ITS) traffic control device to warn drivers of conflicting cross-traffic at rural, non-signalized intersections. Actively illuminated, graphic signs, operating from vehicle detectors, automatically warn approaching vehicles of traffic on the intersecting roadway. The CCS appears feasible in rural highway applications where high intersection accident rates indicate the need for more than conventional signing, while low traffic volumes and high installation costs make conventional traffic signals inappropriate.

The goal was that if found effective, the CCS will become part of the intersection designer's options for expressway intersection design; other available options being an interchange, a traffic signal, and traffic control signs. The research team identified potential sites for the installation of a CCS since none were available in Nebraska but several issues and concerns surfaced prior to the installation, including:

- Drivers on the minor intersection approaches failing to stop if the CCS indicated there was no traffic on the major intersection approaches,
- Drivers relying on the CCS information and failing to pay attention to the presence of vehicles which may not be indicated by the CCS; thus, perhaps increasing accident potential,
- System failures, maintenance costs, and liability concerns,
- Driver understanding of the CCS signs, and
- CCS complexity and cost.

In view of the above and upon the recommendation of the project Technical Advisory Committee (TAC), the research team decided to replace the CCS with bouncing ball beacon

(BBB) system in the study. A BBB system alerts drivers approaching an intersection via a bouncing ball beacon. The research team inventoried the multi-lane divided expressway system in Nebraska and found two intersections where a BBB was in operation (Jct. US-77 and Bluff Road, North of Lincoln and Jct. US-81 and US-136, Southeast of Hebron). However, the two sites were not suitable for a before-and-after evaluation. The BBB at the intersection of US-77 and Bluff Road was installed when the existing highway was upgraded to expressway standards, thus there were no before installation accident data available for the expressway. The BBB at the intersection of US-81 and US-136 was installed simultaneously with other safety-related changes and as such, the effects of the BBB could not be separated from the effects of the other safety-related changes. The research team identified two intersections where a BBB system might be installed for this research (Jct. US-81 and N-91, Northeast of Humphrey and Jct. US-81 and N-64, South of Columbus). However, cost and potential public concerns with the installation and subsequent removal of BBB systems in a relatively short period prohibited the study of BBB systems.

The research team then focused on the study of factors influencing expressway intersection safety in Nebraska including the effects of intersection type (unsignalized, signalized, and interchange). An extensive review of published literature indicated that 35 intersection-related elements were found pertinent to intersection safety or had been recommended for safety investigation by various researchers. As such, information on those intersection elements was collected from different NDOR sources including NDOR Reference Post Log Book, as-built plans, and photolog records. This was a very time consuming process, but it resulted in the collection of valuable data. A total of 41 intersections were included in the database containing information on the 35 intersection-related elements as well as yearly accidents reported between 1988 and 2000 (later than 1988 if the intersection was upgraded to expressway status after 1988) and any changes to those 41 intersections during the study period (1988-2000). This database was subsequently analyzed using sound statistical techniques to study the effects of intersection type other intersection characteristics on expressway safety.

This report chronicles the research team’s efforts regarding identification of factors influencing expressway intersection safety in Nebraska and the recommendations for NDOR expressway intersection guidelines. Figure 1.1 shows the flow of various activities undertaken in this research project.

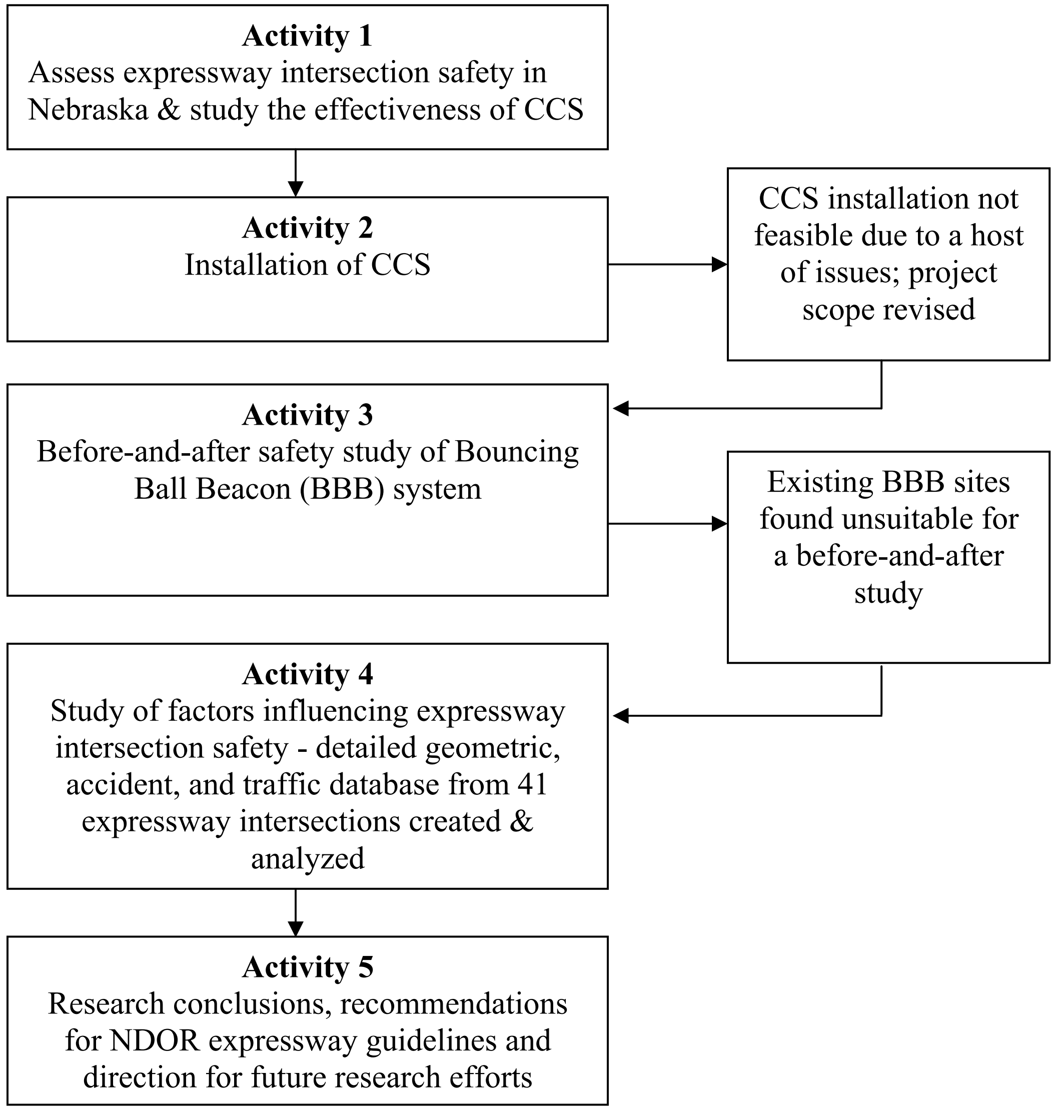

Figure 1.1. Flow of activities

1.2. Report Organization

This report consists of a total of five chapters. This introductory chapter is followed by a chapter that provides details of the literature review on intersection safety. Chapter 3 presents details of the collected data, while Chapter 4 chronicles the analysis of the collected data. Chapter 5 provides research conclusions and recommendations for NDOR expressway guidelines with direction for future expressway safety investigative research efforts.

CHAPTER 2 - LITERATURE REVIEW

As part of the literature review, several documents were examined to identify pertinent information on expressway safety. This information is presented next while a summary of the literature review is provided at the end of this chapter.

2.1. Information from Reviewed Literature

Intersection safety has been well researched and a significant body of knowledge is available on this subject. Topics related to geometric design that have been researched include left and right turn lanes, channelization, number of intersecting legs, intersection skew, intersection sight distance, approach lanes, approach width, shoulder width, median width and type, vertical and horizontal alignment on approaches, and lighting. Among intersection traffic control and operational elements, investigators have looked at signalization, BBB, median traffic control type, type of terrain and average daily traffic (ADT). In case of approach traffic control and operational elements, investigators have looked at major and minor approach ADT, design speed and speed limit on the major approach, warning signage on the two approaches, access control, roadway classification, and presence of stop-line pavement markings. A brief description of the findings of various researchers on different aspects of intersection safety follows.

Left and right turn lanes – Installation of left and right turn lanes at intersections has been studied by several researchers. Foody and Richardson (1973) reported that accident rates decreased by 38 percent due to addition of a left-turn lane at signalized intersections and by 76 percent at unsignalized intersections. McCoy and Malone (1989) reported that installation of left-turn lanes on intersections of urban four-lane highways reduced rear-end, sideswipe, and left-turn related accidents. More recently, Gluck et al. (1999) reported accident rate reductions ranging from 18 to 77 percent due to installation of left-turn lanes at intersections. Bauer and Harwood (1996) indicated that right-turn channelization at intersections resulted in decreased accidents. Similarly, Harwood et al. (2002) reported a 5 percent reduction in accidents due to a right-turn lane along one approach to a rural stop-controlled intersection and a 10 percent reduction due to right-turn lanes along both major approaches. However, an earlier study by Vogt and Bared

(1998) showed a 27 percent increase in intersection accidents due to the presence of right-turn lanes along two-lane rural highways.

Channelization – David and Norman (1976) reported that intersection safety improved due to channelization. In another study, Templer (1980) found that a raised median reduced number of conflicts between pedestrians and vehicles, but the difference was not statistically significant. More recently, Washington et al. (1991) reported that the presence of raised medians on intersection approaches reduced accident rates by 40 percent when compared to intersection approaches with flush medians.

Number of Intersecting Legs – David and Norman (1976) found that for stop-controlled intersections in urban areas with total entering volumes over 20,000 vehicles per day, four-leg intersections experienced twice as many accidents as three-leg intersections. Hanna et al. (1976) found that in rural areas, four-leg intersections experienced approximately 69 percent more accidents than three-leg intersections. Modeling results by Harwood et al. (1995) showed that divided highway intersections with four legs had about twice as many accidents as three-leg intersections for narrow medians and more than five times as many accidents for wide medians. Bauer and Harwood (1996) reported that both rural and urban stop-controlled intersections with four legs experienced approximately twice as many accidents as intersections with three legs.

Intersection Skew – In developing guidelines for NDOR, McCoy et al. (1994) found that accidents at rural two-way stop-controlled intersections increased with increasing skew angle and this result applied to intersections with three as well as four legs.

Intersection Sight Distance – Three types of sight distance are important for the safety of at-grade intersections: intersection sight distance, stopping sight distance, and sight distance to traffic control devices. Mitchell (1972) found that total intersection accidents were reduced by 67 percent when intersection sight obstructions were removed. David and Norman (1976) reported that the reduction in accident experience from a sight distance improvement was highest for intersection approaches whose initial sight distance was lowest. Hanna et al.(1976) found that intersections with poor sight distance had an accident rate of 1.33 accidents per million entering vehicles, while intersections as a whole had an accident rate of 1.13 accidents per million entering vehicles. Fambro (1989) found that accident rates were high for intersections located on crest vertical curves with limited sight distance. The results of another study by Fambro et al.(1997) support the previous finding. Finally, Harwood et al.(2002) provide information on accident mitigation factors related to improvements in intersection sight distances.

Approach Width, Number of Approach Lanes, and Shoulder Width – Studies by Neuman (1985) and Bauer and Harwood (1996) indicated that the wider width of an intersection approach (i.e., combined width of lanes and in some cases, shoulder width as well) resulted in reduced accident rate. Regarding number of lanes, Bauer and Harwood (1996) reported that accidents were higher on facilities with one approach lane when compared to intersections with two or more approach lanes at unsignalized intersections. Shoulder width was investigated by Van Maren (1980) and Harwood et al. (1995) and found not influential in intersection safety.

Median Width – Harwood et al. (1995) reported that accidents at rural four leg signalized intersections decreased as median width increased. However, they also reported that at both signalized and unsignalized intersections in urban and suburban areas, accidents increased with increasing median width. An earlier study by Van Maren (1980) did not find any relationship between median width and accident rates at intersections of divided highways.

Vertical and Horizontal Alignment on Approaches – Vertical curvature on intersection approaches tends to affect safety since sag curves increase stopping distance while crest curves slow vehicle acceleration thus increasing vehicle exposure in the conflict area. Fambro et al. (1989) reported high accident rates at intersections with crest vertical curves. The presence of horizontal curves adds complexity to intersections and Kuciemba and Cirillo (1992) have shown that safety is affected by the presence of horizontal curves in close vicinity of intersections.

Lighting – Bauer and Harwood (1996) found that lighted rural four leg stop-controlled intersections experienced 21 percent fewer accidents than intersections without any lighting. However, the authors did not find similar safety effect due to lighting at other types of intersections.

Intersection Traffic Control and Operational Elements – A number of researchers have examined signalization and found it to be influential in intersection safety (Solomon, 1959; Cribbins et al., 1967; Cribbins et al., 1970; Van Maren 1980). Harwood et al. (1995) found median traffic control type to be not influential in intersection safety but did find terrain type to be influential. The research team uncovered two rather dated and conflicting studies by McDonald (1953) and Priest (1964) on the effect of the total entering traffic volume on intersection safety. The former study did not find any safety impact of the total entering traffic volume while the latter indicated it to be influential in intersection safety.

Approach Traffic Control and Operational Elements – Expressway and minor road traffic volumes were investigated separately and found to affect intersection safety by McDonald (1953), Priest (1964), Cribbins et al. (1967), Harwood et al. (1995) and Maze et al. (2004). Cribbins et al. (1967) found expressway speed limit to be important in intersection safety while Harwood et al. (1995) did not find any effect of expressway design speed on intersection safety.

2.2. Literature Summary

In summary, the reviewed literature indicated that presence of turn lanes generally resulted in safer intersections although in some cases presence of right-turn lanes resulted in increased accidents. Channelization, raised medians, lighting, and availability of clear sight distance improved safety, while higher number of intersecting legs, greater intersection skew, and presence of curvature reduced safety. Approach width and larger number of lanes improved safety. Median width displayed mixed results – improving and reducing safety in certain instances. Intersection traffic control and operational elements such as ADT were also found to affect safety. Although, the research team did not find significant literature particularly focused on expressway intersections, the information obtained from the literature allowed the research team to focus on particular factors during data analysis.

CHAPTER 3 - DATA COLLECTION

This chapter provides information on database construction and characteristics of 41 Nebraska expressway intersections that were studied in this project.

3.1. Study Intersections

A list of the 41 expressway intersections studied in this project appears in Table 3.1. All 41 intersections were located in rural or suburban areas, all approaches were at-grade (i.e., no interchanges) and with major approaches designated as expressways. Portions of expressways consisting of two lanes (i.e., one lane in each direction) were excluded from this study. Due to absence of interchanges, the study was limited to stop-controlled and signalized intersections. The existence of short expressway segments at intersections and intersections at the end of expressway segments caused an inclusion rule to be developed. For an intersection to be included in this study, all expressway approaches to the intersection had to have at least 700 feet of roadway wide enough to accommodate four traffic lanes (two in each direction). The start date in Table 3.1 indicates the date when the expressway intersections were first included in this study; the study period ended on 12/31/2000. A tabulation of the accidents reported on major and minor approaches of the study intersections appears in Appendix A.

3.2. Database Elements

The final database contained 51 variables. Individual intersection approaches were identified by approach number. Expressway approaches were numbered 1 and 2, while non-expressway approaches were numbered 3 and 4. The increasing milepost direction was from approach 1 to approach 2 and from approach 3 to approach 4. Figure 3.1 illustrates the numbering of approaches at intersections. The database variables, their sources of information and collection, and their respective coding are defined next.

Table 3.1. List of study intersections*

Study intersection ID	NDOR intersection ID	Expressway	Cross road	Cross road type	Intersection description	NDOR district	County	Start date**
1	7902000	US-26	N-71	Expressway	W. JCT US-26/N-71 - west of Scottsbluff	5	Scotts Bluff	2/1/1996
2	7901000	US-26	N-71/5703	State/Business	E. JCT US-26/N-71/5703 Bus-71/Avenue I on north edge of Scottsbluff	5	Scotts Bluff	2/1/1996
3	400100	N-71	S-04A/County Road 26	Spur/County	JCT N-71/S-04A Harrisburg spur/County road 26	5	Banner	11/1/1993
4	400200	N-71	N-88	State	S. JCT N-71/N-88 located northeast of Harrisburg	5	Banner	11/1/1993
5	400300	N-71	N-88/County Road 36	State/County	N. JCT N-71/N-88/County road 36 (Pumpkin creek road), located east of LaGrange, WY	5	Banner	11/1/1993
6	Missing1	N-71	Wchgpa Road/ Driveway	County/ Driveway	JCT N-71/Wildcat hills game preserve access road/Private drive	5	Scotts Bluff	8/31/1998
7	100600	US-34/281	S-01D/2050	Spur/County	JCT US-34/281/S-01D Trumbull spur/2050 (94th St)	4	Adams	1/1/1988
8	4000200	US-34/281	S-40B/2070	Spur/County	JCT US-34 / 281 / S-40B Doniphan spur/2070 (Platte river road), on west edge of Doniphan	4	Hall	1/1/1988
9	4001300	US-34 / 281	R-40E/ Driveway	County/ Driveway	JCT US-34/281/R-40E (Mormon Island rec. road)/business driveway	4	Hall	1/1/1988
10	4001000	US-281	US-34/N-2/ 2120	US/County	JCT US-281/US-34/N-2/2120 (W. Husker Hwy) - in Grand Island	4	Hall	1/1/1988
11	8501900	US-81	N-8	State	JCT US-81/N-8 - northeast edge of Chester	4	Thayer	6/1/1994
12	850000022	US-81	7578	County	JCT US-81/7578 (Stoddard road)	4	Thayer	6/1/1994
13	8502100	US-81	L-85F/County Road	Link/County	JCT US-81/L-85F/County road	4	Thayer	10/1/1995
14	8501800	US-81	US-136	US	JCT US-81/US-136 - southeast of Hebron	4	Thayer	10/1/1995
15	8502000	US-81	S-85H/County Road	Spur/County	JCT US-81/S-85H Hebron spur/Lincoln Ave/County road	4	Thayer	10/1/1995
16	8500600	US-81	S-85D/2360	Spur/County	JCT US-81/S-85D Belvidere spur/2360	4	Thayer	3/31/1997
17	8500900	US-81	N-4/County Road	State/County	S. JCT US-81/N-4/County road, located east of Carleton	4	Thayer	4/1/1998
18	8501000	US-81	N-4/County Road	State/County	N. JCT US-81/ N-4/County road, located south of Bruning	4	Thayer	4/1/1998
19	3001200	US-81	N-41/F St	State/Local	N. JCT Old US-81/ N-41(F St) in Geneva	4	Fillmore	1/1/1988
20	930000012	US-81	6314	Local	JCT US-81/6314 Henderson road/S. 50th St in York	4	York	1/1/1988
21	9300800	US-81	US-31/ 6311	US/Local	S. JCT US-81/US-34/6311 Lincoln Ave/25th St in York			1/1/1988
22	1201200	US-81	N-64 / 2750	State/County	JCT US-81/N-64/2750, located south of Columbus	4	Butler	6/1/1991

Table continues on next page

Table 3.1 continued

Study intersection ID	NDOR intersection ID	Expressway	Cross road	Cross road type	Intersection description	NDOR district	County	Start date**
23	7100900	US-81	US-30/S. 9th St	US/County	S. JCT US-81/US-30/S. 9th St, on south edge of Columbus	3	Platte	1/1/1988
24	7101500	US-81	N-22	State	JCT US-81/N-22, located northwest of Columbus	3	Platte	4/1/1996
25	7100400	US-81	S-71B/ County Road	Spur/County	JCT US-81/S-71B Platte Center spur/County road (63rd Ave)	3	Platte	5/4/1998
26	710000036	US-81	2790	County	JCT US-81/2790 Tarnov road/385th St	3	Platte	5/4/1998
27	7100300	US-81	S-71A/ Driveway	Spur/ Driveway	JCT US-81/S-71A Humphrey spur/Private driveway	3	Platte	4/5/1999
28	7101300	US-81	N-91	State	JCT US-81/N-91, located northeast of Humphrey	3	Platte	5/5/1997
29	590000040	US-81	2907/ County Road	Local/County	JCT US-81/2907 Main St/827th road in Madison	3	Madison	5/5/1997
30	5901400	US-81	N-32	State	JCT US-81/N-32 on east edge of Madison	3	Madison	8/1/1992
31	3401000	US-77	S-34D/2920	Spur/County	JCT US-77/S-34D Pickrell spur/2920 (W. Pickrell Road)	1	Gage	8/1/1990
32	340000048	US-77	7808	County	JCT US-77/7808 (DeWitt/Cedar road)	1	Gage	4/1/1992
33	3401600	US-77	N-41	State	W. JCT US-77/N-41, located east of Clatonia	1	Gage	4/1/1992
34	3401700	US-77	N-41	State	E. JCT US-77 / N-41, located south of Cortland	1	Gage	4/1/1992
35	340000082	US-77	4th St	Local	JCT US-77/4th St in Cortland	1	Gage	11/1/1993
36	5500900	US-77	S-55H/Firth Road	Spur/County	JCT US-77/S-55H Hallam spur/Firth road	1	Lancaster	11/1/1993
37	Missing2	US-77	Broad St	Local	JCT US-77/Broad St, in Princeton (unincorporated)	1	Lancaster	4/1/1996
38	550000045	US-77	3270 / W. Panama Road	County	JCT US-77/3270 Panama/Holland road	1	Lancaster	4/1/1996
39	5500800	US-77	S-55G/3280	Spur/County	JCT US-77/S-55G Hickman Spur/3280 (Sprague road)	1	Lancaster	4/1/1996
40	550000095	US-77	3300	County	JCT US-77 / 3300 (Saltillo road)	1	Lancaster	1/1/1988
41	550000047	US-77	7822	County	JCT US-77 / 7822 (Rokeby road)	1	Lancaster	1/1/1988

* A tabulation of the accidents reported on major and minor approaches of the above intersections is given in Appendix A.

** End date for all intersections was 12/31/2000

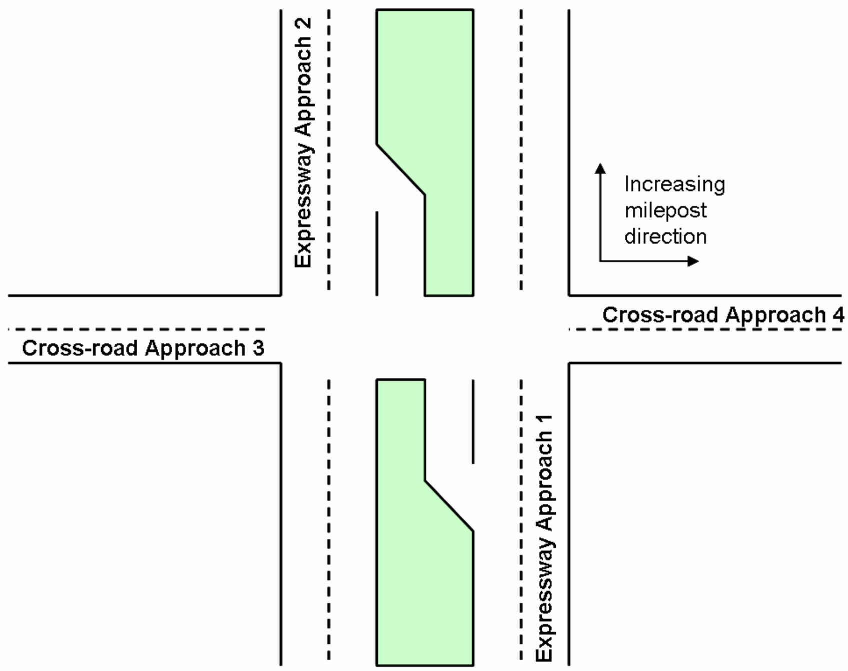

Figure 3.1. Approach numbering system

Observation Number (OBS_NO), this variable is an arbitrary unique identification number given to each row in the database.

Study Intersection Identification Number (INT_ID), this variable is an arbitrary unique identification number given to each intersection included in the study. Table 3.1 lists the study intersection ID and the NDOR intersection ID for each intersection in the database.

Intersection Leg (LEG), individual number given to each intersecting approach. This variable identifies each leg/approach of the intersection – 1 and 2 are always expressway legs/approaches and 3 and 4 are always cross-road legs/approaches (in case of a 3-legged intersection, there will be no number 4 leg/approach).

Group Size (GRP_SIZE), this variable provides the number of observations in a group for panel data analysis (note that the panel is not balanced in this dataset i.e., the group size is not the same for all entities).

Total Number of Intersecting Legs/Approaches (TOT_LEG), this variable identifies the number of intersecting legs/approaches at the intersection. The source of information for this variable was a combination of intersection design plans and photolog records.

Year of Observation (YEAR), represents the year of observation.

Exposure Days (EXPO_DAYS), this variable gives the number of days the leg/approach was open to traffic and when combined with annual average daily traffic (AADT), gives a measure of accident exposure.

Traffic Control Type (SIGNAL), describes the type of traffic control device present at the intersection. The source of information for this variable was a combination of intersection design plans and photolog records. The coding scheme for this variable is:
Not signalized = 0
Signalized = 1
Bouncing Ball Beacon = 2

Area Type (AREA_TYP), describes the type of area surrounding the intersection as rural or suburban. The area type determination was made by a combination of population grouping given in the NDOR GIS database and Federal Highway Administration (FHWA) rules for area type classification. Some exceptions were made based on best judgment (e.g., intersections on Highway 2 through the City of Lincoln). The coding scheme for this variable is:
Rural = 0
Suburban = 1

Roadway Lighting (LIGHT), describes whether roadway lighting is present at the intersection; the source of information for this variable was a combination of intersection design plans and photolog records. The variable is coded as:
No = 0
Yes = 1

Intersection Angle (ANGLE), identifies the measured angle, in degrees, between the intersecting approaches. The measured angle is the angle between the designated leg/approach number 1 and the approach to its left. Source of information on this variable was intersection design plans.

Average Annual Daily Traffic (AADT), provides the average annual daily traffic on each leg/approach and when combined with the variable EXPO_DAYS, gives a measure of accident exposure.

Speed Limit (SPD_LMT), this variable identifies the posted regulatory speed limit in miles per hour (mph) on each intersection approach. Additional sources besides NDOR Traffic Engineering Division were used to obtain speed limit information. A photolog search was conducted both up and downstream to check speed limit signs that applied to the approach in question. If no regulatory signs were found on an approach, the default speed limits as specified in the Nebraska Highway and Bridge Law (Revised statutes of Nebraska 1998/1999 supplement) were used. These are:
25 mph for private driveways or field entrances,
35 mph in business or residential districts on non-state highways,
50 mph for non-paved non-state highways in rural areas,
55 mph for paved non-state highways in rural areas.
In case an approach was not a state maintained road and could not be viewed in the photolog, the posted speed limit was requested from various Nebraska county highway commissioners. If the county highway commissioner indicated that the speed limit was not posted on a particular approach, the default values (given above) were used.

Influence Distance (INFDIST), this variable identifies the distance, in feet, the presence of the intersection is assumed to influence along each intersecting approach. Accident and geometric data were collected within this distance on each approach.

Horizontal Character (HOR_CHR), identifies the presence and length of horizontal curvature, within the specified influence area, on each intersection approach. Values are missing for minor approaches (808 observations).

Horizontal Placement (HOR_PLC), this variable describes the placement of an existing horizontal curve, within the specified influence area, on each intersection approach and the coding scheme is:

None = 0

On Approach = 1

Through = 2

Percent Grade (GRADE), this variable identifies the measured percent grade within the influence area on each intersection approach. If multiple grades were present, the grade that occupied the majority of the influence area was recorded. If the approach was on a vertical curve, the percent grade of the tangent was recorded.

Vertical Character (VRT_CHR), identifies the presence and type of vertical curvature within the specified influence area on each intersection approach. The variable coding scheme is:

None = 0

Crest = 1

Sag = 2

Vertical Placement (VRT_PLC), this variable describes the placement of an existing vertical curve within the specified influence area on the expressway approaches. This variable was not recorded for the cross-roads because the vertical alignment of the cross-roads matches into the cross-slope of the expressway. Therefore, a vertical curve on a cross-road would never go through the intersection center. The coding scheme for this variable is:

None = 0

On Approach = 1

Through = 2

Median Width (MED_WID), this variable identifies the measured width, in feet, of the median on each expressway approach. This element was dropped for the cross-road approaches because most cross-road medians vary in width and only exist at the mouth of the intersection. The database provides a value of zero for cross-road median width where there was no median and a missing value if there was a median but was not measured.

Median Type (MED_TYP), this variable describes the type of median present at the intersection on the approach in question and is coded as:
Depressed = -1
None = 0
Painted = 1
Raised = 2

Number of Through/Shared Lanes (THRU_LN), this variable identifies the number of lanes used by through traffic on each approach. This includes all lanes used exclusively by through traffic and lanes shared by through traffic and right or left turning traffic.

Through/Shared Lane Width (THRUWID), this variable identifies the combined total width, in feet, of all the through lanes on an approach, including both shared left turn and right turn lanes. Widths of exclusive left and right turn lanes are not included in the total through lane width. The number of lanes whose width was measured matches the number of through lanes recorded. The total through lane width was recorded so that the total through lane width divided by the number of through lanes equals the average through lane width for an approach. If the lane width on an approach varied, the through lane width was measured at the point where the curb return radius on that approach began.

Number of Exclusive Left Turn Lanes (LT_LN), identifies the number of exclusive left turn lanes on each approach. A shared lane used by both through and left turning traffic is counted as a through lane, not as a left turn lane.

Width of Exclusive Left Turn Lanes (LT_WID), this variable identifies the combined total width, in feet, of all exclusive left turn lanes on an approach. The number of lanes whose width was measured matches the number of exclusive left turn lanes recorded. The total left turn lane width was recorded so that the total left turn lane width divided by the number of exclusive left turn lanes equals the average left turn lane width for that approach. The left turn lane width measured was its full uniform width.

Length of Exclusive Left Turn Lanes (LT_LNG), variable identifies the total length, in feet, of the exclusive left turn lane(s) on an approach. The left turn lane length was measured from the median nose to the last point at the upstream end where the left turn lane(s) has its full width.

Type of Exclusive Left Turn Lane (LT_TYP), this variable describes the type of exclusive left turn lane present on the approach in question and is coded as:
None = 0
Conventional = 1
Offset = 2

Number of Exclusive Right Turn Lanes (RT_LN), this variable identifies the number of exclusive right turn lanes on each approach. A shared lane used by both through and right turning traffic was counted as a through lane, not as a right turn lane. Separate right turn lanes created with a channelizing island (i.e. free right turn lanes) are included as right turn lanes even if traffic enters the channelizing roadway from a lane shared with through traffic (i.e. there was no exclusive right turn lane upstream of the right turn roadway). This variable does include free right turn lanes (FRT Lane) in its count but free right turn ramps (FRT Ramp) were not counted.

Width of Exclusive Right Turn Lanes (RT_WID), variable identifies the combined total width, in feet, of all exclusive right turn lanes on an approach. The number of lanes whose width was measured matches the number of exclusive right turn lanes recorded. The total right turn lane width was recorded so that the total right turn lane width divided by the number of exclusive right turn lanes equals the average right turn lane width for that approach. The right turn lane width measured for conventional right turn lanes was its full uniform width. The right turn lane width measured for free right turn lanes (FRT Lane) was also its full uniform width. No width was recorded for free right turn ramps (FRT Ramp).

Length of Exclusive Right Turn Lanes (RT_LNG), this variable identifies the total length, in feet, of the exclusive right turn lane(s) on an approach. The right turn lane length for conventional right turn lanes was measured from the median nose to the last point at the upstream end where the right turn lane(s) has its full width. If no median nose was present, the measurement was estimated by matching points between photolog and the intersection plans. The right turn length for free right turn lanes (FRT Lane) was measured along the center line of the lane between the points where the lane had its full width. No length was recorded for free right turn ramps (FRT Ramp).

Type of Right Turn Treatment (RT_TYP), this variable describes the type of right turn treatment present on the approach in question and is coded as:

None = 0

Conventional = 1 (no channelizing island)

FRT Lane = 2 (free right turn lane created by a channelizing island that leaves the mainline of the roadway from within the influence area on that approach)

FRT Ramp = 3 (free right turn ramp that leaves the mainline of the roadway from outside of the influence area on that approach)

Right Turn Curb Return Radius (CURB_RAD), this variable identifies the measured radius, in feet, of the right curb return on each intersection approach. It was recorded as zero if there was no right turn from that approach. If the right curb return consisted of a compound curve, the best or equivalent radius was selected. Also, tapers on the right curb return were ignored.

Right Paved Shoulder Width (RSHLDWD), this variable identifies the measured width, in feet, of the right (outside) paved shoulder on each intersection approach. This distance was measured from the outside edge of the rightmost lane (through or right turn) to the outside edge of the paved shoulder at the point where the curb return radius for that approach begins.

Right Shoulder Type (RSLDTYP), this variable describes the type of right shoulder present on the approach. Its coding scheme is:

Flush = 0; Curbed = 1

Pavement Material (PVT_MTL), this variable identifies the pavement material type on each of the approaches to the intersection. All expressway approaches are hard (paved with concrete or asphalt) while minor approaches can be hard, or soft (gravel or dirt). The coding scheme is:

Soft = 0

Hard = 1

Advance Warning Signs (ADVWARN), this variable describes the presence and type of advance warning sign present on the approach in question.

None = 0

Sign = 1

Beacon = 2

Roadway Classification (CLASS), this variable defines the roadway classification of the approach in question.

BUSINESS	= 1 (business route)INT = Interstate
COUNTY	= 2 (county road outside corporate limits)
DRVWAY	= 3 (private driveway or field entrance)
EXPRWY	= 4 (expressway)
LINK	= 5 (state link)
LOCAL	= 6 (local road within corporate limits)
SPUR	= 7 (state spur)
STATE	= 8 (state highway)
US	= 9 (US highway)

Number of Accesses/Driveways (ACCESS), this variable identifies the total number of accesses/driveways that fall within the influence area on both sides of the intersection leg/approach containing the approach in question.

Total Accidents (TOT_ACC), total accidents reported on the intersection leg/approach

Total Multi-vehicle Accidents (TOT_MV_ACC), represents the total multiple-vehicle accidents on the intersection leg/approach.

Total Single-Vehicle Accidents (TOT_SV_ACC), represents the total single-vehicle accidents on the intersection leg/approach.

Number of Fatal Accidents (FATAL), represents the number of accidents with a fatality. A fatal accident is defined as one in which any involved person dies within 30 days due to injuries sustained in the accident.

Number of Accidents with A-Type Injuries (A-TYP), this variable provides the number of accidents with an A-type injury. An A-type accident is defined as one in which a person is incapacitated.

Number of Accidents with B-Type Injuries (B-TYP), this variable provides the number of accidents with a B-type injury. A B-type accident is defined as one in which a person sustains visible injuries.

Number of Accidents with C-Type Injuries (C-TYP), this variable provides the number of accidents with a C-type injury. A C-type accident is defined as one in which a person complains of pain.

Number of Accidents with Property Damage Only (PDO), this variable provides the number of property damage accidents. A PDO accident does not involve any injured person.

Number of Rear-End Accidents (R_END), provides the number of rear-end accidents.

Number of Angle Accidents (ANGLE_A), this variable gives the number of angle accidents.

Number of Left-turn Leaving Accidents (L_TURN_L), this variable provides the number of left-turning leaving accidents. Note that there are no reported left-turn leaving accidents in the database.

Number of Head-On Accidents (HEAD_ON), this variable provides the number of head-on accidents.

Number of Sideswipe, same direction accidents (SIDESW_S), this variable provides the number of sideswipe accidents when the vehicles involved were traveling in the same direction (there were no reported sideswipe accidents with vehicles traveling in the opposite direction).

3.3. Intersection Characteristics

Data on 51 individual variables were collected on geometric and accident-related aspects of 41 expressway intersections in Nebraska. All study intersections were located in rural or suburban areas, all approaches were at-grade and with major approaches designated as expressways. These intersections include three and four leg intersections. The study focused on stop-controlled and signalized intersections since the database did not include any interchanges. For an intersection to be included in this study, all expressway approaches to the intersection had to have at least 700 feet of roadway wide enough to accommodate four traffic lanes (two in each direction). Data available for this study spans 1988 through 2000, although not all intersections were included for this duration.

CHAPTER 4 – DATA ANALYSIS

This chapter provides information on the analysis of the Nebraska expressway intersection database. First, an exploratory investigation was conducted to obtain an idea about the relationships between the different variables in the database. After the exploratory investigation, the research team developed formal relationships by the use of advanced modeling techniques to gain insights into the safety of expressway intersections. The modeling was based on approach basis, i.e., the safety of minor intersection approaches was treated separate than the safety of major approaches.

4.1. Preliminary Data Analysis

The database provided 460 observations, equally divided between minor and major expressway intersection approaches. Table 4.1 presents the frequency of various characteristics as well as the mean accident rate per million entering vehicles. Figure 4.1 (4.1a and 4.1b) shows the distributions of single-vehicle and multi-vehicle accidents at different types of intersections on major and minor approaches, respectively. All categories of intersections from non-signalized three-legged to signalized four-legged show a preponderance of multi-vehicle accidents, most likely because of the greater number of conflict points at such locations. On three-leg signalized intersections, all reported accidents involve multiple vehicles. Both major and minor approaches on different categories of intersections show somewhat similar distribution of single and multi-vehicle accidents. Non-signalized three-leg intersections have the highest percentage of single-vehicle accidents. One possible reason for the high percentage of single-vehicle accidents at non-signalized intersections may be that unfamiliar drivers on the discontinuous leg cannot stop in time when approaching the road end at nighttime. This scenario is likely due to absence of signals and lighting that may warn nighttime drivers about an approaching T-junction.

Table 4.1. Summary statistics and mean accident rate

Summary element	Frequency	Mean accident rate (per million entering vehicles)	Standard deviation
Approach			
Major	230	0.9323	1.7840
Minor	230	0.8628	4.1429
Intersection legs			
Three-leg	48 (10.4%)	0.7278	1.5286
Four-leg	412 (89.6%)	0.9173	3.3267
Control type			
Non-signalized	386 (83.9%)	0.9042	3.4639
Signalized	74 (16.1%)	0.8630	0.7417
Area type			
Rural	316 (68.7%)	0.6449	2.2390
Sub-urban	144 (31.3%)	1.4520	4.5927
Horizontal curve placement			
None	349 (75.9%)	0.8821	3.4694
On approach	76 (16.5%)	1.1194	2.4278
Through	35 (7.6%)	0.5702	0.7954
Vertical character of the approach			
None	84 (18.3%)	0.8638	3.5341
Crest	203 (44.1%)	0.6155	1.1697
Sag	173 (37.6%)	1.2449	4.3866
Vertical curve placement			
None	78 (17.0%)	0.8888	3.6656
On approach only	243 (52.8%)	0.8037	3.6568
Through the intersection	139 (30.2%)	1.0666	1.6660
Median type on approach			
Depressed	153 (33.3%)	0.9854	2.0867
None	144 (31.3%)	0.7224	4.4143
Painted	11 (2.4%)	0.6221	1.3454
Raised	152 (33.0%)	0.9950	2.8019
Type of exclusive left-turn lane			
None	164 (35.7%)	0.9316	4.8303
Conventional	264 (57.4%)	0.8298	1.4121
Offset	32 (7.0%)	1.2821	3.2442
Type of right-turn lane treatment			
None	363 (78.9%)	0.8000	3.3399
Conventional	72 (15.7%)	1.1825	2.2162
FRT	13 (2.8%)	0.5247	0.2944
FRT ramp	12 (2.6%)	2.5433	4.5575
Right shoulder type			
Flush	409 (88.9%)	0.8443	3.2653
Curbed	51 (11.1%)	1.3244	2.4459
Pavement material			
Soft	71 (15.4%)	0.000	0.000
Hard	389 (84.6%)	1.0614	3.4403
Advanced warning signs			
None	221 (48.0%)	0.7870	1.8344
Sign	225 (48.9%)	0.9972	4.1772
Beacon	14 (3.0%)	1.0419	0.6663

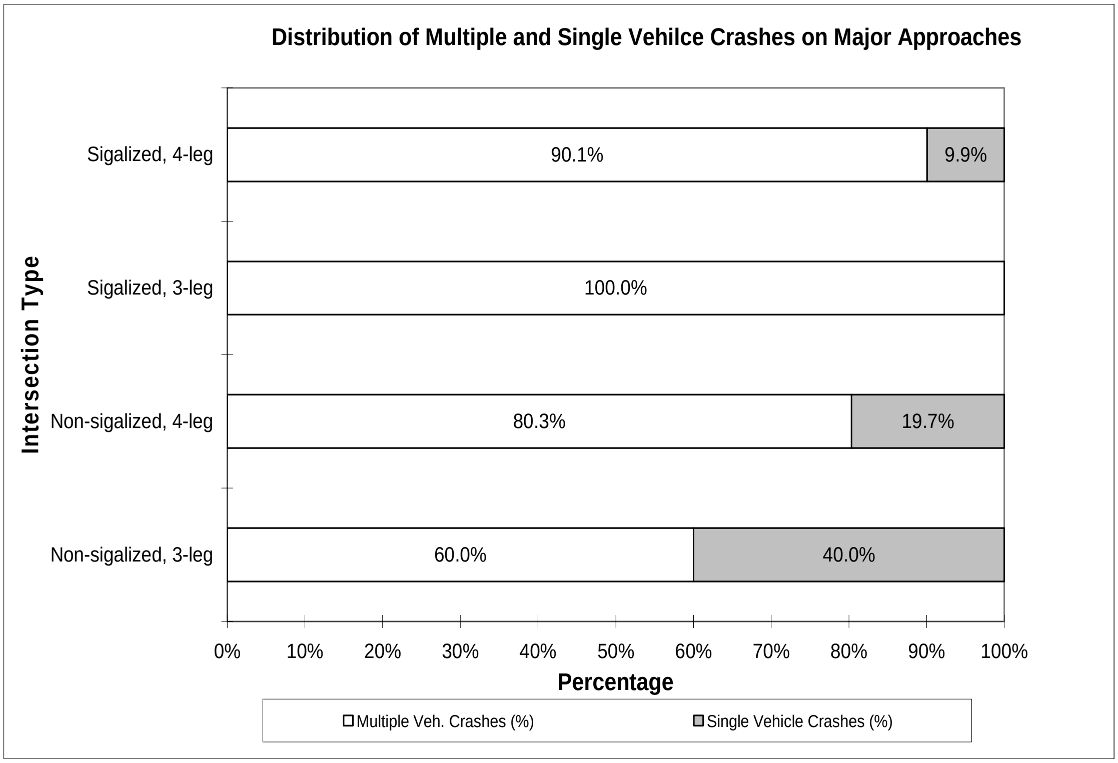

Figure 4.1a. Accidents on major approaches

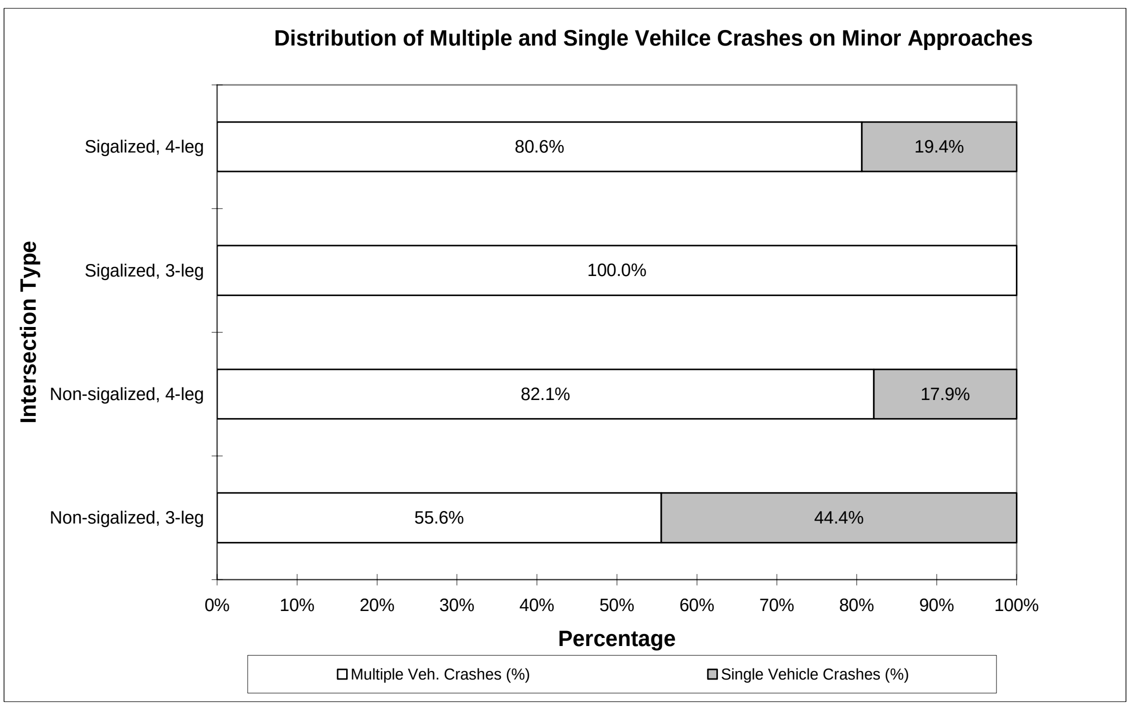

Figure 4.1b. Accidents on minor approaches

Figure 4.1. Distribution of multiple and single vehicle accidents

Figure 4.2 (4.2a and 4.2b) shows the percentage of accidents with various injury severities in different categories of intersections. It is evident that most of the accidents involve property damage only (PDO) on both major and minor approaches and very few accidents with fatalities were recorded. Figure 4.3 (4.3a and 4.3b) shows the accident rate of injury severity at different categories of intersections. Injury severity is aggregated into 3 categories: fatal, injury, and PDO, i.e., types A, B, and C (A: incapacitating injury, B: evident injury, and C: complaint of pain) accidents have been aggregated into a single category. At major approaches, signalized three-leg intersections have the highest accident rate in injury and PDO accidents and the injury and PDO rates across the different categories of intersections are somewhat similar. At minor approaches, signalized three-leg intersection show highest PDO and injury accident rate. PDO accident rate for non-signalized three-leg intersections and non-signalized four-leg intersections is similar for minor approaches. There is no injury type accident rate for signalized three-leg intersection on minor approaches.

Figure 4.4 illustrates the relationship of accident rate with different accident types across different categories of intersections. For major approaches, the accident rate of rear-end and angle accidents is similar at signalized three-leg intersections. For major approaches, rear-end accident rate is the highest at signalized four-leg intersections and it is also fairly high at non-signalized four-leg intersections. At minor approaches, signalized three-leg intersections have the highest rear-end accident rate. It appears that signalized intersections have a higher rear-end accident rate compared to non-signalized intersections.

Figure 4.5 illustrates the relationship of accident rate and accident frequency with different levels of traffic volume measured as average daily traffic (ADT). As presented in Figure 4.5a, accident rate on major approaches decreases with ADT increase from below 5,000 ADT to 10,000 ADT, but it increases when ADT is above 10,000. Accident frequency on major approaches increases as ADT increases. As shown in Figure 4.5b, accident rate on minor approaches increases when ADT increases from below 1,000 ADT to 2,000 ADT then it decreases steadily with increasing ADT. Accident frequency on minor approaches increases as ADT increases from below 1,000 to above 3,000.

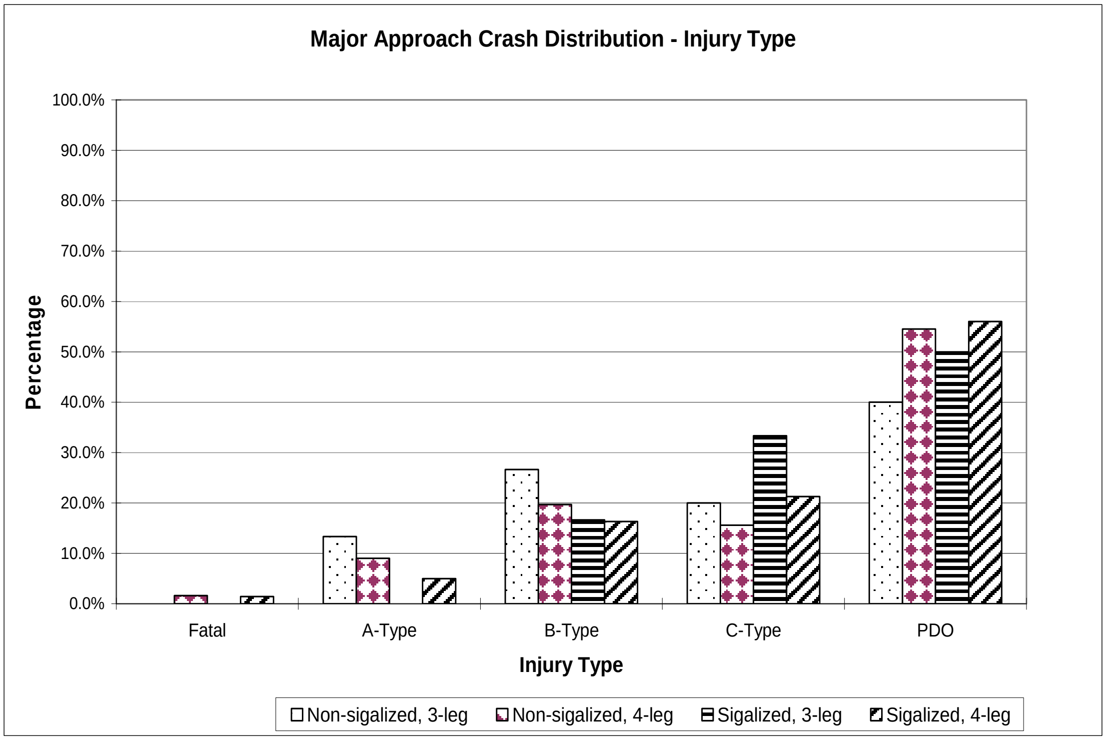

Figure 4.2a Accident distributions on major approaches

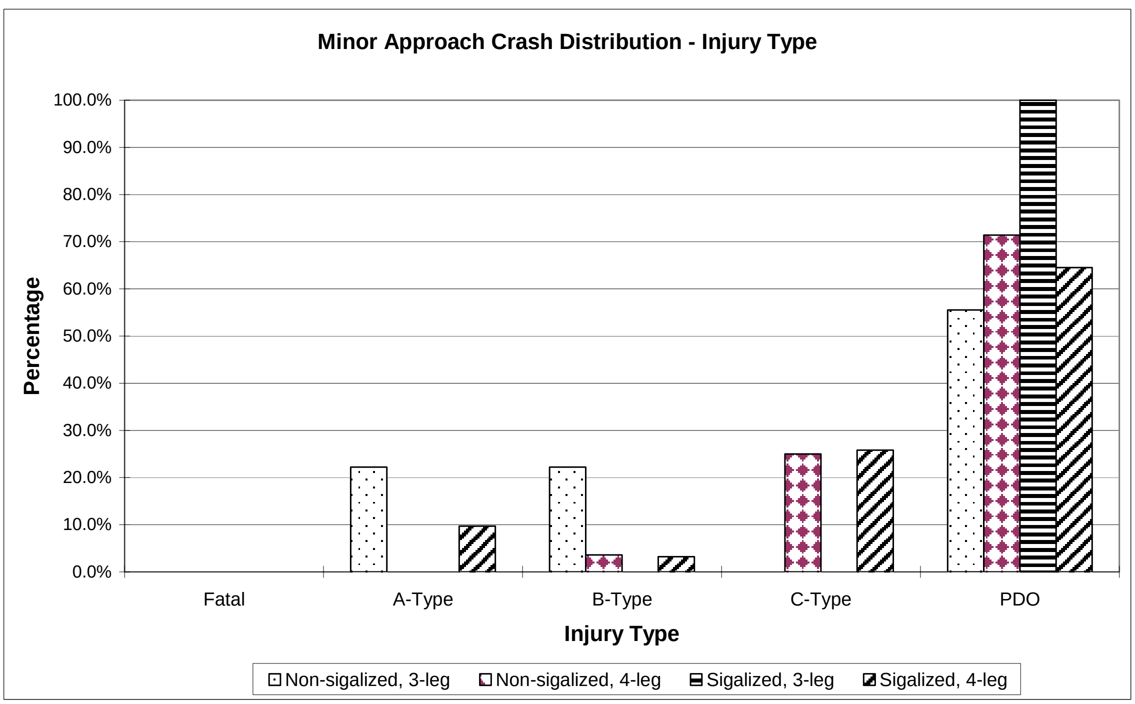

Figure 4.2b Accident distributions on minor approaches

Figure 4.2. Accident distributions and accident rate comparisons based on injury type

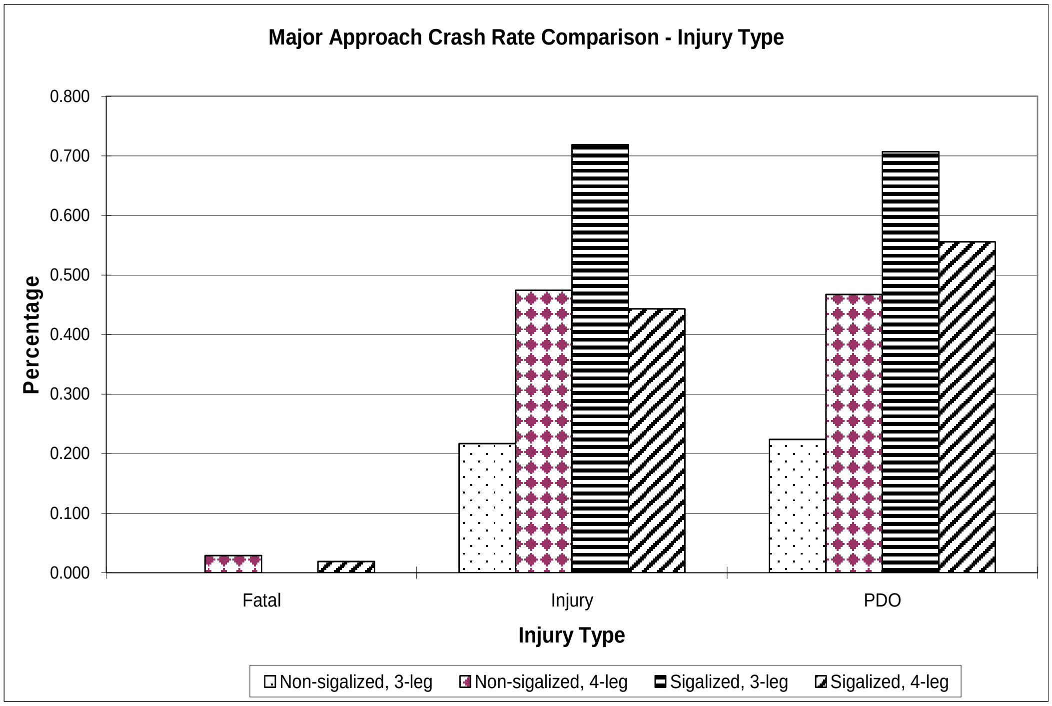

Figure 4.3a Major approaches accident rate comparison

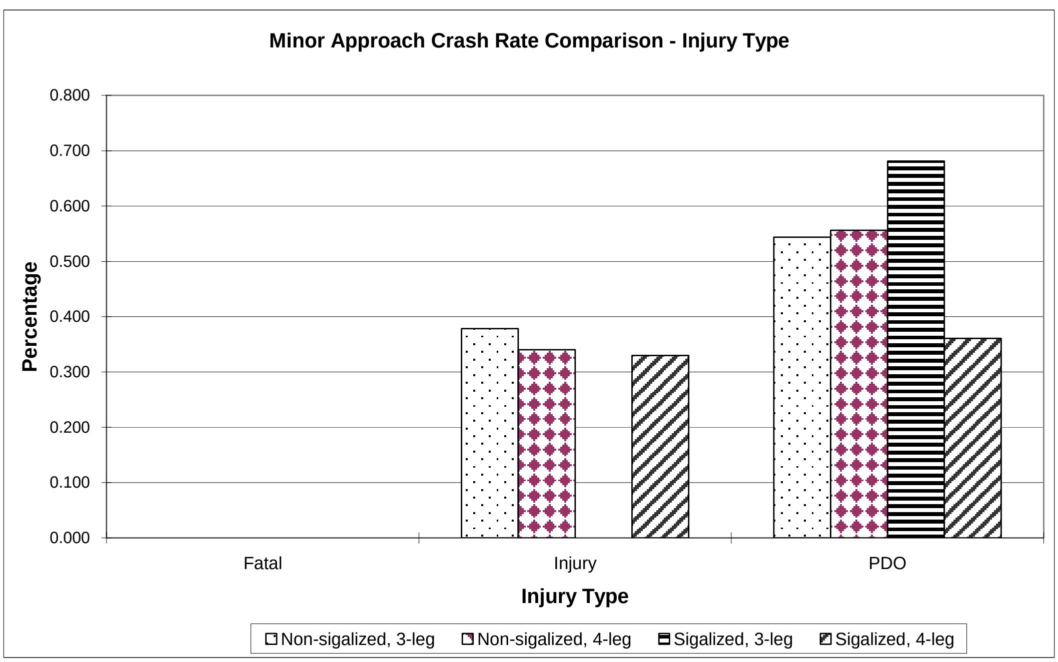

Figure 4.3b Minor approaches accident rate comparison

Figure 4.3. Accident rate comparison based on injury type

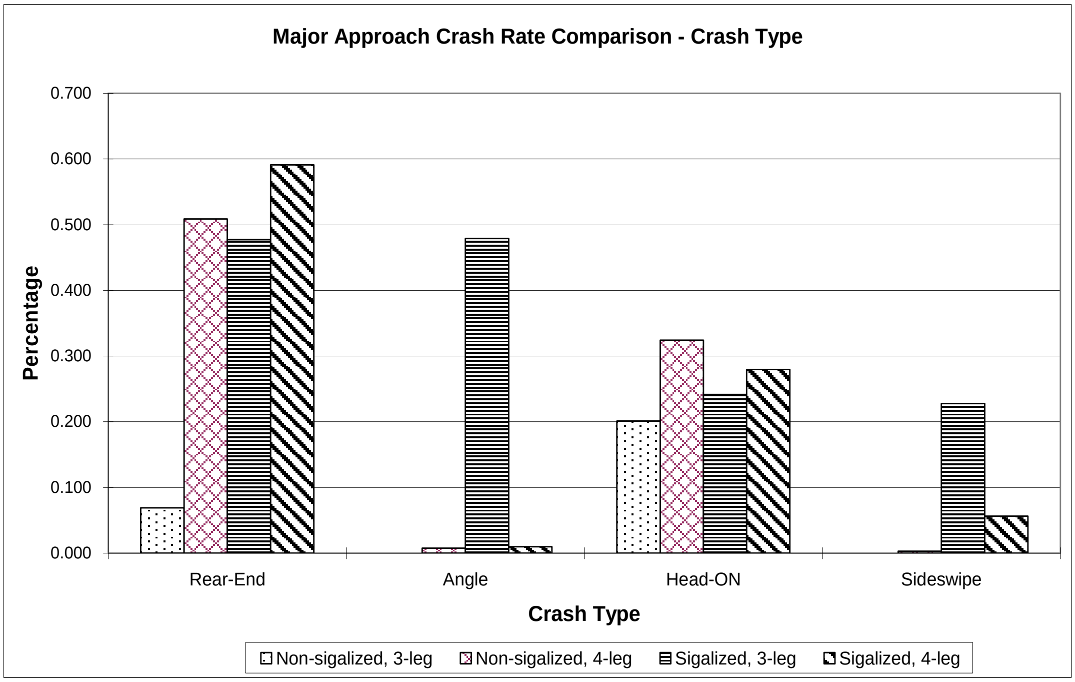

Figure 4.4a Major approaches accident rate comparison based on accident type

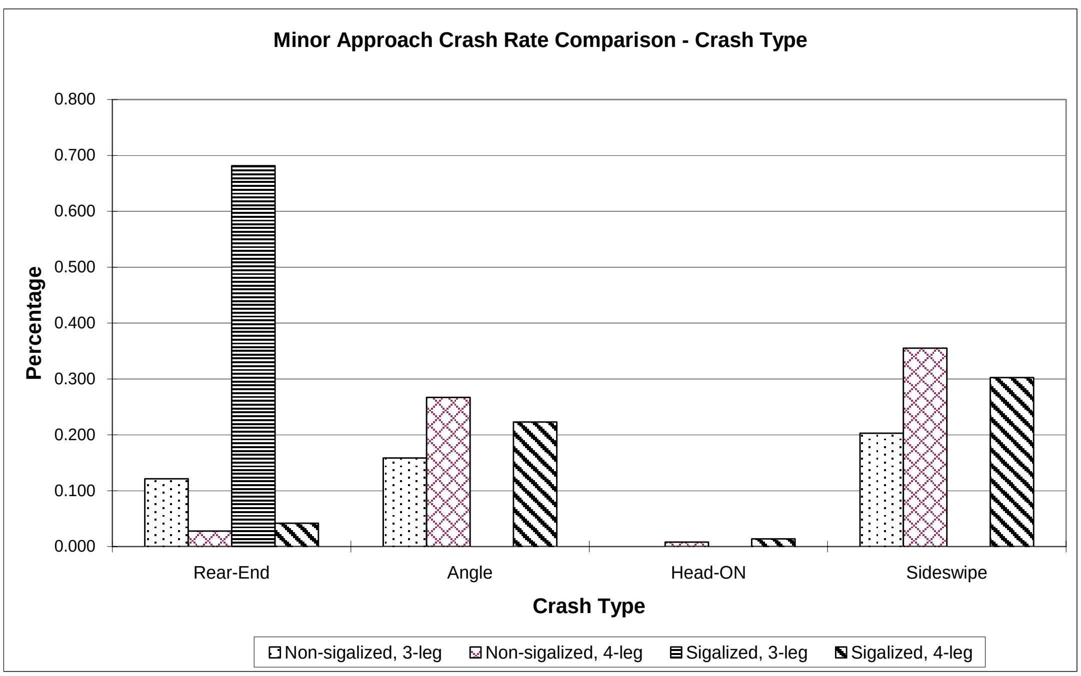

Figure 4.4b Minor approaches accident rate comparison based on accident type

Figure 4.4. Accident rate comparisons based on accident type

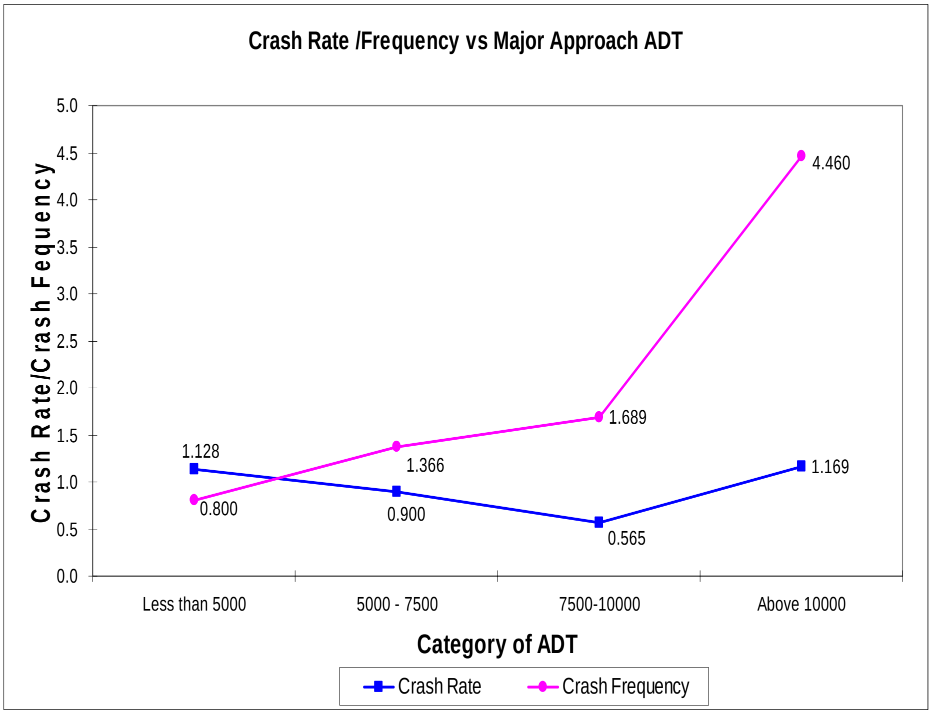

Figure 4.5a Major approach accident rate/frequency at different categories of major ADT

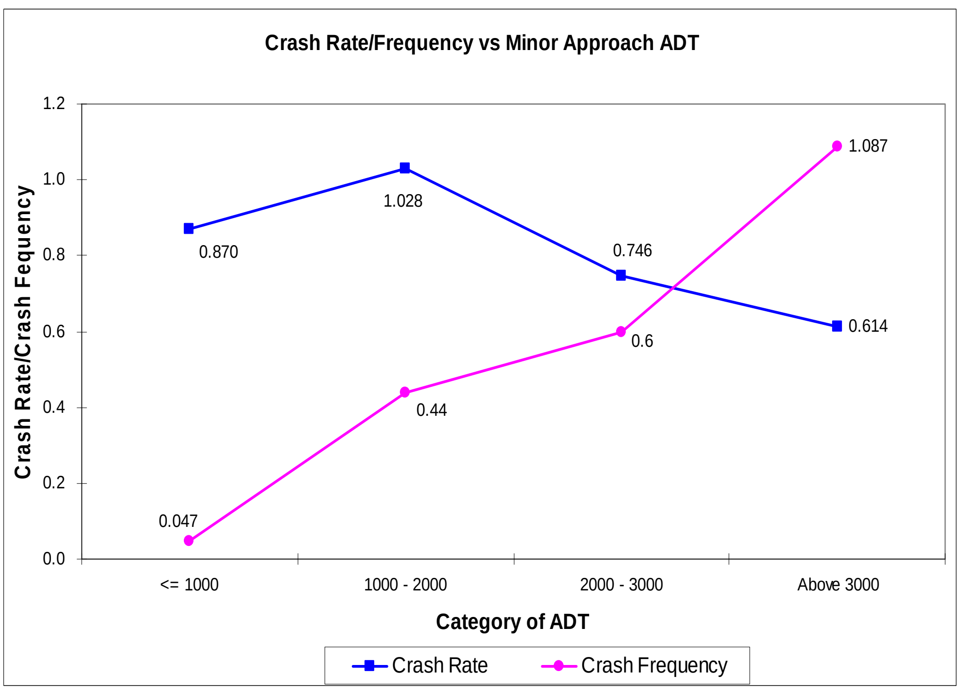

Figure 4.5b. Minor approach accident rate/frequency at different categories of minor ADT

Figure 4.5. Accident rate/frequency at different categories of ADT

Overall, the exploratory investigation indicated that single- and multiple-vehicle accidents were distributed evenly across major and minor approaches, most of the accidents involved property damage only and signalized three-leg intersections appeared to have higher levels of injury and PDO accidents. Rear-end accident rate was highest for signalized four-leg intersections. The next section describes the modeling effort in which the research team established formal relationships between accident frequency and various intersection characteristics.

4.2. Modeling of Accidents

The statistical background, general functions, as wells as the hypothesis tests for appropriate use of Poisson, Negative Binomial and Panel Count Data Models are presented here.

Poisson and Negative Binomial Model

Poisson and negative binomial models are frequently used for modeling accident counts. Accidents occurring at an intersection approach per unit time (e.g., year) generally follow the Poisson distribution. The probability of an intersection *i* having y_i accidents per year is given by:

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!} \tag{4.1}$$

where λ_i is the Poisson parameter for intersection *i*, which is equal to the expected number of accidents per year at intersection *i*, $E[y_i]$. Poisson regression models are estimated by specifying λ_i as a function of explanatory variables in the form of

$$\lambda_i = EXP(\beta X_i) \tag{4.2}$$

where X_i is a vector of explanatory variables and β is a vector of estimated parameters . The model parameters are estimated using the maximum likelihood function.

A well-known limitation of the Poisson model is that the distribution restricts the mean $E[y_i]$ and the variance $VAR[y_i]$ to be equal, which seldom holds true with real-life accident data. When $VAR[y_i]$ is greater than $E[y_i]$, the data are said to be overdispersed (underdisperssion, while possible, is probably rare). Overdispersion occurs in practice because there are many factors affecting accident means and not all of them are accounted in the model. Data are said to be underdispersed when $VAR[y_i]$ is less than $E[y_i]$. The Negative Binomial model is used (for overdispersed data) to relax the limitation of the Poisson model by adding a gamma-distributed error term with a mean equal to 1.0 and variance α^2 to the Poisson parameter,

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \tag{4.3}$$

The addition of this term makes the variance different from the mean as below,

$$VAR[y_i] = E[y_i] + \alpha E[y_i]^2 \tag{4.4}$$

where α is called the overdispersion parameter. When α is zero, the Negative Binomial model reduces to the Poisson model. The likelihood function for the Negative binomial model is,

$$L(\lambda i) = \prod_i \frac{\Gamma((1/\alpha) + y_i)}{\Gamma(1/\alpha) y_i!} \left(\frac{1/\alpha}{(1/\alpha) + \lambda_i} \right)^{1/\alpha} \left(\frac{\lambda_i}{(1/\alpha) + \lambda_i} \right)^{y_i} \tag{4.5}$$

where $\Gamma(.)$ is a gamma function.

A test for overdispersion is suggested by Cameron and Trivedi (1990) to test the null hypothesis of $VAR[y_i] = E[y_i]$ versus the alternate hypothesis of $VAR[y_i] = E[y_i] + \alpha g(E[y_i])$. If the null hypothesis is rejected for a given dataset, a Negative Binomial model is more appropriate to use in place of a Poisson model. If there is not enough evidence to reject the null hypothesis, then a Poisson model is more appropriate for the dataset.

Panel Data and Count Models

Panel data analysis is a method of studying a particular subject, periodically observed over a defined time frame. According to Washington et al. (2003), panel data combine cross-sectional and time-series characteristics and allow researchers to construct and test realistic models that cannot be identified using only cross-sectional or time-series data. A characteristic of the intersection accident database analyzed in this research is that it contains yearly accident counts for intersection approaches over considerable number of years, i.e., consists of a panel of intersections repeatedly observed for fixed time periods (with variable panel size). The individual year data for specific intersection approaches have time-series correlation, which must be accounted for in the analysis. Random- and fixed effects approaches for panel count data are proposed by Hausman et al. (1984) to account for serial correlation. The random effects model assumes that the location-specific (i.e., groupwise) effect is randomly distributed across locations and depending on how the effect deviates from the "average location" and across time, negative or positive serial correlation could occur. The fixed effects model is conditioned on the total number of observed accidents and does not allow for location-specific variation. Since the expressway intersections considered in this research were observed repeatedly, it is reasonable to expect location-specific effects. The location-specific (and time-specific) effects were incorporated in the models by use of dummy variables (see Shankar et al., 1998).

For a random-effect Negative Binomial model, the model parameter λ_{it} is given as:

$$\log \lambda_{it} = \beta' X_{it} + u_i, i = 1,...N, t = 1,...,T \tag{4.6}$$

where X_{it} is a vector of independent variables for intersection approach i in the year t, β' is a parameter vector to be estimated, u_i is a random effect for the i^{th} location group such that $E[\exp(u_i)]$ follows a gamma distribution with mean equal to 1.0 and variance $1/\theta = \alpha$. It is assumed that $1/(1+\alpha)$ is distributed as beta (a, b). The resulting joint density function is:

$$p(y_{i1}, y_{i2},..., y_{iT}) = \frac{\Gamma(a_n + b_n)\Gamma(a_n + \sum_t \lambda_{it})\Gamma(b_n + \sum_t y_{it})}{\Gamma(a_n)\Gamma(b_n)\Gamma(a_n + b_n + \sum_t \lambda_{it} + \sum_t y_{it})} \Pi_t \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it}) y_{it}!} \tag{4.7}$$

Estimation of the two distribution parameters a and b and the β' vector are done by standard maximum likelihood procedures (Shankar et al., 1998).

4.3. Modeling Results

Limdep software (Econometric Software, Inc.) was used to model intersection approach accident frequency. In the model development process, a Negative Binomial model was first tested over a Poisson model and the statistical significance of the overdispersion parameter checked to see if the Negative Binomial model was appropriate. Random effects were incorporated and the panel data structure was utilized while accounting for time-specific effects in the model by using dummy variables for each year. The Zero-Inflated Negative Binomial model was considered but not used in light of a recent research study by Lord et al. (2005), which suggests that excess zero accidents are a reflection of low exposure and/or inappropriate selection of time/space scales and may not be due to any underlying dual state process.

Table 4.2 presents a crash frequency model based on an unbalanced panel of 82 intersection approaches (41 each major and minor). The β-distribution parameters *a* and *b* appear inconsequential with a rather large value for *a*. This could be an artifact of the dataset analyzed in this research and further investigation with larger datasets is needed to determine the range of values for *a* and *b*.

Table 4.2. Random effects negative binomial model (with year-specific dummy variables)

Variable	Estimated coefficient (β)	Standard error	z-statistic	Mean of variable
Natural log transformed exposure (total traffic)	0.635	0.101	6.272	13.375
Area type (rural=1, suburban=0)	0.781	0.297	2.631	0.313
Horizontal curve on approach (yes=1, no=0)	0.803	0.305	2.633	0.165
Vertical curve through intersection (yes=1, no=0)	0.890	0.279	3.190	0.302
Offset left-turn lane (yes=1, no=0)	-0.576	0.318	-1.814	0.070
Dummy for 1993	-0.582	0.351	-1.658	0.048
Dummy for 1997	-0.479	0.256	-1.869	0.113
Constant	-8.157	1.373	-5.942	-
a	26.680	17.727	1.505	-
b	5.276	3.052	1.729	-

Dependent variable: number of yearly crashes per approach
Model statistics:
Number of observations = 460
Log-likelihood function = -479.76
Unbalanced panel = 82 groups

The modeling results in Table 4.2 suggest that natural log-transformed exposure (the product of ADT and Number of exposure days, i.e., total traffic), area type, roadway horizontal and vertical alignment, and type of left turn lane statistically significantly affect intersection approach crash frequency. Statistical significance can be judged from the z-statistic; an absolute value greater than 1.645 indicates statistical significance at 90% confidence (for a two-tailed test). As expected by the research team, the model shows that crash frequency on intersection approaches increases with increasing values of natural log-transformed values of exposure (total traffic). The positive and statistically significant estimated coefficient for area type (rural=1, suburban=0) variable indicates that the crash frequency in rural areas is higher than sub-urban areas. This could be due to differences in driver expectancy and judgment in rural and suburban areas – drivers in rural areas may be more prone to misjudge gaps in on-coming traffic

Expected number of crashes increase when a horizontal curve is placed on the intersection approach. Also, placement of a vertical curve through the intersection increases the expected number of crashes. Existence of curves either on the approaches or through an intersection complicates intersection negotiation; thus, increasing crash frequency. In the model, the negative estimated coefficient for offset left-turn lanes indicates that fewer crashes occur at such locations compared to approaches with no left-turn lanes or with conventional left-turn lanes. The advantage of an offset left turn lane compared to a conventional left-turn lane is that it provides improved sight distance to left-turning drivers, which probably explains the lower crash frequency on such approaches. While the research team included one less than the total number of year-specific dummy variables (1988-2000) to capture time effects, only two (1993 and 1997) were statistically significant, which were retained in the model specification.

A separate model was estimated for major (expressway) approaches only, using the same modeling approach. This model, reported in Table 4.3, is based on 230 observations consisting of an unbalanced panel of 41 intersection major approaches. Again, the β-distribution parameters *a* and *b* appear inconsequential with a rather large value for *a*. The model is similar to the previous (combined) model in terms of the variables as well as signs of the estimated coefficients and statistical significance of the variables. An additional statistically significant variable is the presence of a sag curve on an expressway approach, which tends to result in higher crash frequency. In terms of time effects, only the dummy variable for 1997 showed statistical significance and as such, was the only year-specific dummy variable retained in the model specification.

Table 4.3. Random effects negative binomial for major approaches (with year-specific dummy variables)

Variable	Estimated coefficient (β)	Standard error	z-statistic	Mean of variable
Exposure (total traffic in millions)	0.200	0.089	2.235	2.283
Area type (rural=1, suburban=0)	0.850	0.384	2.214	0.313
Horizontal curve on approach (yes=1, no=0)	0.906	0.496	1.825	0.196
Vertical curve through intersection (yes=1, no=0)	0.610	0.388	1.573	0.604
Sag curve on approach (yes=1, no=0)	0.538	0.305	1.765	0.374
Offset left-turn lane (yes=1, no=0)	-0.662	0.384	-1.723	0.139
Dummy for 1997	-0.480	0.248	-1.936	0.113
Constant	1.411	2.364	0.597	-
a	39.851	92.082	0.433	-
b	3.373	1.915	1.761	-

Dependent variable: number of yearly crashes on major (expressway) approaches
Model statistics:
Number of observations = 230
Log-likelihood function = -344.968
Unbalanced panel = 41 groups

Finally, a separate model was estimated for 41 intersection minor approaches only. Most of the variables that were statistically significant in the previous two models were not significant in the minor approach model, which is presented in Table 4.4. Only two variables from amongst the available factors appear to affect crash frequency on minor approaches: exposure and raised median type. In most cases, the median on minor road only exits at the mouth of the intersection to separate the traffic. However, it is still worth considering because it is within the intersection influence zone. The model shows that raised medians on minor approaches tend to increase the number of expected crashes on the minor approach.

Table 4.4. Random effects negative binomial model for minor approaches (with year-specific dummy variables)

Variable	Estimated coefficient (β)	Standard error	z-statistic	Mean of variable
Exposure (total traffic in millions)	1.267	0.318	3.980	0.448
Raised median on approach (yes=1, no=0)	0.759	0.371	2.047	0.352
Dummy for 1997	-0.731	0.763	-0.957	0.113
Constant	-1.336	1.005	-1.330	-
a	23.986	35.384	0.678	-
b	7.847	17.228	0.455	-

Dependent variable: number of yearly crashes on minor approaches
Model statistics:
Number of observations = 230
Log-likelihood function = -136.731
Unbalanced panel = 41 groups

The review of literature (Chapter 2) had indicated a plethora of factors that were found significant in intersection safety. In the process of developing the model, the research team tested some of those factors for statistical significance; these included: control type (signalized and non-signalized), speed limit, major approach roadway classification, median width and type, right turn treatment (none, conventional, ramp-like), number of intersection legs, intersection angle, percent grade, and presence of advance warning signs. However, the modeling effort did not show any statistical evidence of these factors affecting intersection approach accident frequency. Hence, they were not included in the model specification.

CHAPTER 5 – CONCLUSIONS AND FUTURE RESEARCH

5.1. Conclusions

This research used panel data from Nebraska expressway intersections to investigate various factors that affect crash frequency at these locations. The preliminary statistical analysis of the dataset revealed the following:

- For three-leg signalized intersections, all the crashes recorded were multiple vehicle crashes; however, only 50-60% of the crashes at three-leg non-signalized intersections involved multiple vehicles;
- Four-leg signalized intersections had the highest rear-end crash rate on major approaches; four-leg non-signalized intersections had the highest head-on crash rate on major approaches;
- Three-leg signalized intersections had the highest rear-end crash rate on minor approaches; four-leg non-signalized intersections had the highest sideswipe crashes on minor approaches;
- Crash frequency increases with increasing exposure for both major and minor approaches.

The research team used random effects Negative Binomial models to obtain further insights into crashes at expressway intersections. The modeling employed in this research accounted for overdispersion, group-wise and time series correlation. Important findings from the crash frequency modeling are:

- Exposure (entering traffic volume) is an important factor affecting the safety of an intersection approach. Expected number of crashes increase with increasing traffic volume.
- Roadway geometry, especially the presence of horizontal or vertical curvature at intersections, affects the safety of major approaches. Sag curves, the placement of a horizontal curve on an approach, and the placement of a vertical curve through an intersection increase the expected number of crashes on major approaches.
- Raised medians on minor approaches tend to increase the number of crashes on minor approaches.
- Expressway approaches with offset left-turn lanes have fewer crashes compared to those with conventional left turn-lanes or no left turn lanes.

- This research did not uncover evidence that variables such as speed limit, median width, lane width, shoulder type, etc. affect expressway intersection safety.

The objectives of this research were to determine the safety effects of intersection type (unsignalized, signalized, and interchange) on Nebraska expressway intersections, quantification of the safety effects of a CCS at a selected intersection via a before-and-after study, and update of the NDOR expressway intersection guidelines. A CCS could not be studied for reasons given in Chapter 1. The analysis presented in Chapter 4 did not indicate any statistically significant difference in the safety of unsignalized and signalized expressway approaches (no interchanges were available in the database). However, it did uncover factors that are detrimental to expressway intersection safety: presence of horizontal or vertical curves in and near the vicinity of intersections as well as, the beneficial effect of off-set left turn lanes on safety. It is recommended that emphasis should be added to the NDOR guidelines on avoidance of horizontal or vertical curves in and near the vicinity of intersections. Emphasis should also be added on providing off-set left turn lanes on future expressway intersections and retrofitted to existing intersections, where opportunity to do so exists.

5.2 Future Research

Intersection turning traffic volume and truck traffic play important role in intersection safety. These two factors were not investigated in this study because of unavailability of relevant data in this research. When data are available, models including these two variables may be estimated and tested. A modeling effort that takes into account interactive effects between minor and major approaches may reveal additional insights into expressway intersection safety. Furthermore, causal factors related to different crash types and levels of injury severity may be investigated to better understand the safety performance of expressway intersections.

ACKNOWLDGMENTS

The author is thankful to the members of the project technical advisory committee for their very useful input on this research project. Project technical advisory committee members included: Randy Peters (NDOR), Chuck McCann (NDOR), Tim Weander (NDOR), David Meier (HDR, Inc.), and Virendra Singh (City of Lincoln). The research team received extensive assistance from NDOR staff, including Dave Peterson, Rick Erstmeyer, Ron Walker, Sam Prieb, Michael Niedermeyer, Ron Disney, Bob Carnazzo, Kevin Donahoo, Roger Grant, Ernie Voss, Harvey Bouens, Linda Langdale, Winnie Roseberry, Bill Wehling, Jim Ferguson, Amy Starr, Jodi Gibson, Lieska Halsey, and the archival staff, for which the author is grateful. The author also thanks Nebraska county highway commissioners Edwin Land (Banner county), Rick Meter (Scotts Bluff county), Dawn Miller (Adams county), and Daniel Hostler (Hall county) and numerous others who helped with various stages of the research.

The author is indebted to research team members Dr. Geza Pesti and the late Dr. Patrick McCoy, who helped with the early part of this research. Others on the team who helped with various project tasks were Joshua Hochstein, Linna Zhang and Suid Ching Tee. Financial support for this research was provided by NDOR.

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Appendix A

A tabulation of reported accidents at the study intersections

Int. ID	NDOR Int. ID	Total Legs	Signal	Approach	Total acc.	Multiple vehicle acc.	Single vehicle acc.	Fatal acc.	A-Type acc.	B-Type acc.	C-Type acc.	PDO acc.	Rear-end acc.	Angle acc.	Headon acc.	Sideswipe acc.
1	7902000	3	Yes	Major	12	12	0	0	0	2	4	6	4	4	2	2
				Minor	3	3	0	0	0	0	0	3	3	0	0	0
2	7901000	4	Yes	Major	10	10	0	1	0	2	3	4	5	1	0	4
				Minor	6	4	2	0	0	0	0	6	3	0	1	0
3	400100	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
4	400200	3	No	Major	3	0	3	0	0	0	0	3	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
5	400300	4	No	Major	2	2	0	0	2	0	0	0	2	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
6	Missing1	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
7	100600	4	No	Major	6	6	0	0	0	2	1	3	5	1	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
8	4000200	4	No	Major	24	22	2	1	2	9	1	11	15	2	5	0
				Minor	10	8	2	0	1	0	1	8	3	2	0	2
9	4001300	4	No	Major	46	34	12	0	3	13	7	23	22	0	10	1
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
10	4001000	4	Yes	Major	96	88	8	1	5	14	20	56	71	0	13	1
				Minor	15	15	0	0	1	0	4	11	0	3	0	13
11	8501900	4	No	Major	5	5	0	0	0	2	1	2	3	0	2	0
				Minor	1	0	1	0	0	0	0	1	0	0	0	0
12	850000022	4	No	Major	1	0	1	0	0	0	0	1	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
13	8502100	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
14	8501800	4	No	Major	10	10	0	2	2	2	2	2	7	0	3	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
15	8502000	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
16	8500600	4	No	Major	2	2	0	0	0	0	1	1	2	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
17	8500900	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	1	0	1	0	0	1	0	0	0	0	0	0
18	8501000	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0

Int. ID	NDOR Int. ID	Total Legs	Signal	Approach	Total acc.	Multiple vehicle acc.	Single vehicle acc.	Fatal acc.	A-Type acc.	B-Type acc.	C-Type acc.	PDO acc.	Rear-end acc.	Angle acc.	Headon acc.	Sideswipe acc.
19	3001200	4	No	Major	42	39	3	0	1	7	8	27	19	0	19	0
				Minor	5	5	0	0	0	0	1	4	0	3	0	1
20	930000012	4	No	Major	19	15	4	1	2	3	3	10	4	0	11	0
				Minor	2	2	0	0	0	0	1	1	0	1	0	1
21	9300800	4	No	Major	36	35	1	0	4	3	6	23	21	0	14	0
				Minor	4	4	0	0	0	0	2	2	0	2	1	1
22	1201200	4	No	Major	11	9	2	0	3	2	2	4	4	0	5	0
				Minor	3	3	0	0	0	0	2	1	0	0	0	3
23	7100900	4	Yes	Major	22	19	3	0	1	4	2	15	5	0	14	0
				Minor	9	5	4	0	1	1	4	3	0	5	0	0
24	7101500	3	No	Major	2	2	0	0	0	1	1	0	1	0	1	0
				Minor	1	1	0	0	0	1	0	0	0	1	0	0
25	7100400	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
26	710000036	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
27	7100300	4	No	Major	1	1	0	0	0	0	1	0	1	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
28	7101300	4	No	Major	2	2	0	0	0	0	0	2	1	0	1	0
				Minor	1	1	0	0	0	0	0	1	0	1	0	0
29	590000040	4	No	Major	1	1	0	0	0	0	0	1	0	0	1	0
				Minor	1	1	0	0	0	0	0	1	0	1	0	0
30	5901400	4	No	Major	3	2	1	0	0	2	0	1	2	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
31	3401000	4	No	Major	6	3	3	0	1	1	1	3	1	0	2	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
32	340000048	4	No	Major	9	0	9	0	0	0	1	8	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
33	3401600	3	No	Major	7	4	3	0	1	2	1	3	1	0	3	0
				Minor	1	1	0	0	0	1	0	0	0	1	0	0
34	3401700	3	No	Major	3	3	0	0	1	1	1	0	1	0	2	0
				Minor	7	3	4	0	2	0	0	5	1	0	0	2
35	340000082	4	No	Major	2	1	1	0	1	0	0	1	0	0	1	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
36	5500900	4	No	Major	1	1	0	0	0	0	0	1	0	0	1	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0

Int. ID	NDOR Int. ID	Total Legs	Signal	Approach	Total acc.	Multiple vehicle acc.	Single vehicle acc.	Fatal acc.	A-Type acc.	B-Type acc.	C-Type acc.	PDO acc.	Rear-end acc.	Angle acc.	Headon acc.	Sideswipe acc.
37	Missing2	4	No	Major	0	0	0	0	0	0	0	0	0	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
38	550000045	4	No	Major	2	1	1	0	0	0	0	2	1	0	0	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
39	5500800	4	No	Major	2	1	1	0	1	0	1	0	0	0	1	0
				Minor	1	0	1	0	0	0	0	1	0	0	0	0
40	550000095	4	Yes	Major	13	10	3	0	1	3	5	4	5	0	5	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0
41	550000047	4	No	Major	11	4	7	0	0	2	2	7	3	0	1	0
				Minor	0	0	0	0	0	0	0	0	0	0	0	0

Note:
Accident (acc.) totals represent reported accidents over the observation period for each intersection, which varies among intersections, i.e., not all intersections were observed for the same duration.