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Safety and Operational Analysis of Lane Widths in Mid-Block Segments and Intersection Approaches in the Urban Environment in Nebraska

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16. Abstract
This research examined the safety and operational effects of roadway lane width on mid-block segments between signalized intersections as well as on signalized intersection approaches in the urban environments of Lincoln and Omaha, Nebraska. In the safety analysis, the Poisson and negative binomial regressions with fixed or random parameters were estimated to evaluate the effects of lane width on annual crash frequencies at mid-block segments and intersection approaches. In the operational analysis, linear regressions were used to examine lane width effects on the vehicles' speed at mid-block segments. The Kolmogorov-Smirnov test was applied to explore the effects of lane width on the vehicles' headways in the queue on the intersection approaches. At the mid-block segments in comparison with 11 ft and 12 ft wide lanes, 10 ft lanes on the higher speed limit (40 mph and 45 mph) roadways had ambiguous impacts on safety, with improvements in some locations and reduction in the others. Lanes 11 ft or 12 ft wide were found to be safer than 10 ft lanes on lower speed limit roadways (roadways located outside of the central business district with a 35 mph speed limit). On intersection approaches, the combination of narrowed left-turn lanes and narrowed through lanes was a safer option based on the evidence uncovered in this research.

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Safety and Operational Analysis of Lane Widths in Mid-Block Segments and Intersection Approaches in the Urban Environment in Nebraska

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AASHTO American Association of State Highway and Transportation Officials (AASHTO)
Average Daily Traffic (ADT)
Average Daily Traffic per Lane (ADTPL)
Central Business District (CBD)
Federal Highway Administration (FHWA)
Kolmogorov-Smirnov (K-S)
Negative binomial (NB)
Property Damage Only (PDO)

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Disclaimer

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Abstract

This research examined the safety and operational effects of lane width on mid-block segments between signalized intersections as well as on signalized intersection approaches in the urban environments of Lincoln and Omaha, Nebraska. In the safety analysis, the Poisson and negative binomial regressions with both fixed and random parameters were used to evaluate the effects of lane width on annual crash frequencies at mid-block segments and intersection approaches. In the operational analysis, linear regressions and box plots were used to examine the lane width effects on vehicles' travel speed at mid-block segments. The relationship between lane width and vehicles' lane violation were illustrated by bar graphs. In addition, The Kolmogorov-Smirnov tests were applied to explore the effects of lane width on vehicles' headways in the queue on the intersection approaches. At the mid-block segments, some evidence was found that 10 ft wide lanes are safer or perform near same on the higher speed limit (40 mph and 45 mph) roadways in comparison with lanes 11 ft and 12 ft wide. In contrast, 11 ft and 12 ft wide lanes were recommended for use on 30 to 35 mph speed limit roadways near the central business district (CBD). The 10 ft lanes showed some improvement in safety in the CBD at 25 mph but the number of base sections of 12 ft lanes were limited and more research is needed to further explore these effects. Based on the experiment analysis, it can be hypothesized that 10 ft lanes are not particularly well suited for 30-35 mph roadways close to CBD. This might be due to the fact that the drivers don't decrease their speeds as they are on relatively lower speed limit roads but the conflicts due to narrower lane widths increase. In case of higher speed roads, usually in suburbs, narrower lane widths may leads to reduction in operating speeds and more careful driving. So, the narrower lane widths on speeds of 40-45 mph shows ambiguous

impacts on the safety. On intersection approaches, the combination of narrowed left-turn lanes and narrowed through lanes was a safer option based on the evidence uncovered in this research.

Chapter 1 Introduction

1.1 Background

Complete Streets is a transportation policy that requires streets to be safe, convenient, and comfortable for all street users, regardless of transportation mode. With the recent trend in designing according to Complete Streets, the demand for using reduced lane widths instead of the 12 ft standard lanes has increased significantly. Standard lane widths often accommodate parking, bike lanes, sidewalks, drainage, and utilities on the existing right of way. The use of reduced lane widths is more evident in urban areas where the right of way constraints often limit the desired roadway design. State and local transportation agencies need some guidelines to quantify the trade-offs between the safety and efficiency of operations and the right of way savings. The AASHTO's *A Policy on the Geometric Design of Highways and Streets* (6th Edition), commonly known as the *Green Book*, recommends lanes 10–12 ft wide for urban and suburban arterials (1). It states that 10 ft lanes should generally be used on roadways that have little or no truck traffic, and recommends 11 ft lanes for urban Arterials and 12 ft lanes for higher speed, free-flowing principal arterials. Additionally, lanes 10–12 ft wide are recommended for urban collectors.

A five-state (Wyoming, Missouri, California, Kansas, and Iowa) survey was conducted in this research to investigate policies on roadway lane widths in urban settings. This survey found that California and Iowa had written policies on using narrowed lanes, while Wyoming, Missouri, and Kansas did not have any written policies at the time of survey (2013). All five states indicated that right of way constraints were the key reason for the implementation of narrowed lane widths in their roadway design. Kansans suggested 10–12 ft wide lanes as the acceptable range of lane widths in urban areas while all other states used 11–12 ft wide lanes.

1.2 Problem Statement

A comprehensive literature review on the effect of lane width identified the topics that have not been considered in previous studies and the limitations of existing studies. In past studies, traditional count models (Poisson or negative binomial regression models) were used to evaluate the impact of lane widths on crash frequency at mid-block segments and on intersection approaches. However, unobserved heterogeneity between seemingly homogenous conditions can lead to inconsistent estimates of parameters for traditional count models. For example, two sites may seem to be homogeneous due to their setting of independent parameters, but a specific street section could be close to a store that attracts certain types of drivers. The store would be the unobserved heterogeneity that might lead to inconsistent estimates. This research enhances the existing knowledge pool by applying random parameters that can account for the unobserved heterogeneity to evaluate the effects of lane width on annual crash frequency.

Most of the previous studies analyzed the impact of lane width on crash frequency, crash types, or crash severity based on groups of data categorized by the number of lanes at mid-block segments, the median indicator at mid-block segments, and the number of legs on intersection approaches. In this research, road speed limits and area type (within central business district or not) were used to categorize the initial data for analyzing the safety impact of lane widths. Although previous studies have analyzed the impacts of lane width at mid-block segments and on intersection approaches, these studies focus on either mid-block segments or intersection approaches. This research provides a comprehensive analysis of lane width for both mid-block segments and intersection approaches using data from two Nebraska cities, Lincoln and Omaha.

There is no previous research focusing on lane width impact at mid-block segments and on intersection approaches in Nebraska, and there is no written policy on using narrowed lanes from the Nebraska Department of Roads (NDOR). This study concentrates on performing a safety and operational analysis of lane widths in the two biggest cities in Nebraska, Lincoln and Omaha, and provides a comprehensive lane width usage guide for Nebraska's urban environments and NDOR.

1.3 Research Objectives

This research aimed to examine the effects of lane width at mid-block segments between signalized intersections and on signalized intersection approaches in an urban environment. The safety analysis evaluated the impact of lane width on annual crash frequencies at mid-block segments and on intersection approaches. The operational analysis evaluated the impact of lane width on vehicles' travel speed, lane violation at mid-block segments, and queue discharge headway on intersection approaches.

Chapter 2 Literature Review

2.1 Advantages and Disadvantages of Implementing Narrowed Lane Widths

Based on a review of pertinent literature, table 2.1 summarizes the advantages and disadvantages of using narrow lane widths for different factors.

Table 2.1 Summary of advantages and disadvantages of using narrowed lane widths

Potential factors	Advantages	Disadvantages
Pedestrians	Shorter crossing distance (2, 3)	N/A
Bicyclists	Widening existing bicycle lanes or installing new bicycle lanes increases bicyclist safety (2)	Increase in crash frequency in specific design situation (3)
Heavy vehicles	N/A	1. Higher likelihood of having bus sideswipe and mirror crashes (6) Increased lane width are associated with increased fatalities (4) 2. Reduction in free flow speeds of heavy vehicles is greater than the reduction for passenger cars (5). This will increase the speed variance.
Passenger vehicles	Decrease in crash frequency (7)	Increase in crash frequency (3)
On street parking	1. Widening existing parking lanes reduces the risk of an open car door hitting another vehicle or a cyclist (2) 2. Narrowed lanes result in greater traffic calming, as compared to wider lanes with the same parking density (8)	N/A
Speed reduction	1. Decrease in average traffic speed (9, 10) 2. The narrower the lane, the greater the speed reduction (3)	N/A
Traffic capacity	1. Capacity per unit lane is not decreased (11) 2. Total capacity for all lanes is increased by increasing the number of lanes (12)	Lanes narrower than 12 ft reduce the capacity of a roadway (13)
Pavement damage	N/A	The moving wheels are restricted to a narrower space; it may reduce pavement fatigue life (14)

Narrowing lane width has shown to have both positive and negative impacts on bicyclists, passenger vehicles, and the number of lanes in the road. The narrowing lane width may decrease or increase the crash frequency of bicyclists, heavy vehicles, or passenger vehicles, but, in terms of pedestrians, street parking, and speed reduction, using narrowed lanes is beneficial. There are no consistent findings in regard to the effect of narrowed lane width on crash frequency.

2.2 Effects of Narrowed Lane Width

At mid-block segments and on intersection approaches, researchers have evaluated the impact of narrowed lane width on the safety of urban roads with mixed results. Zegeer et al. (16) reported that lane widening was shown to reduce related accidents by 12% for 1 ft increase in lane width (e.g., 10–11 ft lanes), 23% for 2 ft increase in lane width, 32% for 3 ft increase in lane width, and 40% for 4 ft increase in lane width. Hauer et al. (17) presented six crash frequency models for urban four-lane undivided mid-block segments that classify the crashes based on crash types (property damage–only, injury, and total) and locations (off the road and on the road). The results indicated that lane width had no significant impact on off-the-road accident frequencies, but there was some association between lane width and on-the-road property damage–only crashes. Strathman et al. (18) found that average lane width was positively related to crash frequency on urban freeway segments and negatively related to crash frequency on rural non-freeway segments. This research was conducted by separating functional classifications into freeway and non-freeway and separating location into urban and rural based on the Oregon state highway system. Harwood (13) suggested that the preferred lane width for urban arterial mid-block segments under most circumstances was 11 ft or 12 ft. However, his research found that narrowed lane widths may bring traffic operational and/or safety benefits in many situations. It was found that lane widths narrower than 11 ft can be used effectively in urban arterial street improvement projects where the additional space provided can be used to relieve traffic congestion or address specific accident patterns. Potts et al. (3) analyzed multiple roadway segments in Minnesota and Michigan but did not find a general indication that the use of lane widths narrower than 12 ft on urban and suburban arterials increased crash frequency. In another paper, Potts *et al*. reported a possible indication that accident frequencies may be higher on four-lane undivided arterials with 9–10 ft lanes than on four-lane undivided arterials with 11–12 ft lanes in Minnesota (19). Zegeer *et al*. analyzed bus and motor vehicle accident characteristics and provided recommendations for reducing bus-related highway crashes, such as keeping wide lane widths to minimize the chances of bus sideswipe collisions and providing a lane width of at least 11 ft, but preferably 12 ft whenever possible (20). They found that the narrower the lanes, the larger the potential of sideswipe accidents. Sando and Moses also indicated that narrowed lane widths, especially lane widths of 10 ft or narrower, were overrepresented in the occurrences of bus sideswipe crashes (21). They recommended that 12 ft wide lanes be provided if possible for roadways located on transit routes. More detailed information is included in table 2.2.

Table 2.2 Safety effects of lane width at mid-block segments

Research	**Area type**	**Lane width range**	**Impacts (lane width vs. crash frequency)**
Zegeer et al. (16)	Highway systems in CA, IL, ME, MI, MN, NC, and WA	8–12 ft	Lane widening was shown to reduce related accidents by 12% when 1 ft wider, 23% when 2 ft wider, 32% when 3 ft wider, and 40% when 4 ft wider.
Hauer et al. (17)	Urban in WA	9–12 ft	No significant impact of lane width on off-the-road accident frequency was found.
Strathman et al. (18)	Highway system in OR	9–12 ft	Average lane width was estimated to be positively related to crash frequency for urban freeway segments and negatively related for rural non-freeway segments.

Research	Area type	Lane width range	Impacts (lane width vs. crash frequency)
Harwood (18)	Urban	9–14 ft	The preferred lane width for urban arterial streets under most circumstances is 11 or 12 ft.
Potts et al. (3)	Urban and suburban in MN and MI	9–12 ft	Lanes narrower than 12 ft have no statistically significant impact on arterial crash frequencies.
Potts et al. (19)	Urban four-lane undivided arterials in MN	9–12 ft	Accident frequencies may be higher on four-lane undivided arterials with 9–10 ft lanes than 11–12 ft lanes.
Zegeer et al. (20)	Urban in IL, ME, MI, MN, and UT	N/A	Keep wide lane widths, as they minimize chances of bus sideswipe collisions. Recommend providing lane widths of 12 ft when possible, or at least 11 ft.
Sando & Moses (21)	Urban and suburban in FL	9–12 ft	Lanes 10 ft and narrower are overrepresented in the occurrences of bus sideswipe crashes.

Apart from the safety of mid-block segment lane widths, some researchers analyzed the safety impact of lane width on intersection approaches. Bauer and Harwood (15) indicated that shorter average lane width causes a higher number of total crashes and a higher number of fatal and injury crashes at four-legged, stop-controlled urban intersection approaches. Potts *et al.* (3) also analyzed the relationship of lane width and crash frequency on arterial intersection approaches and reported that intersection approaches with lane widths of 10 ft or less had higher crash frequencies than 11 ft or 12 ft approaches at four-legged, stop-controlled intersections on Minnesota arterials. The same analysis based on Charlotte, North Carolina, data showed that a higher crash frequency was associated with approaches having lanes that are 12 ft wide compared with lanes 9 ft and 10 ft wide on four-legged, stop-controlled intersections. More detailed information is included in table 2.3.

Table 2.3 Safety effects of lane width on intersection approaches

Researcher	Area type	Lane width range	Impacts (lane width vs. crash frequency)
Bauer & Harwood (15)	Four-leg, stop-controlled urban intersection approaches in CA	8–15 ft	Shorter average lane widths increase total crashes, which include fatal and injury crashes.
Potts et al. (3)	Four-leg, stop-controlled intersection approaches in MN	9–12 ft	Lanes 10 ft wide or less had higher crash frequency compared to 11 or 12 ft wide lanes.
	Four-leg, stop-controlled intersection approaches in Charlotte, NC	9–12 ft	Lanes 12 ft wide had higher crash frequencies than 9 or 10 ft lanes.

In order to make the results from table 2.2 and table 2.3 more intuitive, table 2.4 summarizes the effects of individual lane widths (9 ft, 10 ft, and 11 ft) in comparison to 12 ft lanes in terms of crash frequency. The cells in green indicate that the selected lane widths significantly decrease the crash frequency and are therefore safer than 12 ft wide lanes. The cells in red show that the selected lane widths significantly increase the crash frequency and are therefore more dangerous than 12 ft wide lanes. The blank cells indicate that there is no significant effect on crash frequency when comparing that lane width to a 12 ft lane.

Table 2.4 Visual summary of effects of lane width

Sites	Researcher	Area Type	Lane widths (ft)			
			9	10	11	12
Mid-block Segments	Zegeer et al. (16)	Highway systems in CA, IL, ME, MI, MN, NC, and WA	[red]	[red]	[red]	
	Hauer et al. (17)	Urban in WA				
	Strathman et al. (18)	Urban freeway segments, highway system in OR	[green]	[green]		
		Rural non-freeway segments, highway system in OR	[red]	[red]		
	Harwood (13)	Urban	[red]	[red]		
	Potts et al. (3)	Urban and suburban in MN and MI				
	Potts et al. (19)	Urban four-lane undivided arterials in MN	[red]	[red]		
	Sando & Moses (21)	Urban and suburban in FL	[red]	[red]		
Intersection Approaches	Bauer & Harwood (15)	Four-leg, stop-controlled urban intersection approaches in CA	[red]	[red]	[red]	
	Potts et al. (3)	Four-leg, stop-controlled intersection approaches in MN	[red]	[red]		
	Potts et al. (3)	Four-leg, stop-controlled intersection approaches in Charlotte, NC	[green]	[green]		

Key:

[red]	Researchers reported that selected lane widths significantly increase the crash frequency compared to 12 ft wide lanes.
[green]	Researchers reported that selected lane widths significantly decrease the crash frequency compared to 12 ft wide lanes.
	No significant effect on crash frequency when comparing that lane width to a 12 ft lane was reported by the researchers.

2.3 Federal and State Requirements and Recommendations

As mentioned earlier, The AASHTO *A Policy on the Geometric Design of Highways and Streets* (6th Edition) (1), recommends the following range of lane widths: 10–12 ft for urban and suburban arterials, and 10–12 ft for urban collectors. The FHWA publication, "Mitigation Strategies for Design Exceptions" (22), suggests that narrowing lane widths may be used as a method to reduce speed while also shortening crossing distances for pedestrians and incorporating other cross-sectional elements, such as medians for access control, bike lanes, on-street parking, transit stops, low-speed environments, etc. On the other hand, conventional wisdom suggests that reducing lane width can lead to safety concerns, because narrowed lanes might force drivers to go off-track into adjacent lanes or the shoulder, resulting in increased risks for other motorized and non-motorized traffic. The risk may be even greater in special conditions like a heavy percentage of trucks or horizontal curves.

The Nebraska Administrative Code (Title 428) uses an 11 ft lane width as the minimum design standard for new and reconstructed major arterials on municipal state highways. This code also requires 11 ft lanes for local and collector roads on municipal streets. Local and collector roads are made as a 10 ft width concession for rural roads.

2.4 Survey of Highway Agencies

A survey was conducted for this study regarding the lane width policy for urban settings in five U.S. states (Wyoming, Missouri, California, Kansas, and Iowa). This survey found that California and Iowa had written policies on using narrowed lanes, while Wyoming, Missouri, and Kansas did not have written policies at the survey time in 2013. All surveyed states indicated that right of way constraints were the key reason for the implementation of narrowed lane widths in their roadway design. All states except Kansas suggested that the acceptable range of lane widths in urban areas was 11–12 ft, while Kansas used 10–12 ft wide lanes. The survey questions and response are summarized in table 2.5.

Table 2.5 Survey results pertaining to the use of lane width in urban settings

Q1. Written policy of adopting narrowed lane widths in urban settings	
Wyoming	No policy
Missouri	No policy
California	• Division of Planning's Deputy Directive 64-R1 • Highway design manual
Iowa	Design manual, Iowa DOT
Kansas	No policy
Q2. General principles that are used to decide feasibility of using a narrower lane width	
Wyoming	When it is out of right of way width to handle the cross section
Missouri	Usually done as a result of right of way limitations
California	When adding or widening bike lanes or shoulders
Iowa	N/A
Kansas	Right of way constraints
Q3. Current range of lane widths	
Wyoming	11–12 ft
Missouri	11–12 ft
California	11–12 ft
Iowa	11–12 ft
Kansas	10–12 ft
Q4. Any situations in which unequal lane widths would be implemented	
Wyoming	A right-turn auxiliary lane if cross-section width is unavailable
Missouri	No implementation
California	• On a case by case basis • Sight/location characteristics, geometric constraints, operational needs, accident analysis, corridor consistency, driver expectation, design vehicle accommodation, addition of left-turn or right-turn channelization, addition of other roadway features within existing or limited right of way
Iowa	N/A
Kansas	N/A
Q5. Narrowed lane width example	
Wyoming	• Narrowed 12 ft down to 11 ft • Isolated left-turn lanes were narrowed to 10 ft on intersection approaches
Missouri	Converted some freeways from 12 ft to 11 ft in order to provide some additional capacity in the St. Louis area
California	N/A
Iowa	Four-lane to five-lane conversion with narrower lanes
Kansas	Turning lanes are 12 ft, with through lanes being 11 ft

Chapter 3 Data Collection and Reduction

3.1 Safety Data: Geometry Data and Crash Data

For the current study, geometry data and crash data at mid-block segments and on intersection approaches were collected in four cities in Nebraska: Lincoln, Omaha, Grand Island, and South Sioux. A five-step process was used for collection and reduction of the geometry and crash data: 1) data collection site selection, 2) geographical data collection based on field measurements (for validations), 3) geographical data collection based on Google Earth, 4) reduction of ten years of crash data, and 5) combining geographical and crash data.

3.1.1 Data Collection Site Selection

All the roads were identified as urban collectors, urban minor arterials, urban principal arterials-other non-connecting link, and urban principal arterials-other connecting link, based on the National Functional Classification on the map of Lincoln offered by NDOR. A list of data collection sites was prepared based on the findings. Figure 3.1 shows the map of Lincoln used, and figure 3.2 is the sample of the road lists that were prepared.

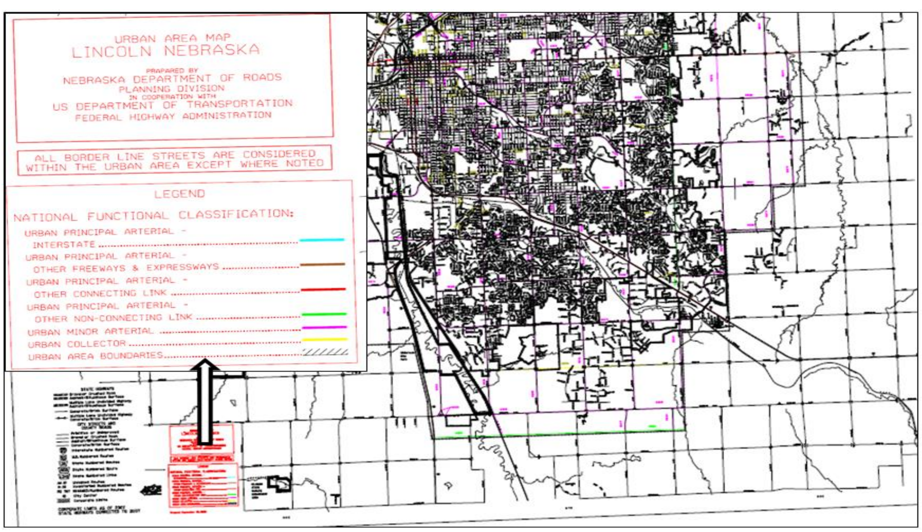


Figure 3.1 Map of Lincoln

Road Lists

	A	B	C	D
1	**Road Functional Classification**	**Main St**	**From**	**To**
2	14	Purple Heart Highway	NW 48th	I-80
3	14	N 56th St	Arbor Rd	Hwy 6
4	14	Hwy 6	N 98 St	W O St
5	14	W O St	N 56 St	S 120th St
6	14	9th St	Q St	Van Dorn St
7	14	10th St	Q St	Van Dorn St
8	14	Hwy 2	Van Dorn St	Yankee Hill Rd
9	15	Cornhusker Hwy	W Adams St	11th St
10	15	Superior St	I-180	Hwy 6
11	15	27th St	Hwy 6	I-80
12	15	N 84th St	Hwy 6	Hwy 2
13	15	Rosa Parks Way	I-77	S-6th St
14	16	NW 48th St	W O St	NW 42nd St
15	16	NW 31 St	W Fletcher Ave	Purple Heart Highway
16	16	W Fletcher Ave	NW 38th St	NW 12th St
17	16	NW 12th St	W Fletcher Ave	W Adams St
18	16	SW 40th St	W O St	W Van Dorn St
19	16	S Coddington Ave	W Claire Blvd	W A St
20	16	NW 1st St	Cornhusker Highway	Irving St
21	16	S Folsom St	W Derton Rd	W Prospector
22	16	10th St	Military Rd	T St
23	16	S 14th St	Saltillo Rd	Old Cheney Rd
24	16	S 13th St	Hwy2	L St
25	16	14th St	Arbdr Rd	Military Rd
26	16	16th St	Q St	South St
27	16	17th St	Q St	Van Dorn St
28	16	S 27th St	Saltillo Rd	Cornhusker Highway
29	16	33rd St	Cornhusker Highway	Hwy 2
30	16	40th St	O St	Saltillo Rd

Figure 3.2 Road lists

3.1.2 Geographical Data Collection Based on Field Measurement

The parameters of segments and intersection approaches to be used for data collection are presented in tables 3.1 and 3.2. Field data collection was performed based on the specified parameters in Lincoln. In total, 56 segment observations and 80 intersection approach observations were obtained during the field data collection period.

Table 3.1 Collected parameters at mid-block segments

Segment parameters	**Description**
Through lane width	Through lane width (ft)
Average daily traffic (ADT)	Average daily traffic on the street
Shoulder presence indicator	0, if there are no shoulders on the street; 1, if street has shoulders
Shoulder width	Shoulder width (ft)
Shoulder type indicator	1, if street has paved shoulder; 2, if street has gravel shoulder; 3, if street has turf shoulder; 4, if street has composite shoulder

Segment parameters	Description
Median presence indicator	0, if there is no median on the street; 1, if median is present
Median type	0, if street has painted or shared median; 1, if street has curbed median
Median width	Median width (ft)
On-street parking presence indicator	0, no on-street parking; 1, has on-street parking
Road speed limit	Road speed limit (MPH)
Number of lanes	Number of through lanes in one direction on the street

Table 3.2 Collected parameters on intersection approaches

Intersection approach parameters	Description
Number of right-turn–only lanes in one direction	Number of right-turn–only lanes in one direction in one intersection approach
Right-turn–only lane width	Right-turn–only lane width (ft)
Number of through lanes in one direction	Number of through lanes in one direction in one intersection approach
Through lane width	Through lane width (ft)
Number of left-turn–only lanes in one direction	Number of left-turn lanes in one direction in one intersection approach
Left-turn–only lane width	Left-turn–only lane width (ft)
Major ADT	Average daily traffic on the main street of the intersection
Minor ADT	Average daily traffic on the minor street of the intersection
Number of legs	Number of legs in the intersection
Shoulder presence indicator	0, if there are no shoulders on the street; 1, if street has shoulders
Shoulder width	Shoulder width (ft)
Shoulder type indicator	1, if street has paved shoulder; 2, if street has gravel shoulder; 3, if street has turf shoulder; 4, if street has composite shoulder
Median presence indicator	0, if there is no median on the street; 1, if median is present
Median type indicator	0, if there is no median on the street; 1, if median is present
Median width	Median width (ft)
Road Speed limit	Road speed limit (MPH)
Skew angle presence indicator	0, if the angle between major and minor streets is 90; 1, if the angle between is less than 90

3.1.3 Geographical Data Collection Based on Google Earth

Google Earth was used as an alternate method of data collection once its measurement tools were deemed sufficiently accurate using the field measurements. The lane and shoulder widths were measured using the ruler function in Google Earth. Median types, shoulder types, speed limit, etc., were observed using the street view function. Figures 3.3 and 3.4 demonstrate the ruler and street view functions in Google Earth. In all, 2,378 mid-block segment observations and 2,764 intersection approach observations were collected in the four cities.

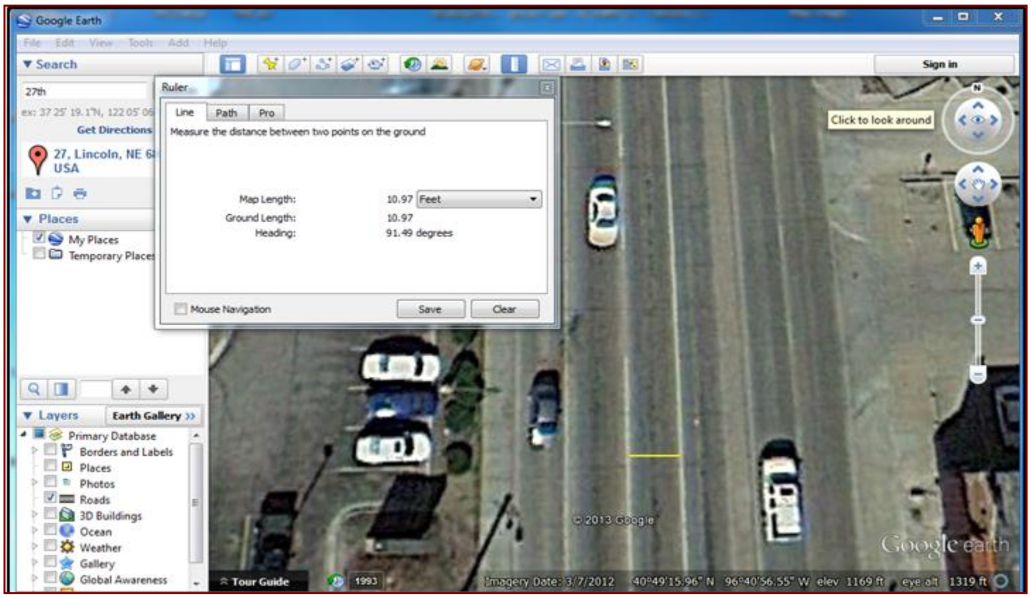


Figure 3.3 Ruler function in Google Earth

Figure 3.4 Street view function in Google Earth

3.1.4 Reduction of Crash Data

Ten years' worth of crash data, from 2003 to 2012, was reduced for the whole of Nebraska. In an effort to make the data readable, the original crash data was transformed from a text format (.txt file) to a Excel format (.xlsx file), as shown in figure 3.5, and crash locations were separated from a single sentence description into major street and minor street locations (figure 3.6). The crash case summary over 10 years, vehicle information, and driver information were combined by matching accident keys via query functions in Microsoft Access (figure 3.7).

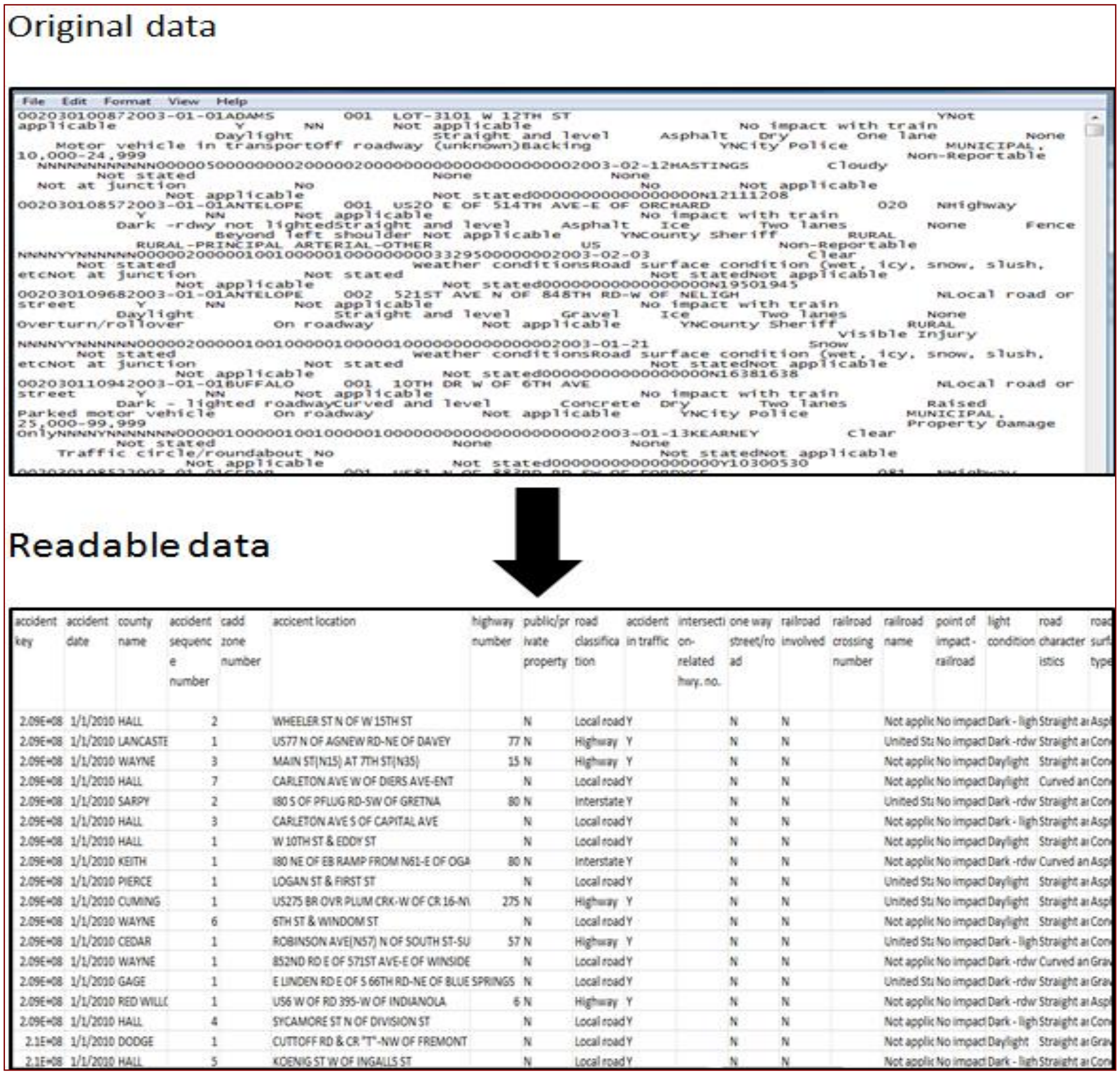


Figure 3.5 Transformation from original data to readable data

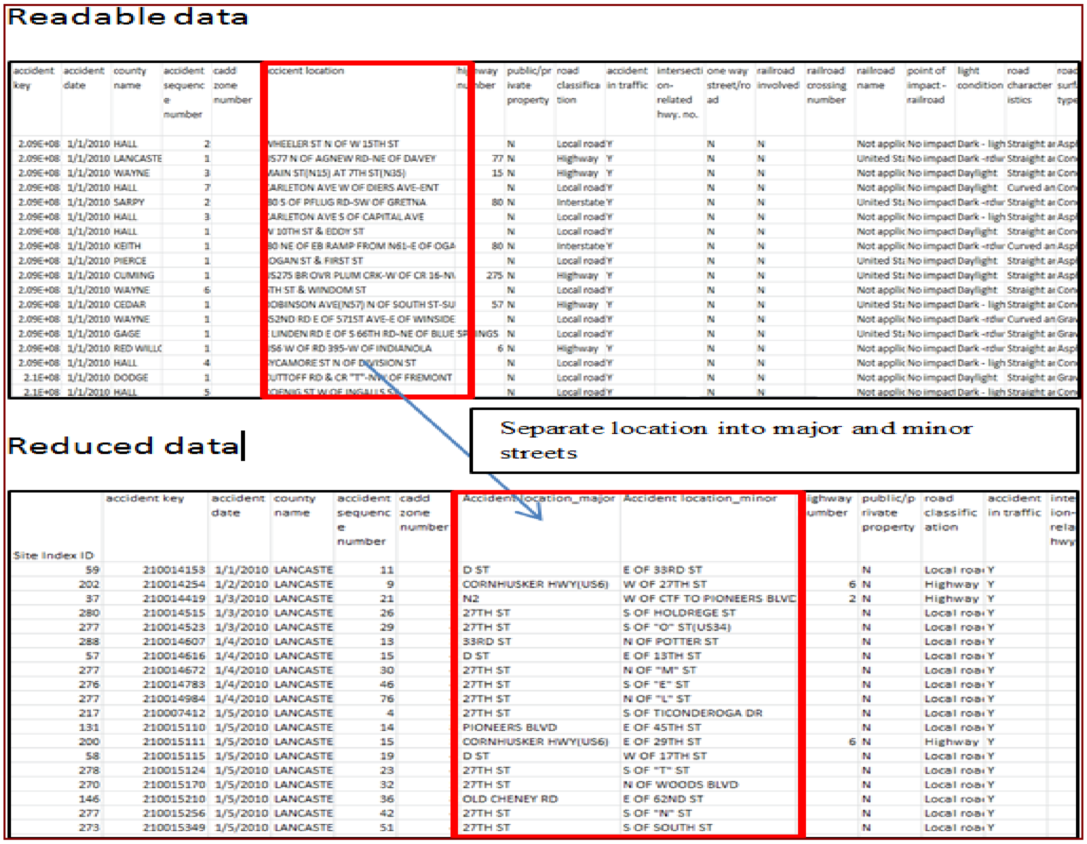


Figure 3.6 Readable data to reduced data

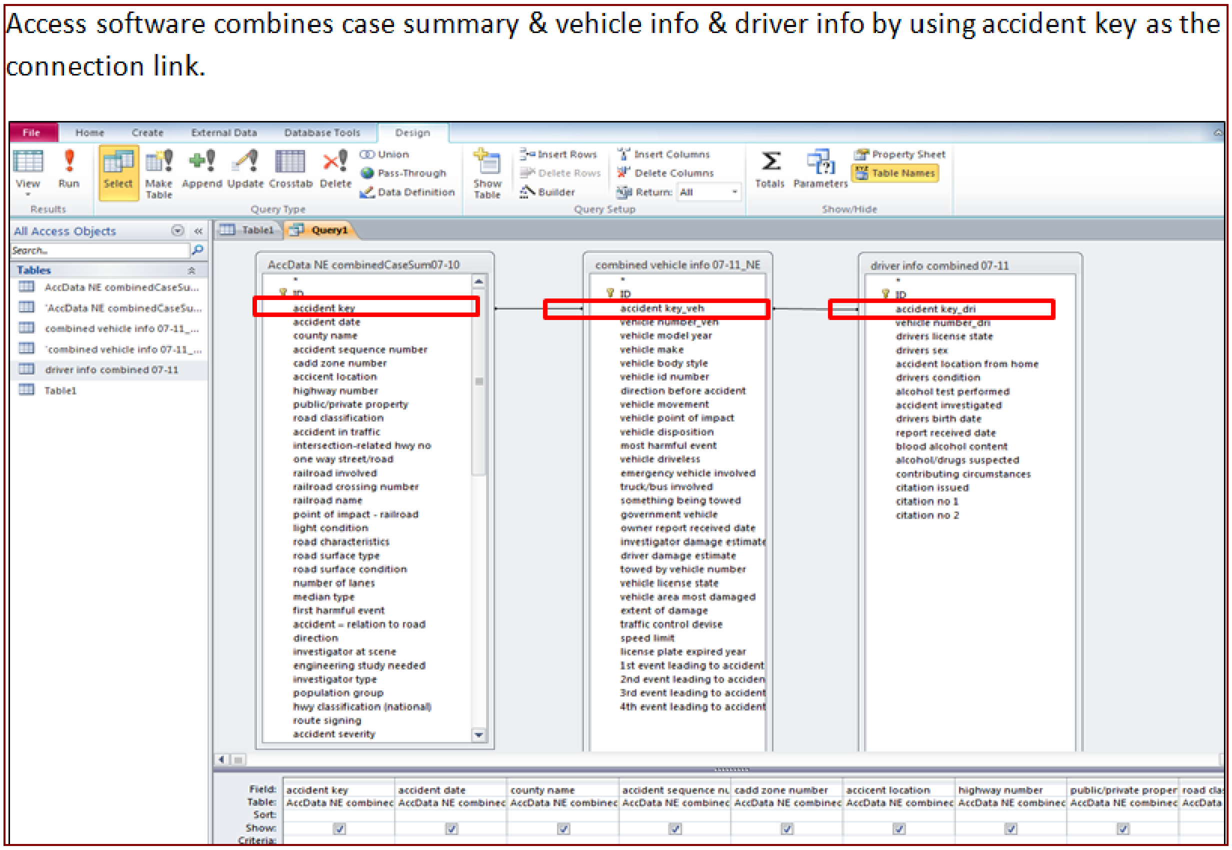


Figure 3.7 Combining and matching case summary, vehicle info, and driver info

3.1.5 Combining Geographical Data and Crash Data

Combining the geographical data collected from Google Earth and crash data obtained from NDOR was very important, the key step being to match the data collection sites to their corresponding historical crashes. Crash data were allocated to specific segments by matching the major and minor street names in both the crash and geographical information data sets. Microsoft Access was then used to separate the accidents into each segment approach by matching vehicle driving direction (crash data set) and the direction of segment observation (geographical information data set). Finally, crash frequencies were computed for each site. Figure 3.8 presents the results of matching segment observations and historical crashes. In order to demonstrate the process of geographical and crash data processing more clearly, a flow chart is provided in figure 3.9.

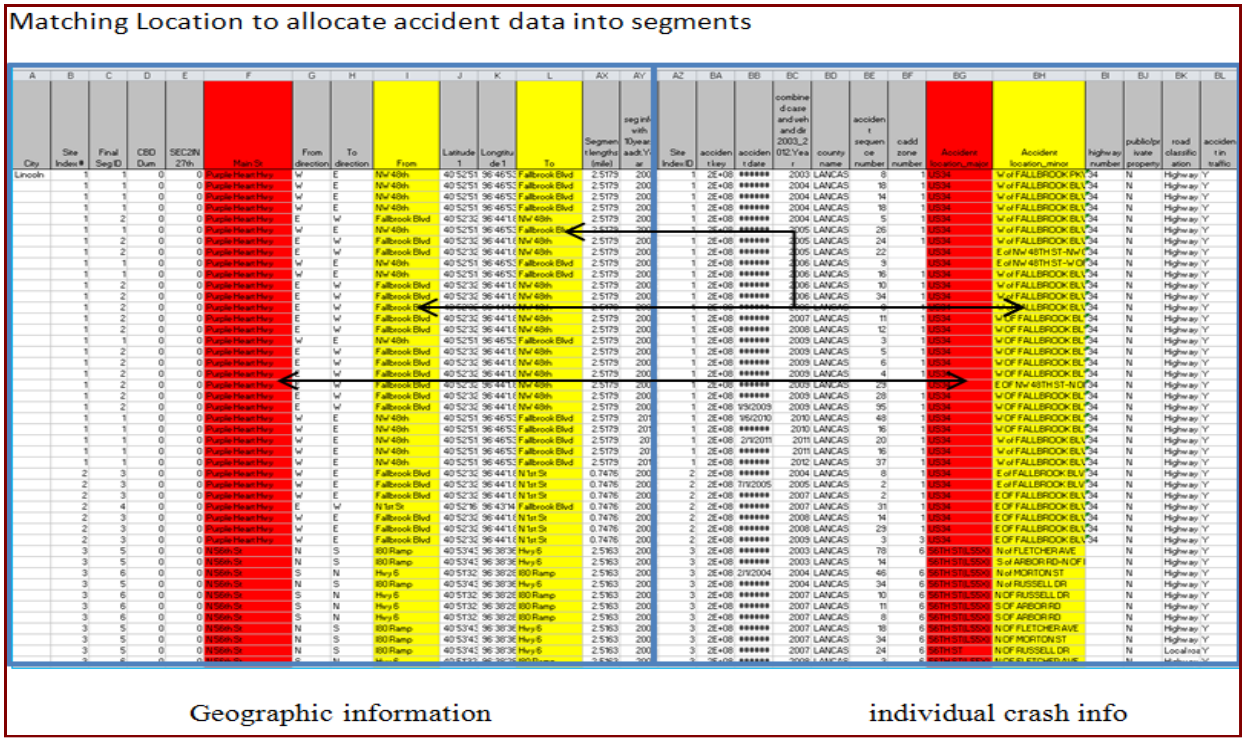


Figure 3.8 Matching segment observations and historical crashes

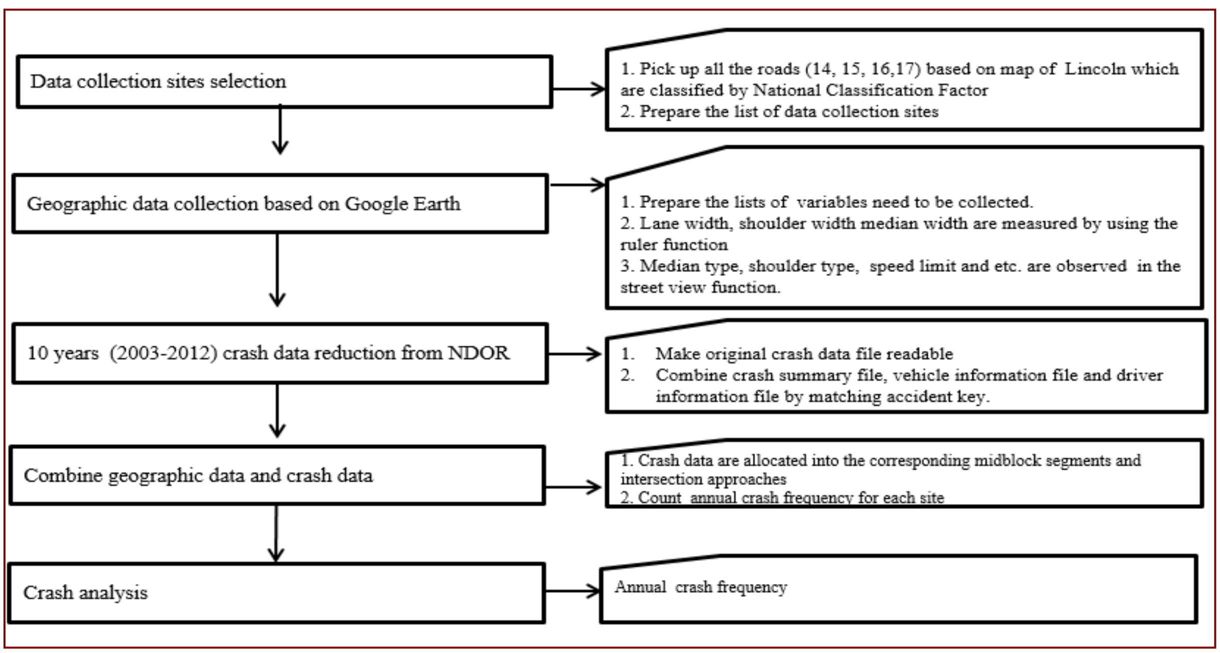


Figure 3.9 Geographical and crash data processing

3.2 Operational Data: Traffic Speed, Lane Violation, and Headway

Operational data such as traffic speed, lane violation, and headway were also collected in Lincoln. A total of 14 directional mid-block segment observations and their corresponding downstream intersection approaches were randomly selected for the operational data collection. The location information of the 14 sites is listed in table 3.3.

Table 3.3 Operational data collection sites

Mid-block segments						
Main St	**Direction**		**From**	**To**	**Group**	**Through lane width (ft)**
	From	To				
12th	S	N	O St	P St	25CBD	9
M St	W	E	12th St	13th St	25CBD	10
12th	S	N	N St	O St	25CBD	11
12th	S	N	M St	N St	25CBD	12
Van Dorn	W	E	S 40th St	S 48th St	35NCBD	9
16th	N	S	A St	South St	35NCBD	10
70th	N	S	South Wedgewood	Teton Dr	35NCBD	11
27th	S	N	Capitol Pkwy	Randolph St	35NCBD	12
West O	E	W	N70th St	N68th St	40MPH	10
Pine Lake	E	W	S 27th St	Ridge Rd/Helen Witt Dr	40MPH	11
Superior	W	E	N 14th St	N 20th St	40MPH	12
27th	S	N	Hwy6	K Mart Dr	45MPH	10
Pine Lake	E	W	Beaver Creek Ln	S 40th St	45MPH	11
27th	N	S	Superior St	Old Dairy Rd	45MPH	12
Intersection approaches						
Main St	**Direction**		**Minor St**	**Group**	**Through lane width (ft)**	**Left-turn lane width (ft)**	**Inter-section Code**
	From	To					
12th	S	N	P St	25CBD	9	No left turn	I0N
M	W	E	13th St	25CBD	10	No left turn	I0N
12th	S	N	O St	25CBD	11	No left turn	I0S
12th	S	N	N St	25CBD	12	12	ISS
Van Dorn	W	E	S 48th St	35NCBD	11	10	INS
16th	N	S	South St	35NCBD	10	9	INN
70th	N	S	Teton Dr	35NCBD	11	10	INS
27th	S	N	Randolph St	35NCBD	12	9	INS
West O	E	W	N68th St	40MPH	10	10	INN
Pine Lake	E	W	Ridge Rd/Helen Witt Dr	40MPH	11	11	ISS
Superior	W	E	N 20th St	40MPH	12	11	ISS
27th	S	N	K Mart Dr	45MPH	10	9	INN
Pine Lake	E	W	S 40th St	45MPH	11	11	ISS
27th	N	S	Old Dairy R	45MPH	12	No left turn	ISS

3.2.1 Vehicle Traffic Speed and Lane Violation at Mid-block Segments

For each mid-block segment observation, vehicle traffic speed and lane violation data were collected in a two-hour nonpeak period (1:00 pm to 3:00 pm) and a two-hour peak period (3:30 pm to 5:30 pm). A Wavetronix HD Sensor was used to detect the vehicles' traffic speed, and one Contour HD camera was used to record the lane violations of vehicles. This study noted lane violations, which are defined as an instance where any tire of a straight moving vehicle touches the road surface marking in the mid-block segment. Figure 3.10 shows the sample layout of devices used for operational data collection in a mid-block segment. Figure 3.11 is an example of a recorded lane violation and shows the left front tire of a pickup truck touching the road surface marking.

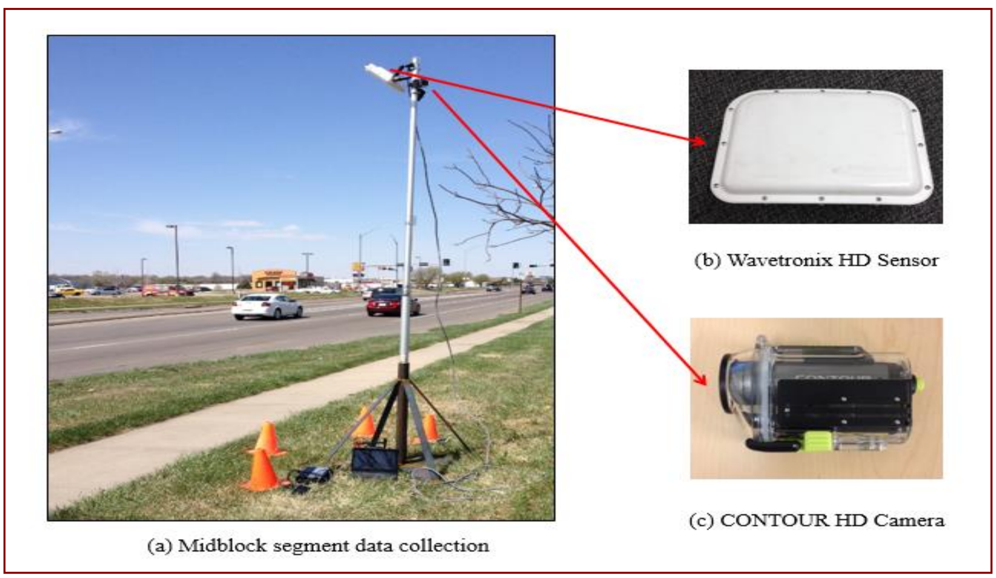


Figure 3.10 Mid-block segments operational data collection

Figure 3.11 Example of a lane violation

3.2.2 Vehicle Headway on Intersection Approaches

Vehicle headway in the queue for each traffic light cycle, in the through and left-turn–only lanes, were collected for each intersection approach in a two-hour nonpeak period (1:00 pm to 3:00 pm) and a two-hour peak period (3:30 pm to 5:30 pm). One Contour HD camera was used to record the queue status in an intersection approach (figure 3.12), and another Contour HD camera was used to record the status of the queue's corresponding stoplight phases.

(a) Intersection approach data collection

(b) CONTOUR HD Camera

Figure 3.12 Intersection approaches operational data collection

Chapter 4 Safety Data Analysis

4.1 Methodology

For the safety data analysis, this research used the count model for evaluating the effects of lane width on the annual crash frequency in both mid-block segments and intersection approaches. Lord and Mannering (23) showed that the count-data modeling technique is an appropriate methodological approach for crash frequency data analysis. These count data are generally modeled with a Poisson regression or its derivatives, which are the negative model and zero inflated model (24), but Lord and Mannering (23) claimed that a Poisson model would result in biased parameter estimates when the mean is much lower than the variance ($E[n_i] << VAR[n_i]$). The negative binomial model is often used in cases where the crash data are over-dispersed. Based on Washington *et al*. (24), the negative binomial model probability density function is as follows:

$$\boldsymbol{P(n_i)} = \left(\frac{\mathbf{1/\alpha}}{\mathbf{(1/\alpha)+\lambda_i}}\right)^{\mathbf{1/\alpha}} \frac{\boldsymbol{\Gamma}[(\mathbf{1/\alpha})+\boldsymbol{n_i}]}{\boldsymbol{\Gamma}(\mathbf{1/\alpha})\boldsymbol{n_i}!} \left(\frac{\boldsymbol{\lambda_i}}{\mathbf{(1/\alpha)+\lambda_i}}\right)^{\boldsymbol{n_i}} \tag{4.1}$$

where $\Gamma(.)$ is a Gamma function. Note that the negative binominal is only appropriate if α (dispersion parameter) is significantly different than zero.

In order to account for unobserved heterogeneity shared by some observations with spatial and/or temporal correlations, random parameters were introduced. These parameters were able to allow for the flexibility of each observation possessing its own set of model coefficients and thus account for any potential heterogeneity (25). Marginal effects were computed to determine the impact of specific variables on the mean number of crashes. These variables affect the expected number of crashes (λ_i) at each observation of the mid-block segment or intersection approach by changing one unit in any one independent variable.

All the Poisson regression models and native binomial models in the current research were run in LIMDEP software (26). LIMDEP is software used for econometric and statistical estimation and analysis of linear and nonlinear models, with cross-sections, time series, and panel data. The main feature of the package is a suite of more than 100 built-in estimators for all forms of the linear regression model; discrete choice and limited dependent variable models, including models for binary, censored, truncated, survival, count, discrete, and continuous variables; and a variety of sample selection models (25). All of the optimal outputs for the final safety models are decided based on the value of output parameters from statistical models, such as log-likelihood with constant only, log-likelihood at convergence, McFadden's pseudo R-squared, and chi squared.

4.2 Effects of Lane Widths on Annual Crash Frequency at Mid-block Segments

4.2.1 Empirical Setting

All the data used in this study were collected in urban or suburban areas of Lincoln, Omaha, Grand Island, and South Sioux, Nebraska. The sample sizes in Grand Island and South Sioux were too small to make individual models for each city, so the final annual crash frequency analysis was completed based on the data from Lincoln and Omaha. The mid-block segments considered in this study were on the roadway between two signalized intersections. Based on National Functional Classifications, the roadway types were classified as 14 - urban principal arterial other connecting link, 15 - urban principal arterial other non-connecting link, 16 - urban minor arterial, or 17 - urban collector. The range of lane widths for the mid-block segments was from 9 ft to 12 ft. Since the sample sizes of segments that were less than 9 ft or more than 12 ft wide were too small to make the estimation model, those observations were not included in the analysis data set. The effects of 9 ft, 10 ft, 11 ft, and 12 ft lanes on crash frequency were analyzed. The geometric data was collected using Google Earth software, and a random sample of 52 segments was used to validate the Google Earth data via field visits. Ten years (2003–2012) worth of crash data for the 2,378 mid-block segments were obtained from NDOR. This research did not count heavy vehicle or alcohol-related crashes, all crashes were not caused by road surface conditions, and the first event leading to the crash was motor vehicles in transit.

4.2.2 Preliminary Processing of Data

The data processing resulted in a high correlation between road speed limit and all other variables. Therefore, crash frequency models were created based on different speed limits. The posted speed limits on the analyzed segments vary among 25 mph, 30 mph, 35 mph, 40 mph, and 45 mph. some low speed(less than 35 mph) segments. In addition to the posted speed limit, the area type was also used to classify the data by determine whether a segment was in a central business district (CBD). The segments included in the analyses were categorized into five groups

Segments with a speed limit of 25 mph and located within a central business district, 30 mph and located outside of the central business district, 35 mph and located outside of the central business district, 40 mph, and 45 mph were taken into consideration.

The observations in were categorized into five different groups, which were surrogates of the area type and speed limit, as follows:

- Group 1: speed limit of 25 mph and inside the central business district (25CBD)
- Group 2: speed limit of 30 mph and outside of the central business district (30NCBD)
- Group 3: speed limit of 35 mph and outside of the central business district (35NCBD)
- Group 4: speed limit of 40 mph (40MPH)
- Group 5: speed limit of 45 mph (45MPH)

The summary of the number of mid-block segments based on lane width in five groups and two cities is shown in table 4.1. The segments whose sample size was less than six were not included or analyzed in this study because of the small variance and low representation for that category. The cells in grey are those whose sample size was less than six.

Table 4.1 Sample size for mid-block segments

LINCOLN					
	25CBD	30NCBD	35NCBD	40MPH	45MPH
9 ft	5	0	42	0	0
10 ft	23	0	88	32	2
11 ft	2	0	72	19	37
12 ft	7	0	27	32	54
OMAHA					
	25CBD	30NCBD	35NCBD	40MPH	45MPH
9 ft	0	0	0	0	0
10 ft	0	17	54	8	14
11 ft	7	79	70	120	134
12 ft	28	52	139	268	254

The number of lanes for each mid-block segment were found to be highly correlated with the ADT on each segment. To accommodate correlation, ADT per lane (ADTPL), was used as a measure of traffic volume instead of ADT.

The descriptive statistics of the variables found to be significant in forthcoming crash frequency models are provided in table 4.2.

Table 4.2 Descriptive statistics of crash frequency–related variables

LINCOLN_25CBD	
Variables	**Value**
Average annual crash frequency for each direction of the mid-block segments (std. dev.) (min) (max)	0.38 (0.72) (0) (4)
Average of average daily traffic in vehicles per lane for each direction of the mid-block segments (std. dev.) (min) (max)	3009.45 (1520.898) (1100) (7200)
Percentage of each direction of the mid-block segments on M St from 11th St to Centennial Mall St	13
Percentage of each direction of the mid-block segments on N St from Centennial St to 9th St	20
Percentage of 10 ft lane width for each direction of the mid-block segments	77
LINCOLN_35NCBD	
Variables	**Value**
Average annual crash frequency for each direction of the mid-block segments (std. dev.) (min) (max)	1.29 (2.08) (0) (23)
Average of average daily traffic in vehicles per lane for each direction of the mid-block segments (std. dev.) (min) (max)	5989.56 (2630.39) (1250) (14846.69)
Percentage of each direction of the mid-block segments on 27th St between Nebraska Highway and Cornhuskers Highway	11
Percentage of each direction of the mid-block segments on 40th St between Van Dorn St and Pioneers Blvd	1
Percentage of one lane for each direction of the mid-block segments	61
Percentage of the mid-block segments on the one-way road	69
Percentage of 9 ft lane width for each direction of the mid-block segments	18
Percentage of 10 ft lane width for each direction of the mid-block segments	38
Percentage of 11 ft lane width for each direction of the mid-block segments	31
LINCOLN_40MPH	
Variables	**Value**
Average annual crash frequency for each direction of the mid-block segments (std. dev.) (min) (max)	1.15 (1.48) (0) (9)
Average of average daily traffic in vehicles per lane for each direction of the mid-block segments (std. dev.) (min) (max)	5858.79 (2721.52) (2300) (19480.37)
Average segment lengths (std. dev.) (min) (max)	0.41 (0.27) (0.11) (1.00)
Percentage of each direction of the mid-block segments on Cornhusker Highway between N 29th St and N 33rd St	2
Percentage of each direction of the mid-block segments for which average daily traffic in vehicles per lane is less than 10,000	94
Percentage of two lanes for each direction of the mid-block segments	72
Percentage of 10 ft lane width for each direction of the mid-block segments	39
Percentage of 11 ft lane width for each direction of the mid-block segments	23

LINCOLN_45MPH	
Variables	**Value**
Average annual crash frequency for each direction of the mid-block segments (std. dev.) (min) (max)	0.80 (1.21) (0) (10)
Average of average daily traffic in vehicles per lane for each direction of the mid-block segments (std. dev.) (min) (max)	5291.65 (2223.07) (862.50) (11650)
Average segment lengths (std. dev.) (min) (max)	0.52 (0.34) (0.09) (2.00)
Percentage of each direction of the mid-block segments on 27th St between Old Dairy Rd and Kmart Dr	2
Percentage of each direction of the mid-block segments on Nebraska Highway from S 33rd St to S 27th St	1
Percentage of 11 ft lane width for each direction of the mid-block segments	41

OMAHA_30NCBD	
Variables	**Value**
Average annual crash frequency for each direction of the mid-block segments (std. dev.) (min) (max)	0.47 (0.97) (0) (8)
Average of average daily traffic in vehicles per lane for each direction of the mid-block segments (std. dev.) (min) (max)	3572.33 (1617.75) (110.77) (13500)
Average segment lengths (std. dev.) (min) (max)	0.42 (0.35) (0.02) (2.01)
Percentage of one lane for each direction of the mid-block segments	66
Percentage of two lanes for each direction of the mid-block segments	28
Percentage of each direction of the mid-block segments on Farnam St from Saddle Creek Rd to S 50th St	1
Percentage of each direction of the mid-block segments on N 24th St between L St and Q St	1
Percentage of each direction of the mid-block segments on S 36th St between Harrison St and Q St	1
Percentage of shoulder appearance in the mid-block segments	24
Percentage of median appearance in the mid-block segments	21
Percentage of 10 ft lane width for each direction of the mid-block segments	11
Percentage of 11 ft lane width for each direction of the mid-block segments	53

OMAHA_35NCBD	
Variables	**Value**
Average annual crash frequency for each direction of the mid-block segments (std. dev.) (min) (max)	0.99 (1.91) (0) (39)
Average of average daily traffic in vehicles per lane for each direction of the mid-block segments (std. dev.) (min) (max)	5480.36 (2290.47) (996.49) (10975)
Average segment lengths (std. dev.) (min) (max)	0.33 (0.24) (0.02) (1.48)
Percentage of each direction of the mid-block segments on N 72nd St between Hickory St and Grover St	3
Percentage of each direction of the mid-block segments on N 72nd St between Dodge St and Farnam St	1
Percentage of each direction of the mid-block segments on S 42nd St from Grover St to Bancroft St	0.3
Percentage of median appearance in the mid-block segments	61

Percentage of 10 ft lane width for each direction of the mid-block segments	21
Percentage of 11 ft lane width for each direction of the mid-block segments	27
OMAHA_40MPH	
Variables	**Value**
Average annual crash frequency for each direction of the mid-block segments (std. dev.) (min) (max)	0.67 (1.14) (0) (13)
Average segment lengths (std. dev.) (min) (max)	0.31 (0.18) (0.03) (1.01)
Percentage of each direction of the mid-block segments on S 120th St between Pacific St and W Center St	0.3
Percentage of each direction of the mid-block segments on S 84th St between L St and F St	0.4
Percentage of each direction of the mid-block segments which average daily traffic in vehicles per lane is less than 10,000	98
Percentage of one lane for each direction of the mid-block segments	7
Percentage of two lanes for each direction of the mid-block segments	93
Percentage of 10 ft lane width for each direction of the mid-block segments	2
Percentage of 11 ft lane width for each direction of the mid-block segments	30
OMAHA_45MPH	
Variables	**Value**
Average annual crash frequency for each direction of the mid-block segments (std. dev.) (min) (max)	0.67 (1.51) (0) (19)
Average segment lengths (std. dev.) (min) (max)	0.41 (0.27) (0.09) (1.52)
Percentage of each direction of the mid-block segments on N 168th St between Frances St and Pacific St	0.3
Percentage of each direction of the mid-block segments on W Center Rd between I 680 and 133rd St	2
Percentage of 10 ft lane width for each direction of the mid-block segments	3
Percentage of 11 ft lane width for each direction of the mid-block segments	33

Figure 4.1 is the box plot of the relationship between lane width and annual crash frequency in different models in Lincoln. Figure 4.2 is the box plot of the relationship between lane width and annual crash frequency in different models in Omaha.

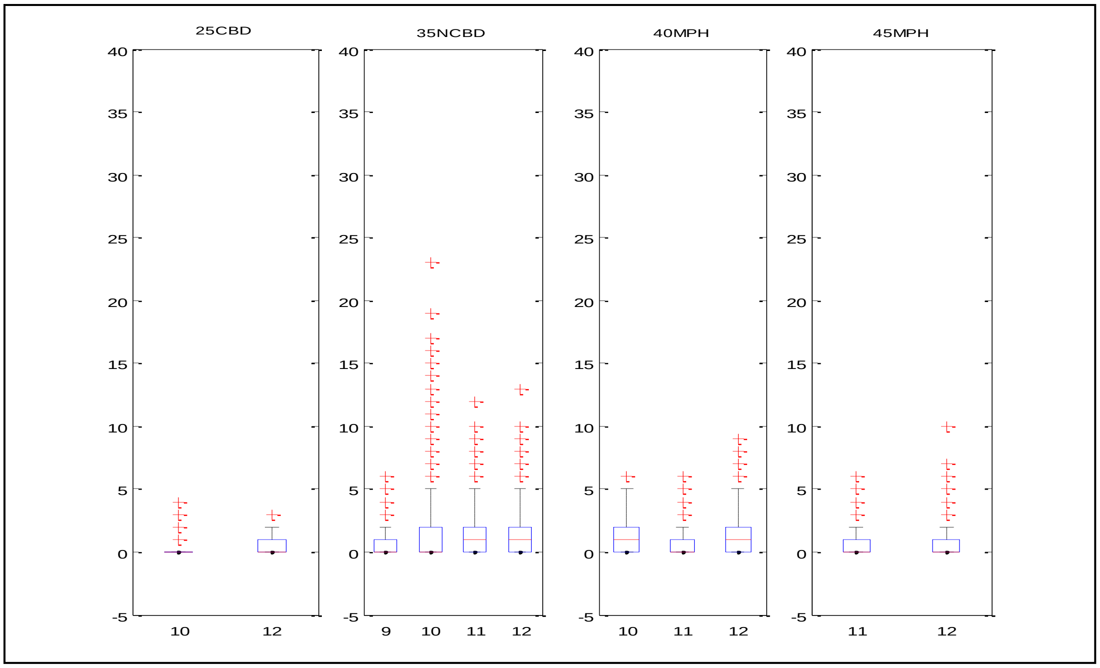


Figure 4.1 Lane width vs. crash frequency for mid-block segments in Lincoln

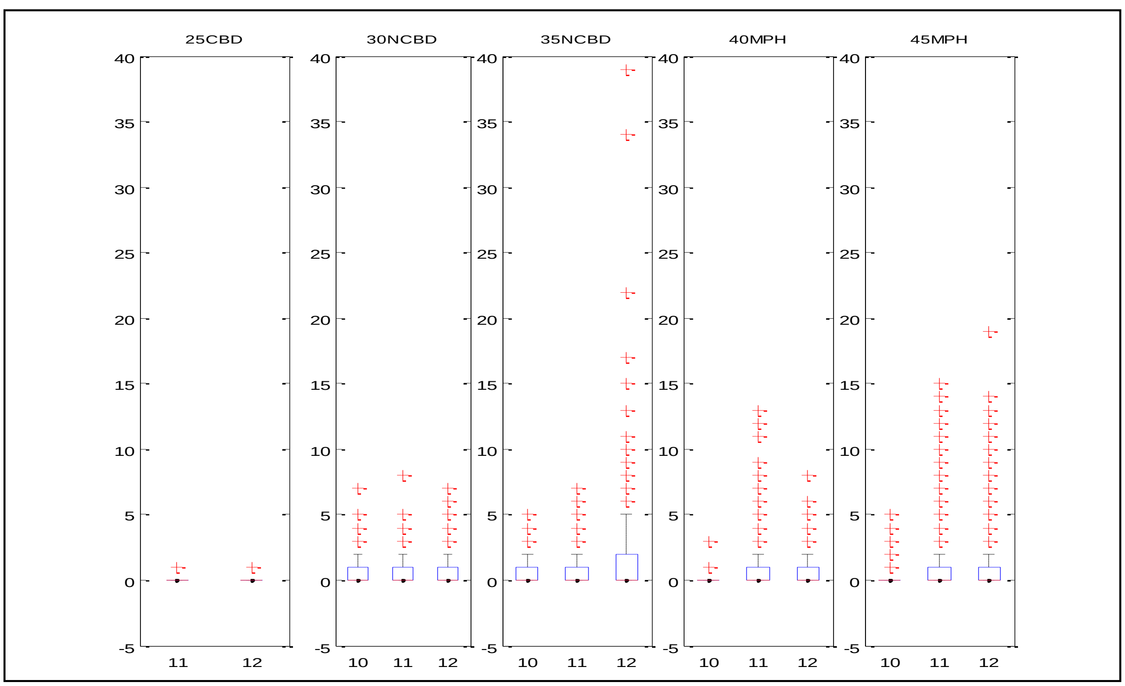


Figure 4.2 Lane width vs. crash frequency for mid-block segments in Omaha

4.2.3 Models Output

4.2.3.1 Results for group 25CBD in Lincoln

A random parameter Poisson model was used for the crash frequency at the mid-block segments with a 25 mph speed limit in the central business district of Lincoln. The estimated parameters and the corresponding average marginal effects are shown in table 4.3.

Table 4.3 Random parameter Poisson model results for group 25CBD in Lincoln

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-1.17	-3.82	-0.32
Indicator of 10 ft lane width for each direction	-0.73	-3.51	-0.20
Indicator of each direction of the mid-block segments on M St from 11th St to Centennial Mall St	1.19	3.84	0.32
Indicator of each direction of the mid-block segments on N St from Centennial St to 9th St	1.40	6.33	0.38
Average daily traffic in vehicles per lane for each direction of the mid-block segments *	-0.36D-05 (0.00012)	-0.05 (4.26)	-0.97D-06
Number of observations	*300*		
Log-likelihood with constant only	*-249.29*		
Log-likelihood at convergence	*-218.29*		
McFadden's pseudo R-squared	*0.12*		
Chi squared	*62.01*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

The model showed three significant fixed parameters and one significant random parameter. Overall, the model does not fit very well, as indicated by the log-likelihood at convergence (−218.29). This, however, shows an improvement over the log-likelihood that only included the constant in the model (−249.29).

Fixed parameters. A 10 ft lane width reduces crashes by 0.2 per year, compared to a 12 ft lane width. Mid-block segment observations on M St from 11th St to Centennial Mall St and on N St from Centennial St to 9th St reveal a 0.32 and 0.38 increase in crashes per year, respectively, compared to other segment observations.

Random parameter. The traffic volume per lane was found to be a normally distributed random parameter with a slightly negative but insignificant effect on the average (the parameter mean). However, this parameter estimation has a statistically significant standard deviation. Given the estimated standard deviation, the mean, and the normal distribution of parameters, it was found that a one-vehicle increase in daily traffic volume per lane decreases the crash frequency at 51.2% of mid-block segment observations and increases crash frequency at 49.8% of mid-block segment observations.

4.2.3.2 Results for group 35NCBD in Lincoln

A random parameter negative binomial model was used for the crash frequency data outside of the central business district with a 35 mph speed limit in Lincoln. The parameter estimation results and the corresponding average marginal effects are shown in table 4.4.

Table 4.4 Random parameter NB model results for group 35NCBD in Lincoln

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-1.25	-15.35	-1.01
Indicator of each direction of the mid-block segments on 27th St between Nebraska Highway and Cornhusker Highway	0.93	15.26	0.75
Indicator of each direction of the mid-block segments on 40th St between Van Dorn St and Pioneers Blvd	1.60	10.61	1.29
Indicator of 1 lane for each direction of the mid-block segments	-0.62	-11.94	-0.50
Indicator of the mid-block segments on the one way road	0.39	3.37	0.31
Indicator of 9 ft lane width for each direction of the mid-block segments	-0.36	-4.05	-0.29
Indicator of 11 ft lane width for each direction of the mid-block segments	-0.30	-4.18	-0.24
Average daily traffic in vehicles per lane for each direction of the mid-block segments *	0.0003 (0.89D-04)	23.635 (26.518)	0.0002
Indicator of 10 ft lane width for each direction of the mid-block segments *	-0.28 (0.52)	-4.17 (14.26)	-0.22
Dispersion parameter	*7.14*	*6.70*	
Number of observations	*2290*		
Log-likelihood with constant only	*-5544.58*		
Log-likelihood at convergence	*-3001.87*		
McFadden's pseudo R-squared	*0.46*		
Chi squared	*5085.41*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses

There are six significant fixed parameters and two significant random parameters in the model. Overall, the model fits very well, as indicated by the log-likelihood at convergence (-3001.87), which is an improvement over the log-likelihood that only included the constant in the model (-5544.58). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. Observations of mid-block segments on 27th St between Nebraska Highway and Cornhusker Highway show 0.75 more crashes per year compared to mid-block segments on other roads in the same category. Observations of mid-block segments on 40th St between Van Dorn St and Pioneers Blvd show 1.29 more crashes per year compared to mid-block segment observations on other roads. The presence of one lane for each direction of the mid-block segments decreases the crash frequency by 0.5 crashes per year, compared to two lanes and three lanes in each direction of the segments. Segment observations on a one-way road show a crash increase of 0.31 per year compared to segments observations on non–one-way roads. Lanes that are 9 ft wide reduce crashes by 0.29 per year, compared to the effect of 12 ft wide lanes on crash frequencies. Compared to lanes that are 12 ft wide, 11 ft lanes reduce crashes by 0.24 per year.

Random parameters. A one-vehicle increase in daily traffic volume per lane increases crashes per year by 0.0002 at 61.4% of mid-block segment observations and decreases crash frequency at 38.6% of mid-block segment observations. Compared to lanes that are 12 ft wide, lane widths of 10 ft decrease crashes by 0.22 per year at 70.5% of mid-block segment observations.

4.2.3.3 Results for group 40MPH in Lincoln

For the crash frequency data with a 40 mph speed limit in Lincoln, a random parameter negative binomial model was used, and the parameter estimation results and corresponding average marginal effects are shown in table 4.5.

Table 4.5 Random parameter NB model results for group 40MPH in Lincoln

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-3.39	-12.07	-3.04
Average daily traffic in vehicles per lane for each direction of the mid-block segments	0.0002	12.88	0.0002
Segment length	1.17	7.08	1.05
Indicator of each direction of the mid-block segments on Cornhusker Highway between N 29th St and N 33rd St	1.01	0.09	0.91
Indicator of each direction of the mid-block segments which average daily traffic in vehicles per lane is less than 10000	1.79	10.145	1.60
Indicator of 2 lanes for each direction of the mid-block segments	-0.38	-3.28	-0.34
Indicator of 10 ft lane width for each direction of the mid-block segments *	0.06 (0.39)	0.56 (6.71)	0.05
Indicator of 11 ft lane width for each direction of the mid-block segments *	-0.33 (0.71)	-2.27 (6.14)	-0.29
Dispersion parameter	*5.03*	*1.08*	
Number of observations	*830*		
Log-likelihood with constant only	*-1649.98*		
Log-likelihood at convergence	*-1113.51*		
McFadden's pseudo R-squared	*0.33*		
Chi squared	*1072.95*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are five significant fixed parameters and two significant random parameters shown in the model. Overall, the model fits well, as indicated by the log-likelihood at convergence (-1113.51), which shows an improvement over the log-likelihood that only included the constant in the model (-1649.98). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which indicated that the negative binomial model was appropriate for the data.

Fixed parameters. A one-vehicle increase in average daily traffic per lane would increase crashes by 0.0002 per year. A one-mile increase of segment length would increase crashes 1.05 by per year. Segment observations of Cornhusker Highway between N 29th St and N 33rd St show an increase of 0.91 crashes per year. Mid-block segment observations where the average daily traffic per lane is less than 10,000 show an increase of crashes of 1.6 per year relative to segment observations where the average daily traffic per lane is equal to or more than 10,000. Two lanes for each direction on the mid-block segments decreases crashes by 0.34 per year compared to segments with one lane and three lanes.

Random parameters. A 10 ft lane width increases crashes per year by 0.05 at 56% of mid-block segment observations, and an 11 ft lane width decreases crashes per year by 0.29 at 68% of mid-block segment observations.

4.2.3.4 Results for group 45MPH in Lincoln

For the crash frequency data with a 45 mph speed limit in Lincoln, a random parameter negative binomial model was used, and the parameter estimation results and corresponding average marginal effects are shown in table 4.6.

Table 4.6 Random parameter NB model results for group 45MPH in Lincoln

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-1.86	-17.91	-1.15
Average daily traffic in vehicles per lane for each direction of the mid-block segments	0.0001	11.73	0.0001
Indicator of each direction of the mid-block segments on 27th St between Old Dairy Rd and Kmart Dr	1.58	7.51	0.98
Indicator of each direction of the mid-block segments on Nebraska Highway from S 33rd St to S 27th St	0.94	2.71	0.58
Segment length	0.65	5.35	0.40
Indicator of 11 ft lane width for each direction of the mid-block segments *	-0.06 (0.52)	-0.68 (7.49)	-0.03
Dispersion parameter	*7.21*	*2.76*	
Number of observations	*910*		
Log-likelihood with constant only	*-1331.99*		
Log-likelihood at convergence	*-1004.13*		
McFadden's pseudo R-squared	*0.25*		
Chi squared	*655.72*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are four significant fixed parameters and one significant random parameter displayed in the model. Overall, the model fits well, as indicated by the log-likelihood at convergence (-1004.13), which shows an improvement over the log-likelihood that only included the constant in the model (-1331.99). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means that the negative binomial model was appropriate to the data.

Fixed parameters. A one-vehicle increase of average daily traffic per lane would result in 0.0001 more crashes per year. The mid-block segment observations on 27th St between Old Dairy Rd and Kmart Dr show an increase in crashes of 0.98 per year, and the mid-block segment on Nebraska Highway from S 33rd St to S 27th St show an increase in crashes of 0.58 per year. A one-mile increase in segment length will increase crashes by 0.40 per year.

Random parameter. An 11 ft wide lane decreases crashes by 0.29 per year at 54% of mid-block segment observations.

4.2.3.5 Results for group 30NCBD in Omaha

A random parameter Poisson model was used for the crash frequency data for Omaha outside of the central business district and with a 30 mph speed limit. Parameter estimation results and the corresponding average marginal effects are shown in table 4.7.

Table 4.7 Random parameter Poisson model results for group 30NCBD in Omaha

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-0.59	-4.48	-0.18
Indicator of one lane for each direction of the mid-block segments	-1.24	-7.623	-0.37
Indicator of two lanes for each direction of the mid-block segments	-0.33	-2.349	-0.10
Indicator of each direction of the mid-block segments on Farnam St from Saddle Creek Rd to S 50th St	2.40	10.68	0.72
Indicator of each direction of the mid-block segments on N 24th St between L St and Q St	1.98	11.82	0.60

Variable	Parameter estimate	t-Stat.	Average marginal effect
Indicator of each direction of the mid-block segments on S 36th St between Harrison St and Q St	2.09	11.72	0.63
Indicator of shoulder appearance in the mid-block segments	-0.47	-3.86	-0.14
Indicator of median appearance in the mid-block segments	-0.38	-3.51	-0.11
Percentage of 10 ft lane width for each direction of the mid-block segments	0.29	2.28	0.09
Segment length	0.94	7.13	0.28
Average daily traffic in vehicles per lane for each direction of the mid-block segments *	-0.68D-05 (0.0001)	-0.22 (11.78)	-0.20D-05
Indicator of 11 ft lane width for each direction of the mid-block segments *	0.04 (0.25)	0.38(3.79)	0.01
Number of observations	1480		
Log-likelihood with constant only	*-1431.78*		
Log-likelihood at convergence	*-1149.01*		
McFadden's pseudo R-squared	*0.20*		
Chi squared	*565.54*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are nine significant fixed parameters and two significant random parameters in the model. Overall, the model fits well, as indicated by the log-likelihood at convergence (-1149.01), which shows an improvement over the log-likelihood that only included the constant in the model (-1431.78).

Fixed parameters. One-lane and two-lane mid-block segment observations saw a decrease in crashes by 0.37 and 0.1 per year, respectively, when compared to three-lane mid-block segment observations. Mid-block segment observations on Farnam St from Saddle Creek Rd to S 50th St found 0.72 more crashes per year. Mid-block segment observations on N 24th St between L St and Q St found an increase in crash frequency by 0.60 crashes per year, and mid-block segment observations on S 36th St between Harrison St and Q St found 0.63 more crashes per year. Observations of mid-block segment with a shoulder found a decrease in crash frequency by 0.14 crashes per year, compared to segments with no shoulders. Observations of mid-block segments with medians found a decrease in crash frequency by 0.11 crashes per year, compared to segments with no medians. Lanes 10 ft wide increase crashes by 0.09 per year as opposed to a 12 ft wide lane. A one-mile increase in segment length increases the crash frequency by 0.28 per year.

Random parameters. A one-vehicle increase of average daily traffic in vehicles per lane for each direction of the mid-block segments decreases crash frequency by 0.000002 crashes per year at 52% of mid-block segment observations, and 11 ft wide lanes increase crash frequency by 0.01 crashes per year at 56% of mid-block segment observations.

4.2.3.6 Results for group 35NCBD in Omaha

A random parameter negative binomial model was used for the crash frequency data for Omaha that is outside of the central business district and has a 35 mph speed limit. Parameter estimation results and the corresponding average marginal effects are shown in table 4.8.

Table 4.8 Random parameter NB model results for group 35NCBD in Omaha

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	0.78	-6.84	-0.39
Indicator of each direction of the mid-block segments on N 72nd St between Hickory St and Grover St	1.87	19.59	0.92
Indicator of each direction of the mid-block segments on N 72nd St between Dodge St and Farnam St	1.47	7.68	0.72
Indicator of each direction of the mid-block segments on S 42nd St from Grover St to Bancroft St	2.59	12.96	1.28
Indicator of median appearance in the mid-block segments	-0.35	-5.31	-0.17
Segment length	-0.40	-2.89	-0.19
Indicator of 10 ft lane width for each direction of the mid-block segments	0.28	3.72	0.14
Average daily traffic in vehicles per lane for each direction of the mid-block segments *	0.45D-04 (0.0002)	2.776 (33.22)	0.22D-04
Indicator of 11 ft lane width for each direction of the mid-block segments *	-0.17 (1.21)	-2.22 (17.25)	-0.09
Dispersion parameter	*6.44*	*6.88*	
Number of observations	*2630*		
Log-likelihood with constant only	*-5122.15*		
Log-likelihood at convergence	*-2727.47*		
McFadden's pseudo R-squared	*0.47*		
Chi squared	*4789.36*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are six significant fixed parameters and two significant random parameters in the model. Overall, the model fits well, as indicated by the log-likelihood at convergence (-2727.47), which shows an improvement over the log-likelihood that only included the constant in the model (-5122.15). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate to the data.

Fixed parameters. Mid-block segments observed on N 72nd St between Hickory St and Grover St have 0.92 more crashes per year. Mid-block segment observations on N 72nd St between Dodge St and Farnam St show 0.72 more crashes per year, and mid-block segment observations on S 42nd St from Grover St to Bancroft St show 1.28 more crashes per year. A median decreases crash frequency by 0.17 crashes per year for mid-block segments, compared to mid-block segments without a median. Increasing segment length by one mile results in 0.19 fewer crashes per year.

Random parameters. A one-vehicle increase of average daily traffic in vehicles per lane for each direction of the mid-block segments increases crash frequency by 0.000022 crashes per year at 59% of mid-block segment observations. The 11 ft lane width decreases crashes by 0.09 per year at 55% of mid-block segment observations.

4.2.3.7 Results for group 40MPH in Omaha

A random parameter negative binomial model was used for the crash frequency data in Omaha with a 40 mph speed limit. Parameter estimation results and the corresponding average marginal effects are shown in table 4.9.

Table 4.9 Random parameter NB model results for group 40MPH in Omaha

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-0.53	-1.14	-1.12
Indicator of each direction of the mid-block segments on S120th St between Pacific St and W Center St	1.31	5.67	0.60
Indicator of each direction of the mid-block segments on S 84th St between L St and F St	1.65	10.47	0.75
Indicator of each direction of the mid-block segments which average daily traffic in vehicles per lane is less than 10,000	-0.55	-3.99	0.75
Segment length	1.99	17.29	0.91
Indicator of 10 ft lane width for each direction of the mid-block segments	-1.02	-3.95	0.47
Indicator of 1 lane for each direction of the mid-block segments *	-0.63 (0.79)	-0.48 (6.13)	0.29
Indicator of 2 lanes for each direction of the mid-block segments *	0.30 (0.77)	0.23 (29.81)	0.14
Indicator of 11 ft lane width for each direction of the mid-block segments *	0.06 (0.07)	1.29 (1.86)	0.03
Dispersion parameter	*5.69*	*5.39*	
Number of observations	*3960*		
Log-likelihood with constant only	*-5440.91*		
Log-likelihood at convergence	*-4045.09*		
McFadden's pseudo R-squared	*0.26*		
Chi squared	*2791.65*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are five significant fixed parameters and three significant random parameters shown in the model. Overall, the model fits well, as indicated by the log-likelihood at convergence (-4045.09), which shows an improvement over the log-likelihood that only included the constant in the model (-5440.91). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. Mid-block segment observations reveal that S 120th St between Pacific St and W Center St sees 0.60 more crashes per year compared to other mid-block segments. Similarly, mid-block segment observations on S 84th St between L St and F St revealed 0.75 more crashes per year than other mid-block segments. Mid-block segments whose average daily traffic in vehicles per lane is less than 10,000 have 0.75 crashes per year, compared to mid-block segments whose average daily traffic in vehicles per lane is equal to or more than 10,000. A one-mile increase in segment length increases crashes by 0.91 per year. Lanes 10 ft wide have 0.47 more crashes per year compared to lanes 12 ft wide.

Random parameters. Mid-block segments with one lane have an increase in crash frequency by 0.29 crashes per year compared to segments with three lanes at 78% of mid-block segment observations. Mid-block segment observations with two lanes show an increase of 0.14 crashes per year relative to segment observations with three lanes at 65% of mid-block segment observations. Lanes 11 ft wide increase the crash frequency by 0.03 crashes per year compared with 12 ft wide lanes at 81% of mid-block segment observations.

4.2.3.8 Results for group 45MPH in Omaha

For the crash frequency data on segments with a 45 mph speed limit in Omaha, a random parameter negative binomial model was used. Parameter estimation results and the corresponding average marginal effects are shown in table 4.10.

Table 4.10 Random parameter NB model results for group 45MPH in Omaha

Variable	Parameter estimate	t-Stat.	Average marginal effect
Constant	-2.63	-37.69	-1.19
Average daily traffic in vehicles per lane for each direction of the mid-block segments	0.0003	37.16	0.0001
Indicator of each direction of the mid-block segments on N 168th St between Frances St and Pacific St	1.34	2.35	0.60
Indicator of each direction of the mid-block segments on W Center Rd between I 680 and 133rd St	1.95	16.48	0.88
Segment length	0.33	5.24	0.15
Indicator of 11 ft lane width for each direction of the mid-block segments	-0.33	-9.85	-0.15
Indicator of 10 ft lane width for each direction of the mid-block segments *	-0.64 (1.34)	-2.72 (5.39)	-0.29
Dispersion parameter	*0.81*	*24.69*	
Number of observations	*4020*		
Log-likelihood with constant only	*-5814.82*		
Log-likelihood at convergence	*-3727.27*		
McFadden's pseudo R-squared	*0.36*		
Chi squared	*4175.11*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are five significant fixed parameters and one significant random parameter shown in the model. Overall, the model fits very well, as indicated by the log-likelihood at convergence (-3727.27), which shows an improvement over the log-likelihood that only included the constant in the model (-5814.82). Finally, the statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. A one-vehicle increase of average daily traffic in vehicles per lane for each direction of the mid-block segments increases crashes by 0.0001 per year. The mid-block segment observations on N 168th St between Frances St and Pacific St show an increase in crashes by 0.6 per year relative to mid-block segments on other roads. Mid-block segment observations on W Center Rd between I 680 and 133rd St have 0.88 more crashes per year relative to mid-block segments on other roads. A one-mile increase of segment length increases crash frequency by 0.15 crashes per year. Lanes 11 ft wide decrease crashes by 0.15 per year compared to the effect of lanes 12 ft wide on crash frequency.

Random parameter. A 10 ft lane width decreases crash frequency by 0.29 crashes per year at 68% of mid-block segments.

4.2.4 Summary

The effects of lane width based on the output from the models discussed above are summarized in table 4.11.

Table 4.11 Summary on the effects of lane width

a. Number of segments used for modeling

LINCOLN					
	25CBD	30NCBD	35NCBD	40MPH	45MPH
9 ft	5	0	42	0	0
10 ft	23	0	88	32	2
11 ft	2	0	72	19	37
12 ft	7	0	27	32	54
OMAHA					
	25CBD	30NCBD	35NCBD	40MPH	45MPH
9 ft	0	0	0	0	0
10 ft	0	17	54	8	14
11 ft	7	79	70	120	134
12 ft	28	52	139	268	254

b. Marginal impacts of Narrow lane widths

Baseline	**12 ft**				
LINCOLN					
	25CBD	30NCBD	35NCBD	40MPH	45MPH
9 ft	-	-	-0.29	-	-
10 ft	-0.20+	-	-0.22 (61%)	0.05 (56%)	-
11 ft	-	-	-0.24	-0.3 (68%)	-0.03 (54%)
OMAHA					
	25CBD	30NCBD	35NCBD	40MPH	45MPH
9 ft	-	-	-	-	-
10 ft	-	0.08	0.13	-0.47*	-0.29 (68%)
11 ft	Not sig*	0.01 (56%)	-0.09 (55%)	0.03 (81%)	-0.14
* Less than 10 sites available for modelling + Baseline has less than 10 sites					

The base value of the lane widths is 12 ft. The cells in green indicate that the corresponding lane width decreases crash frequency when compared to a 12 ft lane. In other words, the narrowed lane is safer than 12 ft wide lanes. The cells in red indicate that the corresponding lane width increases crash frequency compared to a 12 ft wide lane. In other words, the narrowed lane is more dangerous than 12 ft wide lanes. The cells in yellow indicate that the corresponding lane width has a random effect on crash frequency, and the percentage in the parentheses is the probability of the corresponding lane width effect. An "-" in the cell means that the specific lane width was not analyzed in this study because of a small sample size. The "Not Sig" indicate that there is no significant difference between a specific lane width and 12 ft wide lanes.

Based on table 4.11, one can see that a 10 ft lane width is safer than a 12 ft lane width in 25CBD in Lincoln, but it should be noted the result is drawn from the data set that had only seven 12 ft lane width segments to compare against. In 30NCBD Omaha, 12 ft lanes are safer than 10 ft lanes and 11 ft lanes shows an ambiguous effects with nearly half the segments being worse and other half being safer than 12 ft lanes. For 35 NCBD, 9 ft lanes and 11 ft lanes are safer and 10 ft lane have ambiguous effect on safety when compared to a 12 ft lane. For 40 mph, 10 ft wide lanes had ambiguous impacts on safety in Lincoln and improved safety in Omaha. A fact to be noted is number of segments in Omaha for 10 ft lanes at 40 mph was only 8. 10 ft lanes were found to have ambiguous impacts on safety as compared to 12 ft lane for 45 mph roadways. In conclusion, these are the most important insights gained by the analysis:

i. In most cases, 10 ft lanes tend to either have negative or ambiguous impact on safety with more negative influence in the cases of 30 to 35 mph roadways near CBD.

ii. In most cases, 11 ft lanes have little or no impact on safety as compared to a 12 ft lanes.

iii. 9 ft lanes sample were shown to have positive impacts in improving safety 35 mph NCBD roads but further exploration with larger number of segments is needed on other road types

4.3 Effects of Lane Width on Annul Crash Frequency on Intersection Approaches

4.3.1 Empirical Setting

All the data used in this study were collected in urban or suburban areas of Lincoln, Omaha, Grand Island, and South Sioux, Nebraska. Because the sample sizes in Grand Island and South Sioux were too small to make individual models for each city, the final annual crash frequency analysis was based on the data from Lincoln's and Omaha's intersection approaches. The intersection approaches considered in this study were approaches to signalized intersections. Based on National Functional Classifications, the roadway types were classified as follows: 14 - urban principal arterial other connecting link, 15 - urban principal arterial other non-connecting link, 16 - urban minor arterial, or 17 - urban collector. Furthermore, the range of the intersection approaches' left-turn lane width was from 10 ft to 12 ft, and the range of the intersection approaches' through lane widths was from 9 ft to 12 ft. Right-turn lanes were not analyzed in this study. The 11–12 ft lane width was categorized as the standard lane width, while lane widths less than 11 ft were categorized as narrowed lane widths. The safety effects of five combinations from the left-turn lane width category and the through lane width category are discussed in this paper. The five lane width combinations are also presented as follows:

- I0N: no left-turn lane with narrowed through lane width
- I0S: no left-turn lane with standard through lane width

- INN: indicator of narrowed left-turn lane width with narrowed through lane width
- INS: indicator of narrowed left-turn lane width with standard through lane width
- ISS: indicator of standard left-turn lane width with standard through lane width)

The sample sizes of lanes wider than 12 ft were too small to make an estimation model, so those observations were not included in the data analysis. The effects between I0N and I0S and the effects among INN, INS, and ISS were analyzed separately. The geometric data was collected using Google Earth software, and a random sample of 52 segments was used to validate the collected data through a field visit. Ten years (2003–2012) worth of crash data for the 2,764 intersection approaches were obtained from NDOR. This research did not count heavy vehicle or alcohol-related crashes, all crashes were not caused by road surface conditions, and the first event leading to the crash was motor vehicles in transit.

4.3.2 Preliminary Processing of Data

The analysis found a high correlation between road speed limit and all other variables, and, therefore, crash frequency models were based on different speed limits. The speed limits of analyzed segments were 25 mph, 30 mph, 35 mph, 40 mph, and 45 mph. In addition to road speed limit, the area type that defined the observed segments as in or out of the central business district was one of the factors used to separate the data into groups. Segments with a speed limit of 25 mph and located within the central business district, 30 mph and located outside of the central business district, 35 mph and located outside of the central business district, 40 mph, and 45 mph, were taken into consideration. In addition, because the number of lanes for each mid-block segment and ADT on the segment was found to be highly correlated, a new variable, ADTPL, was used to represent traffic volume. The observations were classified into five different groups by surrogates of the area type and speed limit, as follows:

- Group 1: speed limit of 25 mph and inside the central business district (25CBD)
- Group 2: speed limit of 30 mph and outside of the central business district (30NCBD)
- Group 3: speed limit of 35 mph and outside of the central business district (35NCBD)
- Group 4: speed limit of 40 mph (40MPH)
- Group 5: speed limit of 45 mph (45MPH)

A summary of the number of intersection approaches based on lane width for the five groups and two cities is shown in table 4.12. The segments with a sample size less than 6 were not included or analyzed in this study because of the small variance and low representation for that category. The cells in grey indicate that the sample size is less than 6.

Table 4.12 Sample size for intersection approaches

LINCOLN						
	25CBD	25NCBD	30NCBD	35NCBD	40MPH	45MPH
I0N	18	28	0	20	4	2
I0S	4	0	0	23	3	5
INN	3	0	1	70	22	4
INS	2	0	0	50	20	9
ISS	0	0	0	44	49	70
OMAHA						
	25CBD	25NCBD	30NCBD	35NCBD	40MPH	45MPH
I0N	0	3	9	21	1	4
I0S	16	30	73	79	78	44
INN	0	3	5	17	5	9
INS	1	3	15	13	25	8
ISS	17	7	62	124	346	333

The descriptive statistics of the variables found to be significant in forthcoming crash frequency models are provided in table 4.13. The crash frequency models consider the number of crashes per year on individual intersection approaches.

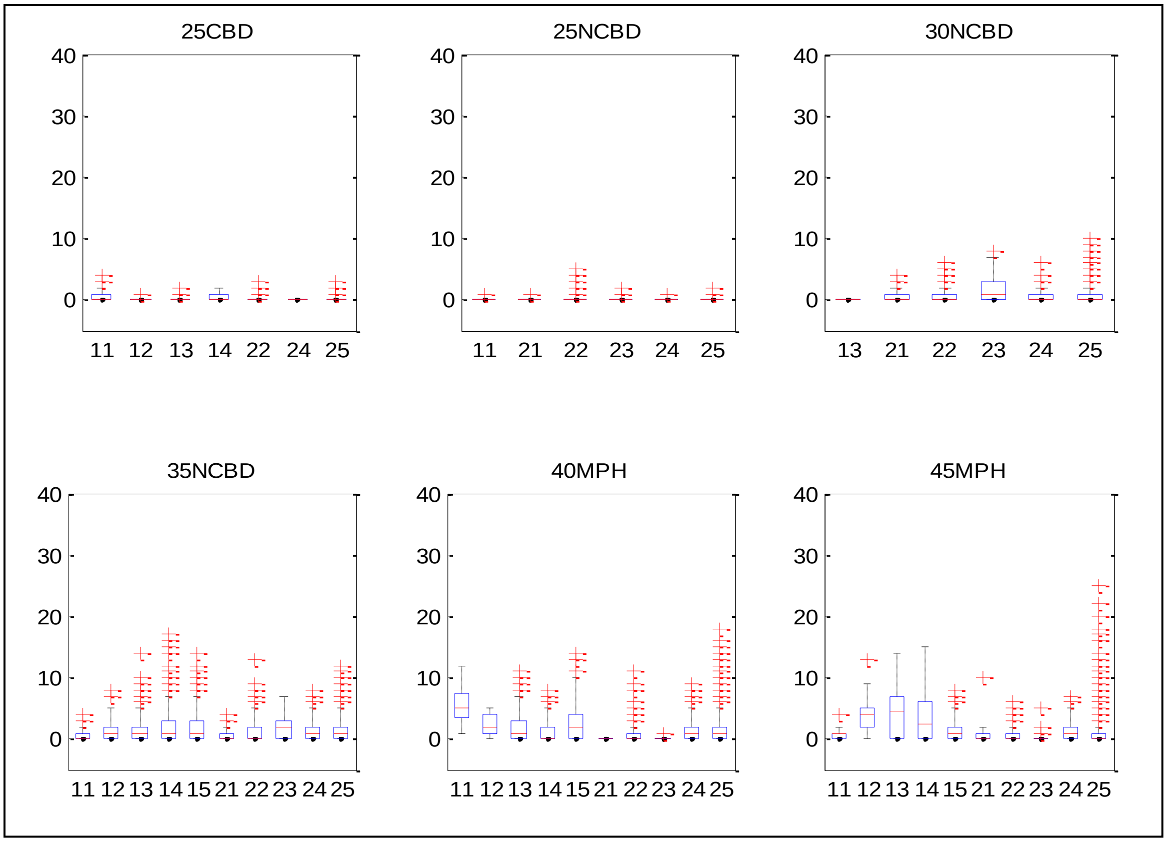
Table 4.13 Descriptive statistics of crash frequency-related variables

LINCOLN_35NCBD_I0N, I0S	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	0.98 (1.41) (0) (8)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	4761.99 (3086.74) (766.67) (16750)
Percentage of intersection approach with median	9.3
Percentage of combination of no left-turn lane and narrowed through lane width for each intersection approach	46.51
Percentage of the intersection approach which has three legs	16.27
LINCOLN_35NCBD_INN, INS, ISS	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	1.69 (2.3) (0) (17)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	4026.65 (2212.26) (100) (10800)
Average of average daily traffic in vehicles in minor street corresponding to each intersection approach (std. dev.) (min) (max)	14626.16 (15358.76) (1350) (87475)
Percentage of combination of narrowed left-turn lane and narrowed through lane width for each intersection approach	42.68
Percentage of southbound and northbound intersection approaches of 27th St and Vine St	1.09
Percentage of 90° skew angle of the intersection	86.58
LINCOLN_40MPH_ INN, INS, ISS	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	2.06 (2.32) (0) (14)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	3276.66 (1762.94) (283.33) (10100)
Percentage of combination of narrowed left-turn lane and standard through lane width for each intersection approach	21.98
Percentage of the intersection approach which has three legs	7.69
Percentage of the intersection approach which has one left-turn lane	85.71
Percentage of the intersection approach which has two through lanes	14.29
LINCOLN_45MPH_ INS, ISS	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	1.57 (2.06) (0) (15)
Percentage of combination of narrowed left-turn lane and standard through lane width for each intersection approach	11.39
Percentage of westbound and eastbound intersection approaches of Nebraska Hwy and 27th St	2.53
Percentage of the intersection approach which has two through lanes	84.81

OMAHA_30NCBD_I0N, I0S	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	0.48 (0.86) (0) (6)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	2962.38 (2031.86) (140) (6565)
Percentage of the intersection approach which has three legs	7.3
OMAHA_30NCBD_INS, ISS	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	0.91 (1.50) (0) (10)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	2813.41 (1919.62) (402.67) (14559.33)
Percentage of intersection approach with shoulder	9.09
OMAHA_35NCBD_I0N, I0S	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	0.97 (1.47) (0) (13)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	4035.27 (3101.36) (500) (10325)
Average of average daily traffic in vehicles in minor street corresponding to each intersection approach (std. dev.) (min) (max)	3707.78 (6892.36) (154) (38534)
Percentage of 90° skew angle of the intersection	73.49
Percentage of southbound and northbound intersection approaches of 72nd St and Cass St	0.6
Percentage of the intersection approach which has three legs	28
OMAHA_35NCBD_INN, INS, ISS	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	1.47 (1.97) (0) (12)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	365244 (2113.39) (581.2) (9704.67)
Average of average daily traffic in vehicles in minor street corresponding to each intersection approach (std. dev.) (min) (max)	10917 (14511) (593) (79562)
Percentage of 90° skew angle of the intersection	82.47
Percentage of the intersection approach which has three legs	9.74
Percentage of the intersection approach which has one left-turn lane	90.26
OMAHA_40MPH_INS, ISS	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	1.48 (2.18) (0) (18)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	4173.03 (2299.59) (350) (10579.6)
Percentage of southbound and northbound intersection approaches of 120th St and W center St	0.54
Percentage of westbound and eastbound intersection approaches of	0.54

West maple St and N 90th St	
Percentage of the intersection approach which has three legs	7.81
Percentage of the intersection approach which has one left-turn lane	90.02
Percentage of the intersection approach which has one through lane	8.36
OMAHA_45MPH_INN, INS, ISS	
Variables	**Value**
Average annual crash frequency for each intersection approach (std. dev.) (min) (max)	1.05 (2.12) (0) (25)
Average of average daily traffic in vehicles per lane for each intersection approach (std. dev.) (min) (max)	3936.78 (2500.42) (239.2) (11620)
Average of average daily traffic in vehicles in minor street corresponding to each intersection approach (std. dev.) (min) (max)	11876.94 (10879.35) (591) (45832)
Percentage of combination of narrowed left-turn lane and narrowed through lane width for each intersection approach	2.57
Percentage of combination of narrowed left-turn lane and standard through lane width for each intersection approach	2.28
Percentage of northbound and southbound intersection approaches of N 144th St and Q St	0.43
Percentage of northbound and southbound intersection approaches of N 144th St and S Industrial Rd	0.42
Percentage of northbound and southbound intersection approaches of West maple St and 132nd St	0.54
Percentage of the intersection approach which has four legs	91.71
Percentage of the intersection approach which has one left-turn lane	80.57
Percentage of intersection approach with shoulder	37.14

Figure 4.3 depicts the box plot of the relationship between the combinations of lane widths and the annul crash frequency of different models for Lincoln and Omaha.



Lincoln: 11= I0N, 12= I0S, 13=INN, 14=INS, 15=ISS
Omaha: 21 = I0N, 22 = I0S, 23 = INN, 24 = INS, 25 = ISS

Figure 4.3 Lane width vs. crash frequency in Lincoln and Omaha on intersection approaches

4.3.3 Models Output

4.3.3.1 Results for group LINCOLN_35NCBD_I0N, I0S

A random parameter negative binomial model was used to analyze crash frequency data for Lincoln that is outside of the central business district, has a 35 mph speed limit, and uses the following combinations: narrowed through lanes without left-turn lanes and standard through lanes without left-turn lanes.

Table 4.14 shows parameter estimation results and the corresponding average marginal effects.

Table 4.14 Random parameter NB model results for group LINCOLN_35NCBD_I0N, I0S

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-0.46	-3.63	-0.36
Average daily traffic in vehicles per lane for each intersection approach	0.0001	6.07	0.00009
Indicator of intersection approach with median	-0.86	-2.51	-0.67
Indicator of combination of narrowed through lanes without left-turn lanes for each intersection approach	-0.44	-3.56	-0.34
Indicator of the intersection approach which has three legs *	-0.65 (0.59)	-2.83 (2.62)	-0.51
Dispersion parameter	*2.11*	*3.71*	
Number of observations	*430*		
Log-likelihood with constant only	*-778.43*		
Log-likelihood at convergence	*-541.99*		
McFadden's pseudo R-squared statistic	*0.30*		
Chi squared	*472.89*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are three significant fixed parameters and one significant random parameter shown in the model. Overall, the model fits well, as indicated by the log-likelihood at convergence (-541.99), which indicates an improvement over the log-likelihood that only includes the constant in the model (-778.43). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. A one-vehicle increase of average daily traffic in vehicles per lane for each intersection approach increases crash frequency by 0.00009 crashes per year. Intersection approaches with a median decrease crashes by 0.67 per year relative to intersection approaches without a median, while a combination of narrowed through lane widths without left-turn lanes for each intersection approach decreases the crash frequency by 0.34 crashes per year. This result is compared to the combination of standard through lanes without left-turn lanes for each intersection approach.

Random parameter. Intersection approaches at three-legged intersections decrease the crash frequency by 0.51 crashes per year at 87% of intersection approaches compared to intersection approaches at four-legged intersections.

4.3.3.2 Results for group LINCOLN_35NCBD_INN, INS, ISS

A random parameter negative binomial model was used to analyze crash frequency data for Lincoln that was outside of the central business district, had a 35 mph speed limit, and contained the following combinations: narrowed left-turn lanes and narrowed through lanes, narrowed left-turn lanes and standard through lanes, and standard left-turn lanes and standard through lanes.

Parameter estimation results and their corresponding average marginal effects are shown in table 4.15.

Table 4.15 Random parameter NB model results for group LINCOLN_35NCBD_INN, INS, ISS

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-0.62	-5.74	-0.85
Average daily traffic in vehicles per lane for each intersection approach	0.0002	22.89	0.0004
Indicator of combination of narrowed left-turn lanes and narrowed through lanes for each intersection approach	-0.12	-1.88	-0.17
Indicator of southbound and northbound intersection approaches of 27th St and Vine St	1.33	3.81	1.81
Average daily traffic in vehicles in the minor street for each intersection	0.00001	5.25	0.00002
Indicator of 90° skew angle of the intersection *	-0.34 (0.29)	-4.68 (8.82)	-0.45
Dispersion parameter	*2.26*	*10.41*	
Number of observations	*1640*		
Log-likelihood with constant only	*-4637.05*		
Log-likelihood at convergence	*-2375.88*		
McFadden's pseudo R-squared	*0.49*		
Chi squared	*4522.35*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses

There are four significant fixed parameters and one significant random parameter shown in the model. Overall, the model fits very well, as indicated by the log-likelihood at convergence

(-2374.88), which shows an improvement over the log-likelihood that only included the constant in the model (-4637.05). The statistical significance of the dispersion parameter indicated that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. A one-vehicle increase of average daily traffic in vehicles per lane for each intersection approach increases crash frequency by 0.0004 crashes per year. The combination of narrowed left-turn lanes and narrowed through lanes for each intersection approach decreases crashes by 0.17 per year compared to the other two combinations. The southbound and northbound intersection approaches of 27th St and Vine St increase crashes by 1.81 per year compared to other intersection approaches. A one-vehicle increase of average daily traffic in vehicles on the minor street of the intersection increases crashes by 0.00002 per year.

Random parameter. A 90° skew angle at the intersection decreases crash frequency by 0.45 crashes per year at 63% of intersection approaches.

4.3.3.3 Results for group LINCOLN_40MPH_ INN, INS, ISS

A random parameter negative binomial model was used to analyze crash frequency data in Lincoln with a 40 mph speed limit and the following combinations: narrowed left-turn lanes and narrowed through lanes, narrowed left-turn lanes and standard through lanes, and standard left-turn lanes and standard through lanes.

Parameter estimation results and the corresponding average marginal effects are shown in table 4.16.

Table 4.16 Random parameter NB model results for group LINCOLN_40MPH_ INN, INS, ISS

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	1.48	10.08	2.56
Average daily traffic in vehicles per lane for each intersection approach	0.0002	7.56	0.0003
Indicator of the intersection approach which has three legs	-0.85	-5.56	-1.99
Indicator of the intersection approach which has 1 left-turn lane	-0.89	-7.70	-1.54
Indicator of the intersection approach which has 2 through lanes	-0.73	-5.59	-1.26
Indicator of combination of narrowed left-turn lanes and standard through lanes for each intersection approach *	-0.17 (0.28)	-1.8 (2.14)	-0.29
Dispersion parameter	*2.00*	*7.87*	
Number of observations	*910*		
Log-likelihood with constant only	*-3185.87*		
Log-likelihood at convergence	*-1596.46*		
McFadden's pseudo R-squared	*0.50*		
Chi squared	*3178.82*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses

There are four significant fixed parameters and one significant random parameter shown in the model. Overall, the model fits very well, as indicated by the log-likelihood at convergence (-1596.46), which shows an improvement over the log-likelihood that only included the constant in the model (-3185.87). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters: A one-vehicle increase in average daily traffic in vehicles per lane for each intersection approach increases crash frequency by 0.0003 crashes per year. Intersection approaches that are located at three-legged intersections decrease crash frequency by 1.99 crashes per year compared to intersection approaches at four-legged intersections. Intersection approaches with only one left-turn lane decrease crashes by 1.39 per year compared to intersection approaches with two left-turn lanes. Intersection approaches with two through lanes have 0.82 less crashes per year compared to intersection approaches with one or three through lanes.

Random parameter: A combination of narrowed left-turn lanes and standard through lane widths for each intersection approach decreases crash frequency by 0.29 crashes per year at 73% of intersection approaches compared to the other two lane width combinations.

4.3.3.4 Results for group LINCOLN_45MPH_ INS, ISS

A random parameter negative binomial model was used to analyze crash frequency data in Lincoln with a 45 mph speed limit and the following combinations: narrowed left-turn lanes with standard through lanes and standard left-turn lanes with standard through lanes.

Parameter estimation results and the corresponding average marginal effects are shown in table 4.17.

Table 4.17 Random parameter NB model results for group LINCOLN_45MPH_ INS, ISS

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	0.41	3.79	0.59
Indicator of combination of narrowed left-turn lanes and standard through lanes for each intersection approach	0.39	2.23	0.56
Indicator of westbound and eastbound intersection approaches of Nebraska Hwy and 27th St	1.44	3.30	2.07
Indicator of the intersection approach which has 2 through lanes *	-0.15 (0.20)	-1.23 (4.04)	-0.22
Dispersion parameter	*1.44*	*7.41*	
Number of observations	*790*		
Log-likelihood with constant only	*-2306.58*		
Log-likelihood at convergence	*-1308.83*		
McFadden's pseudo R-squared	*0.43*		
Chi squared	*1995.50*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses

There are two significant fixed parameters and one significant random parameter shown in the model. Overall, the model fits very well, as indicated by the log-likelihood at convergence (-1308.83), which shows an improvement over the log-likelihood that only included the constant in the model (-2306.58). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which indicates that the negative binomial model was appropriate for the data.

Fixed parameters. The combination of narrowed left-turn lanes and standard through lanes for each intersection approach increases the crash frequency by 0.56 crashes per year relative to the combination of standard left-turn lanes and standard through lanes. The westbound and eastbound intersection approaches of Nebraska Hwy and 27th St increase crashes by 2.07 per year compared to other intersection approaches.

Random parameter. Intersection approaches with two through lanes decrease crash frequency by 0.22 crashes per year at 77% of the intersection approaches compared to intersection approaches with one or three through lanes.

4.3.3.5 Results for group OMAHA_30NCBD_I0N, I0S

A random parameter negative binomial model was used to analyze crash frequency data in Omaha that was outside of the central business district, had a 30 mph speed limit, and used the following combinations: narrowed through lanes without left-turn lanes and standard through lanes without left-turn lanes.

Parameter estimation results and the corresponding average marginal effects are shown in table 4.18.

Table 4.18 Random parameter NB model results for group OMAHA_30NCBD_I0N, I0S

Variable	Parameter estimate	t-Stat.	Average marginal effect
Constant	-1.02	-8.07	-0.52
Average daily traffic in vehicles per lane for each intersection approach	0.0001	3.16	0.00006
Indicator of the intersection approach which has three legs *	-0.82 (1.13)	-2.24 (3.03)	-0.42
Dispersion parameter	*1.19*	*4.70*	
Number of observations	*820*		
Log-likelihood with constant only	*-863.61*		
Log-likelihood at convergence	*-717.53*		
McFadden's pseudo R-squared	*0.17*		
Chi squared	*292.16*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There is one significant fixed parameter and one significant random parameter shown in the model. Overall, the model does not fit very well, as indicated by the log-likelihood at convergence (-717.53), which shows an improvement over the log-likelihood that only included the constant in the model (-863.61). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameter. For each intersection approach, an increase in average daily traffic in vehicles per lane by one vehicle increases crashes by 0.00006 per year.

Random parameter. Intersection approaches at three-legged intersections decrease the crash frequency by 0.42 crashes per year at 76% of the intersection approaches compared to intersection approaches at four-legged intersections.

4.3.3.6 Results for group OMAHA_30NCBD_INS, ISS

A random parameter negative binomial model was used to analyze crash frequency data in Omaha that was outside of the central business district, had a 30 mph speed limit, and contained the following combinations: narrowed left-turn lanes with standard through lanes and standard left-turn lanes with standard through lanes.

Parameter estimation results and the corresponding average marginal effects are shown in table 4.19.

Table 4.19 Random parameter NB model results for group OMAHA_30NCBD_INS, ISS

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-0.61	-5.53	-0.49
Indicator of intersection approach with shoulder	-2.24	-8.70	-1.81
Average daily traffic in vehicles per lane for each intersection approach *	0.00017 (0.00013)	5.30 (8.69)	0.0001
Dispersion parameter	*1.41*	*7.29*	
Number of observations	*770*		
Log-likelihood with constant only	*-1444.89*		
Log-likelihood at convergence	*-933.69*		
McFadden's pseudo R-squared	*0.35*		
Chi squared	*1022.39*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There is one significant fixed parameter and one significant random parameter shown in the model. Overall, the model fits well, as indicated by the log-likelihood at convergence (-933.69), which shows an improvement over the log-likelihood that only included the constant in the model (-1444.89). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameter. Intersection approaches with a shoulder decrease crash frequency by 1.81 crashes per year compared to intersection approaches without a shoulder.

Random parameter. For each intersection approach, a one-vehicle increase in average daily traffic (vehicles per lane) increases crash frequency at 91% of the intersection approaches.

4.3.3.7 Results for group OMAHA_35NCBD_I0N, I0S

A random parameter negative binomial model was used to analyze crash frequency data that was outside of the central business district in Omaha, had a 35 mph speed limit, and contained the combinations of no left-turn lanes with narrowed through lanes and no left-turn lanes with standard through lanes.

Parameter estimation results and the corresponding average marginal effects are shown in table 4.20.

Table 4.20 Random parameter NB model results for group OMAHA_35NCBD_I0N, I0S

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-1.14	-6.98	-1.11
Average daily traffic in vehicles per lane for each intersection approach	0.0001	6.33	0.0001
Indicator of southbound and northbound intersection approaches of 72nd St and Cass St	1.29	2.23	1.26
Indicator of the intersection approach that has three legs	-0.25	-2.59	-0.24
Average daily traffic in vehicles in the minor street for each intersection	0.00002	3.986	0.00002
Indicator of 90° skew angle of the intersection *	0.46 (0.29)	4.78 (5.74)	0.45
Dispersion parameter	*3.27*	*4.01*	
Number of observations	*1000*		
Log-likelihood with constant only	*-1552.78*		
Log-likelihood at convergence	*-1079.09*		
McFadden's pseudo R-squared	*0.31*		
Chi squared	*947.37*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are four significant fixed parameters and one significant random parameter shown in the model. Overall, the model fits well, as indicated by the log-likelihood at convergence (-1079.09), which shows an improvement over the log-likelihood that only included the constant in the model (-1552.78). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. For each intersection approach, a one-vehicle increase in average daily traffic in vehicles per lane increases crashes by 0.0001 per year. The southbound and northbound intersection approaches of 72nd St and Cass St increase crashes by 1.26 per year compared to other intersection approaches. Intersection approaches with three legs have 0.24 fewer crashes per year compared to two-legged and four-legged intersections. A one-vehicle increase in average daily traffic on the minor street will increase crashes by 0.00002 per year in the intersection approach located at the corresponding major street.

Random parameter. A 90° skew angle of the intersection increases crash frequency by 0.45 crashes per year at 94% of the intersection approaches.

4.3.3.8 Results for group OMAHA_35NCBD_INN, INS, ISS

A random parameter negative binomial model was used to analyze crash frequency data outside of the central business district in Omaha, had a 35 mph speed limit, and had the following combinations: narrowed left-turn lanes with narrowed through lanes, narrowed left-turn lanes with standard through lanes, and standard left-turn lanes with standard through lanes.

The parameter estimation results and corresponding average marginal effects are shown in table 4.21.

Table 4.21 Random parameter NB model results for group OMAHA_35NCBD_INN, INS, ISS

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-0.81	-3.79	-1.15
Average daily traffic in vehicles per lane for each intersection approach	0.0002	8.90	0.0003
Indicator of the intersection approach that has three legs	-0.76	-5.25	-1.08
Indicator of the intersection approach which has one left-turn lane	-0.26	-2.35	-0.36
Average daily traffic in vehicles in the minor street for each intersection	0.00001	4.97	0.00002
Indicator of 90° skew angle of the intersection *	0.53 (0.29)	4.63 (7.51)	0.76
Dispersion parameter	*1.66*	*9.86*	
Number of observations	*1540*		
Log-likelihood with constant only	*-3467.41*		
Log-likelihood at convergence	*-2168.99*		
McFadden's pseudo R-squared	*0.44*		
Chi squared	*3467.41*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are four significant fixed parameters and one significant random parameter shown in the model. Overall, the model fits very well, as indicated by the log-likelihood at convergence (-2168.99), which shows an improvement over the log-likelihood that only included the constant in the model (-3467.41). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. For each intersection approach, a one-vehicle increase in average daily traffic in vehicles per lane increases crashes by 0.0003 per year. Intersection approaches with three legs have 1.08 fewer crashes per year compared to four-legged intersections. Intersection approaches with one left-turn lane decrease the crash frequency by 0.36 crashes per year compared to intersection approaches with two left-turn lanes. A one-vehicle increase in average daily traffic on the minor street will increase crashes by 0.00002 per year in the intersection approach located at the corresponding major street.

Random parameter. A 90° skew angle of the intersection increases the crash frequency by 0.76 crashes per year at 96% of the intersection approaches.

4.3.3.9 Results for group OMAHA_40MPH_INS, ISS

A random parameter negative binomial model was used to analyze crash frequency data with a 40 mph speed limit in Omaha and the following combinations: narrowed left-turn lanes with standard through lanes and standard left-turn lanes with standard through lanes.

The parameter estimation results and corresponding average marginal effects are shown in table 4.22.

Table 4.22 Random parameter NB model results for group OMAHA_40MPH_INS, ISS

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	0.29	3.34	0.43
Average daily traffic in vehicles per lane for each intersection approach	0.0002	15.30	0.0002
Indicator of southbound and northbound intersection approaches of 120th St and W center St	1.41	2.03	2.06
Indicator of westbound and eastbound intersection approaches of West maple St and N 90th St	1.51	1.76	2.21
Indicator of the intersection approach that has one left-turn lane	-0.62	-7.35	-0.90
Indicator of the intersection approach that has one through lane	-0.27	-3.31	-0.39
Indicator of the intersection approach which has three legs *	-1.05 (0.86)	-8.02 (6.75)	-1.53
Dispersion parameter	*0.99*	*27.03*	
Number of observations	*3710*		
Log-likelihood with constant only	*-10830.40*		
Log-likelihood at convergence	*-5662.55*		
McFadden's pPseudo R-squared	*0.48*		
Chi squared	*10335.72*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are five significant fixed parameters and one significant random parameter shown in the model. Overall, the model fits very well, as indicated by the log-likelihood at convergence (-10830.40), which shows an improvement over the log-likelihood that only included the constant in the model (-5662.55). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. For each intersection approach, a one-vehicle increase in average daily traffic in vehicles per lane increases crashes by 0.0002 per year. The southbound and northbound intersection approaches of 120th St and W Center St increase crashes by 2.06 per year compared to other intersection approaches. The westbound and eastbound intersection approaches of West Maple St and N 90th St increase crashes by 2.21 per year compared to other intersection approaches. Intersection approaches with one left-turn lane decrease the crash frequency by 0.82 crashes per year compared to intersection approaches with two left-turn lanes. Intersection approaches with one through lane decrease crashes by 0.18 per year relative to intersection approaches with two or three through lanes.

Random parameter. Intersection approaches at three-legged intersections decrease the crash frequency by 1.53 crashes per year at 89% of the intersection approaches compared to intersection approaches at four-legged intersections.

4.3.3.10 Results for group OMAHA_45MPH_INN, INS, ISS

A random parameter negative binomial model was used to analyze crash frequency data with a 45 mph speed limit in Omaha and the following combinations: narrowed left-turn lanes with narrowed through lanes, narrowed left-turn lanes with standard through lanes, and standard left-turn lanes with standard through lanes.

Parameter estimation results and the corresponding average marginal effects are shown in table 4.23.

Table 4.23 Random parameter NB model results for group OMAHA_45MPH_INN, INS, ISS

Variable	**Parameter estimate**	**t-Stat.**	**Average marginal effect**
Constant	-2.11	-12.92	-1.39
Average daily traffic in vehicles per lane for each intersection approach	0.0003	20.24	0.0002
Indicator of combination of narrowed left-turn lanes and narrowed through lanes for each intersection approach	-1.77	-6.19	-1.17
Indicator of combination of narrowed left-turn lanes and standard through lanes for each intersection approach	0.64	3.96	0.42
Indicator of northbound and southbound intersection approaches of N 144th St and Q St	1.02	2.12	0.67
Indicator of northbound and southbound intersection approaches of N 144th St and S Industrial Rd	1.12	4.19	0.74
Indicator of northbound and southbound intersection approaches of West maple St and 132nd St	0.93	3.52	0.61
Indicator of the intersection approach that has four legs	0.64	4.87	0.42
Average daily traffic in vehicles in the minor street for each intersection	0.00004	12.42	0.00003
Indicator of the intersection approach that has one left-turn lane *	-1.03 (0.99)	-14.21 (24.69)	-0.68
Indicator of intersection approach with shoulder *	0.32 (0.43)	6.00 (11.87)	0.21
Dispersion parameter	*1.63*	*15.33*	
Number of observations	*3500*		
Log-likelihood with constant only	*-7286.39*		
Log-likelihood at convergence	*-3516.09*		
McFadden's pseudo R-squared	*0.52*		
Chi squared	*7540.57*		

* Random parameter; all random parameters are normally distributed; the standard deviation of parameter distribution is shown in parentheses.

There are eight significant fixed parameters and two significant random parameters shown in the model. Overall, the model fits very well, as indicated by the log-likelihood at convergence (-3516.09), which shows an improvement over the log-likelihood that only included the constant in the model (-7286.39). The statistical significance of the dispersion parameter showed that it was significantly different than zero, which means the negative binomial model was appropriate for the data.

Fixed parameters. For each intersection approach, a one-vehicle increase in average daily traffic in vehicles per lane increases crashes by 0.0002 per year. The combination of narrowed left-turn lanes and narrowed through lanes for each intersection approach decreases crashes by 1.17 per year, and the combination of narrowed left-turn lanes and standard through lanes for each intersection approach increases crashes by 0.42 per year. These results are compared to the combination of standard left-turn lanes and standard through lanes. The northbound and southbound intersection approaches of N 144th St and Q St increase the crash frequency by 0.67 crashes per year compared to other intersection approaches. The northbound and southbound intersection approaches of N 144th St and S Industrial Rd increase crashes by 0.74 per year compared to other intersection approaches. The northbound and southbound intersection approaches of West Maple St and 132nd St increase crashes by 0.61 per year compared to other intersection approaches. Intersection approaches at four-legged intersections increase the crash frequency by 0.42 crashes per year compared to intersection approaches at three-legged or six-legged intersections. A one-vehicle increase of average daily traffic on the minor street will increase crashes by 0.00003 per year in the intersection approach located at the corresponding major street.

Random parameters. Intersection approaches with one left-turn lane decrease the crash frequency by 0.68 crashes per year at 94% of the intersection approaches compared to intersection approaches that have two left-turn lanes. Intersection approaches with a shoulder increase the crash frequency by 0.21 crashes per year at 77% of the intersection approaches relative to those approaches without shoulders.

4.3.4 Summary

The effects of the lane widths based on the output from the models discussed above are summarized in table 4.24.

Table 4.24 Summary of the effects of lane width

a. Number of sites

Lincoln				
	30 NCBD	35 NCBD	40	45
I0N	0	20	4	2
I0S	0	23	3	5
INN	1	70	22	4
INS	0	50	20	9
ISS	0	44	49	70
OMAHA				
	30NCBD	35NCBD	40MPH	45MPH
I0N	9	21	1	4
I0S	73	79	78	44
INN	5	17	5	9
INS	15	13	25	8
ISS	62	124	346	333

b. Marginal Impacts of lane widths

LINCOLN				
	30 NCBD	35NCBD	40MPH	45MPH
I0N	-	-0.22	-	-
I0S	-	Base	-	-
INN	-	-0.13	Not Sig	-
INS	-	Not Sig	-0.15 (71%)	0.614*
ISS	-	Base	Base	Base
OMAHA				
	30NCBD	35NCBD	40MPH	45MPH
I0N	Not Sig*	Not Sig	-	-
I0S	Base	Base	-	-
INN	-	Not Sig	-	0.47*
INS	Not Sig	Not Sig	Not Sig	0.42*
ISS	Base	Base	Base	Base

* Less than 10 sites available for modelling

The base values of lane width combinations are I0S or ISS. The cells in green indicate that the corresponding lane width combination decreases the crash frequency compared to I0S or ISS, meaning the green-shaded lane width combination is safer than I0S or ISS. The cells in red indicate that the corresponding lane width combination increases crash frequency compared to I0S or ISS. In other words, the lane width combination is more dangerous than I0S or ISS. The cells in yellow indicate that the corresponding lane width combination has a random effect on crash frequency, and the percentage in parentheses shows the probability of a corresponding lane width effect. An "-" in the cell means that the specific lane width combination was not analyzed in this study because of a small sample size. A “Not Sig” cell indicates that there is no significant difference between a specific lane width and 12 ft wide lanes.

Taking the results from Lincoln and Omaha into consideration, table 4.24 shows that the combination of no left-turn lanes and narrowed through lanes (I0N) decreases the crash frequency compared to the combination of no left-turn lanes and standard through lanes (I0S) at 35NCBD. The combination of narrowed left-turn lanes and narrowed through lanes (INN) decreases the crash frequency at 35NCBD and 45MPH compared to the combination of standard left-turn lanes and standard through lanes (ISS). However, the combination of narrowed left-turn lanes and standard through lanes (INS) increases the crash frequency compared to the combination of standard left-turn lanes and standard through lanes (ISS). It can be recommended that a combination of narrow left turn bay with standard through lane should be avoided for high speed intersections. Also, usually narrow lane width for both through as well as left turn bay enhances safety or has no impacts for speed limit of 35 mph.

Chapter 5 Operational Data Analysis

5.1 Effects of Lane Width on Traffic Speed at Mid-block Segments

Vehicle traffic speed was analyzed by creating linear regression models and box plots. The linear regression models test the effect that lane widths have on the traffic speed of vehicles compared to 12 ft wide lanes. The null hypothesis of the linear regression model is that the specific lane width has no significant effect on vehicle traffic speed compared to a 12 ft lane. There is a 95% confidence interval for the linear regression model. The tested variables are vehicles' traffic speed, and the independent variables are through lane widths, shoulder indicator, shoulder type, shoulder width, median indicator, median type, median width, number of through lanes, segment length, and five-minute real-time volume in the tested segment. The collected sites are divided into four groups (25CBD, 35NCBD, 40MPH, and 45MPH) and two data collection time periods (1:00 pm to 3:00 pm, 3:30 pm to 5:30 pm), resulting in eight linear regression models. The models' outputs are listed in tables 5.1 and 5.2. The information collected on the mid-block segments is shown in table 3.3.

Table 5.1 Results of linear regression models (1:00 pm to 3:00 pm)

Model Summary in 25CBD		
Dependent Variable		Vehicles' Traffic speed
Number of Observations		1456
Adjusted R Square		0.177
Coefficient Estimation		
Independent Variables	Unstandardized Coefficient	t-statistics
Constant	23.651	41.539
Indicator of 9 ft lane width	-6.186	-14.445
Indicator of 10 ft lane width	-4.236	-8.654
Model Summary in 35NCBD		
Dependent Variable		Vehicles' Traffic speed
Number of Observations		3099
Adjusted R Square		0.055
Coefficient Estimation		
Independent Variables	Unstandardized Coefficient	t-statistics
Constant	36.972	31.009
Indicator of 9 ft lane width	3.213	3.795
Indicator of shoulder appearance	2.503	7.390
Number of through lanes	-0.832	-2.165
Number of vehicles in every five minutes	-0.024	-3.998
Model Summary in 40MPH		
Dependent Variable		Vehicles' Traffic speed
Number of Observations		5005
Adjusted R Square		0.379
Coefficient Estimation		
Independent Variables	Unstandardized Coefficient	t-statistics
Constant	42.885	113.809
Indicator of 10 ft lane width	-6.279	-24.451
Indicator of 11 ft lane width	1.209	5.339
Number of vehicles in every five minutes	-0.029	-5.129
Model Summary in 45CBD		
Dependent Variable		Vehicles' Traffic speed
Number of Observations		4415
Adjusted R Square		0.448
Coefficient Estimation		
Independent Variables	Unstandardized Coefficient	t-statistics
Constant	34.885	64.940
Indicator of 10 ft lane width	-3.587	-18.952
Indicator of 11 ft lane width	9.901	28.769
Number of vehicles every five minutes	0.029	5.934

Table 5.2 Results of linear regression models (3:30 pm to 5:30 pm)

Model Summary in 25CBD		
Dependent Variable		Vehicles' Traffic speed
Number of Observations		2250
Adjusted R Square		0.226
Coefficient Estimation		
Independent Variables	Unstandardized Coefficient	t-statistics
Constant	23.717	64.830
Indicator of 9 ft lane width	-7.934	-19.961
Indicator of 10 ft lane width	1.323	4.115
Indicator of 11 ft lane width	-3.497	-9.501
Number of vehicles in every five minutes	-0.026	-2.924
Model Summary in 35NCBD		
Dependent Variable		Vehicles' Traffic speed
Number of Observations		4864
Adjusted R Square		0.119
Coefficient Estimation		
Independent Variables	Unstandardized Coefficient	t-statistics
Constant	36.193	64.337
Indicator of 9 ft lane width	1.962	3.349
Indicator of 10 ft lane width	3.947	13.738
Indicator of 11 ft lane width	7.636	19.598
Number of vehicles in every five minutes	-0.067	-9.623
Model Summary in 40MPH		
Dependent Variable		Vehicles' Traffic speed
Number of Observations		7754
Adjusted R Square		0.205
Coefficient Estimation		
Independent Variables	Unstandardized Coefficient	t-statistics
Constant	40.056	487.711
Indicator of 10 ft lane width	-5.211	-39.248
Indicator of 11 ft lane width	1.147	7.239
Model Summary in 45CBD		
Dependent Variable		Vehicles' Traffic speed
Number of Observations		6082
Adjusted R Square		0.588
Coefficient Estimation		
Independent Variables	Unstandardized Coefficient	t-statistics
Constant	43.394	77.442
Indicator of 10 ft lane width	-6.839	-48.637
Indicator of 11 ft lane width	6.064	23.430
Number of vehicles every five minutes	-0.031	-6.433

According to the linear regression models' output from 1:00 pm to 3:00 pm for 25CBD, lanes 9 ft and 10 ft wide significantly decrease traffic speed compared to lanes 11 ft and 12 ft wide (figure 5.1).

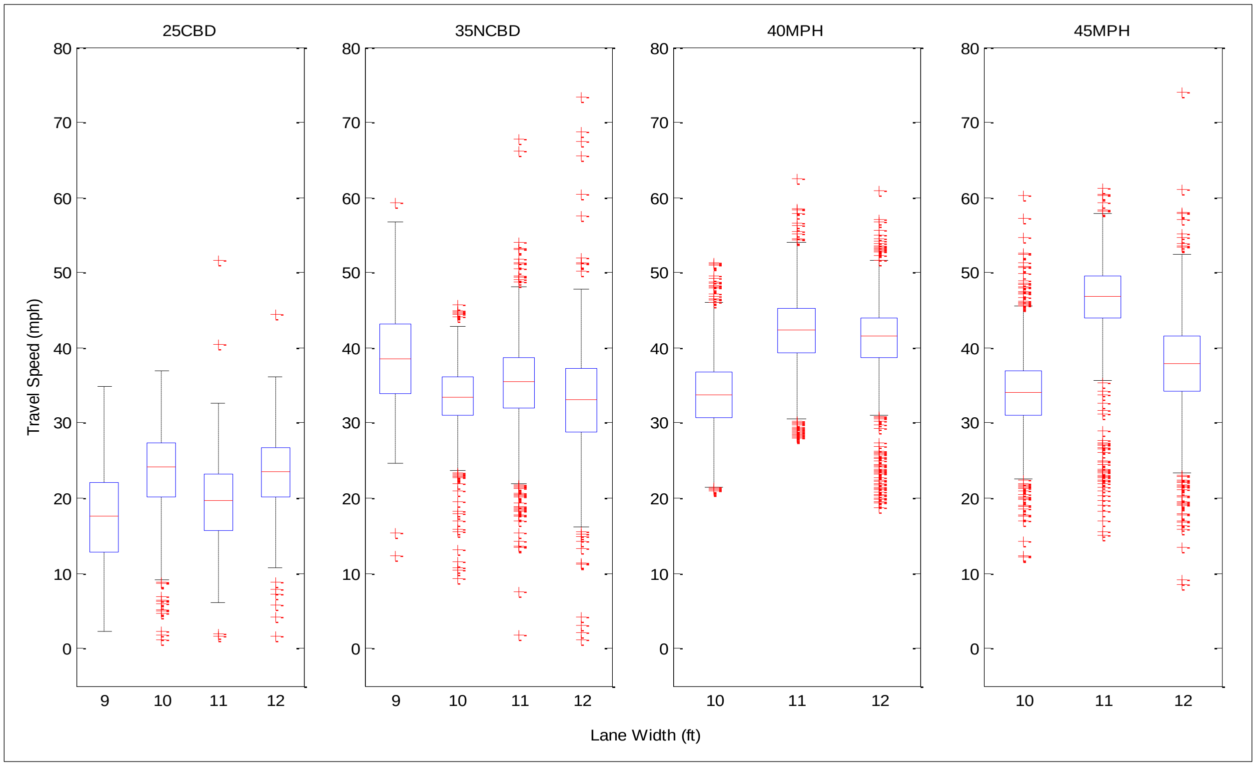


Figure 5.1 Lane width vs. traffic speed (1:00 pm to 3:00 pm)

For 35NCBD, a 9 ft lane width had higher traffic speed compared to 10 ft, 11 ft, and 12 ft wide lanes. Additionally, mid-block segments with shoulders increase traffic speed compared to mid-block segments without shoulders. An increased number of lanes at mid-block segments decreases traffic speed, and a higher number of vehicles for every five minutes decreases traffic speed at mid-block segments. For 40MPH, 10 ft lanes decrease the traffic speed compared to 12 ft lanes. Lanes 11 ft wide increase the traffic speed when compared to 12 ft lanes. A higher number of vehicles for every five minutes decreases the traffic speed in the segments. For 45MPH, 10 ft lanes decrease the traffic speed compared to 12 ft lanes. An 11 ft lane width increases traffic speed when compared to a 12 ft lane width.

As for the linear regression models' output from 3:30 pm to 5:30 pm for 25CBD, a 9 ft lane width had significantly lower traffic speed compared to a 12 ft lane width, and a 10 ft lane width increases the traffic speed compared to a 12 ft lane width (figure 5.2).

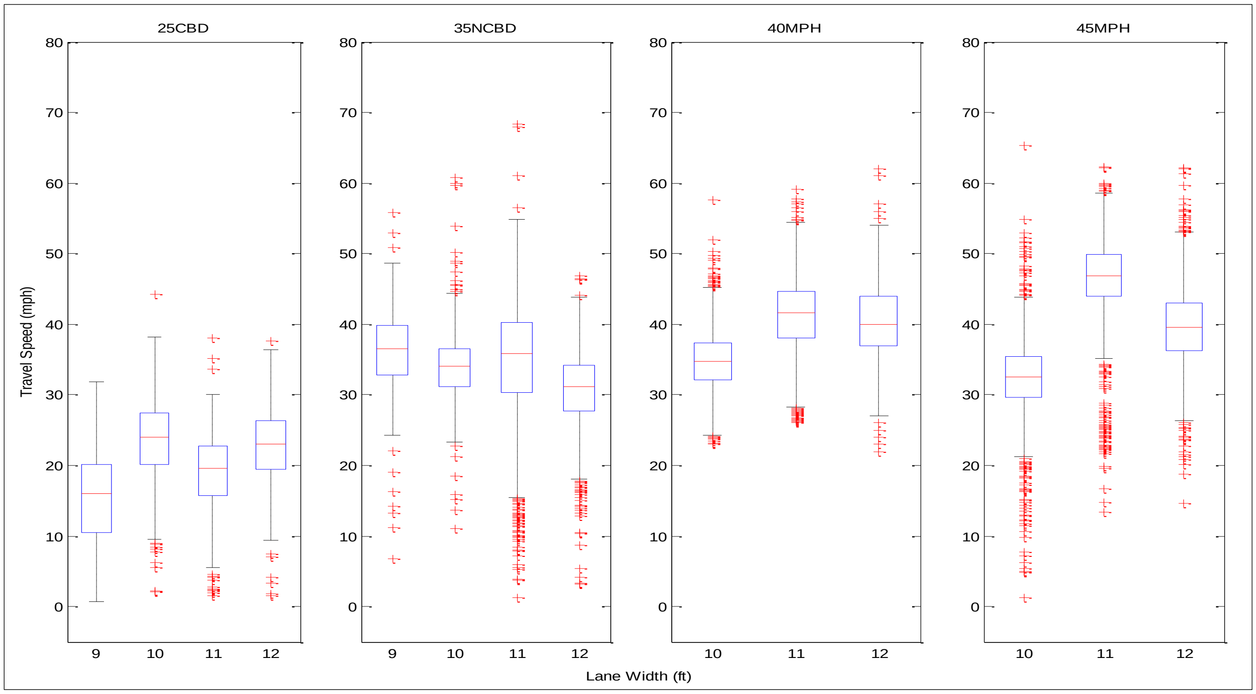


Figure 5.2 Lane width vs. traffic speed (3:30 pm to 5:30 pm)

Additionally, an 11 ft lane width had significantly lower the traffic speed compared to a 12 ft lane width, and at mid-block segments a higher number of vehicles for every five minutes decreases traffic speed. For 35NCBD, 9 ft, 10 ft, and 11 ft lane widths had significantly higher traffic speed when compared to a 12 ft lane width. In the mid-block segments, a higher number of vehicles for every five minutes decreases the traffic speed. For 40MPH, 10 ft lanes have lower traffic speed in comparison with 12 ft lanes. Lanes 11 ft wide have higher traffic speed when compared to lanes 12 ft wide. For 45MPH, a 10 ft lane had significantly lower traffic speed and an 11 ft lane increases the traffic speed when compared to a 12 ft wide lane. Finally, at mid-block segments a higher number of vehicles every five minutes decreases traffic speed.

Considering the box plots for vehicles' traffic speed by lane width, the plot trends are consistent with the linear regression models' output regarding the effects of lane width on traffic speed. As shown in the box plots from both 1:00 pm to 3:00 pm and 3:30 pm to 5:30 pm, narrow lane widths (9 ft or 10 ft) correspond to a higher traffic speed compared to wider lane widths (11 ft or 12 ft) for both 25CBD and 35NCBD. However, the trend illustrates the opposite for the 40MPH and 45MPH areas, where a 10 ft lane width reflects lower vehicle traffic speed compared to wider lane widths (11 ft or 12 ft).

5.2 Effects of Lane Width Lane Violation at Mid-block Segments

The lane violation analysis is based on the number of lane violations per vehicle by lane width in different groups (25CBD, 35NCBD, 40MPH, 45MPH) for both 1:00 pm to 3:00 pm and 3:30 pm to 5:30 pm. The vehicles were also divided into three categories: (1) sedan; (2) sport utility vehicle (SUV), pickup, and van; and (3) truck, bus, and recreational vehicle (RV). Figures 5.3 and 5.4 show the number of lane violations per vehicle for all types of vehicles. Figures 5.5 and 5.6 show the number of lane violations per vehicle for SUVs, pickups, and vans. Figures 5.7 and 5.8 depict the number of lane violations per vehicle for trucks, buses, and RVs.

Figures 5.3 and 5.4 illustrate that for all types of vehicles in 25CBD and 35NCBD, a greater number of lane violations per vehicle occurred with the 9 ft and 10 ft lanes as compared to the 11 ft and 12 ft lanes. Additionally, at 40MPH and 45MPH, a smaller number of lane violations per vehicle occurred in 10 ft lanes in comparison to 11 ft and 12 ft lanes.

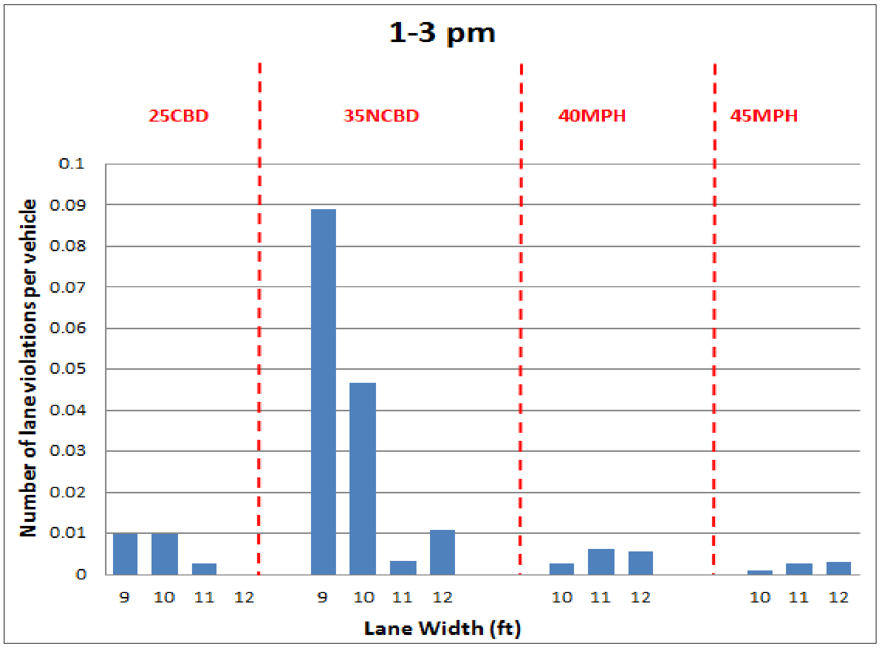


Figure 5.3 Number of lane violations per vehicle from 1:00 pm to 3:00 pm (all types of vehicles)

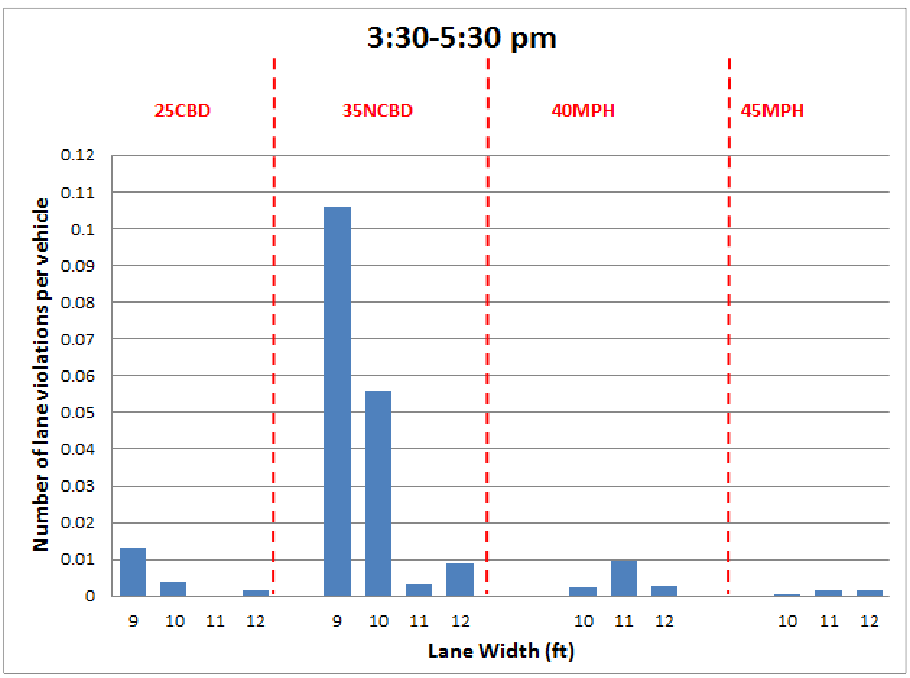


Figure 5.4 Number of lane violations per vehicle from 3:30 pm to 5:30 pm (all types of vehicles)

As for sedans, figures 5.5 and 5.6 illustrate that a greater number of lane violations per vehicle occurred in 25CBD and 35NCBD in 9 ft and 10 ft lanes compared to 11 ft and 12 ft lanes, and a smaller number of lane violations per vehicle occurred at 45MPH in 10 ft lanes compared to 11 ft and 12 ft lanes.

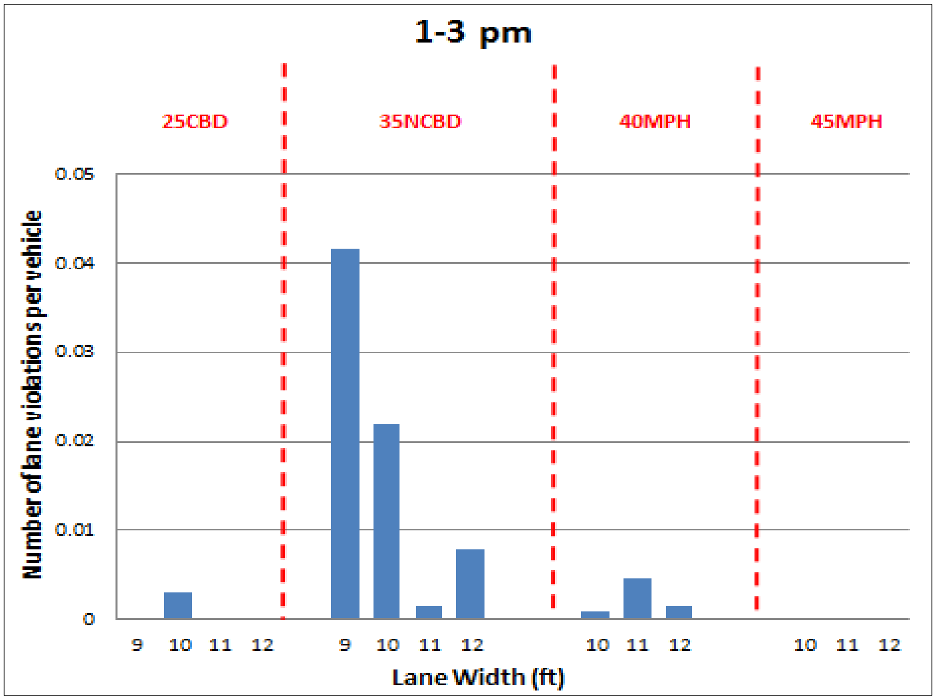


Figure 5.5 Number of lane violations per vehicle from 1:00 pm to 3:00 pm (sedan)

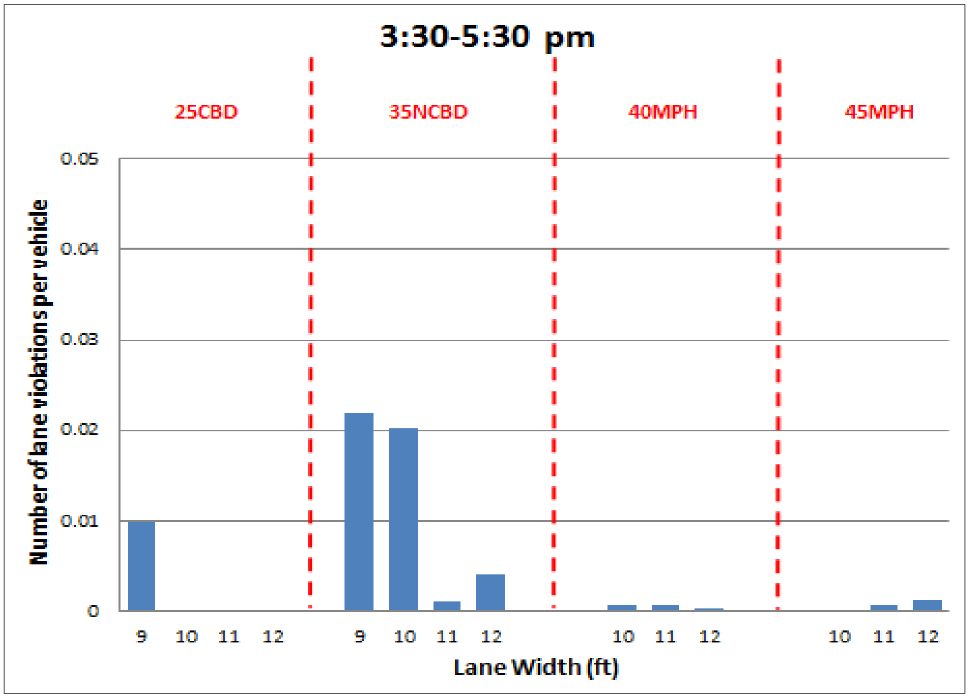


Figure 5.6 Number of lane violations per vehicle from 3:30 pm to 5:30 pm (sedan)

At 40MPH, figure 5.5 shows that lanes 10 ft wide have a smaller number of lane violations per vehicle relative to lanes 11 ft and 12 ft wide. Figure 5.6 shows that a similar number of lane violations per vehicle occurred in 10 ft, 11 ft, and 12 ft lanes.

Lane violations of SUVs, pickups, and vans are analyzed in figures 5.7 and 5.8.

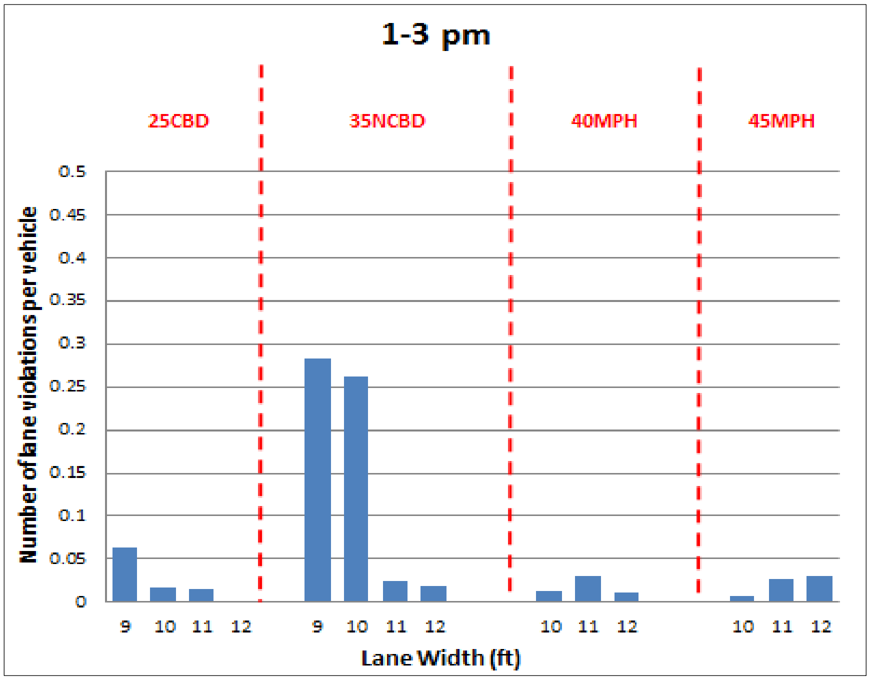


Figure 5.7 Number of lane violations per vehicle from 1:00 pm to 3:00 pm (SUV, pickup, van)

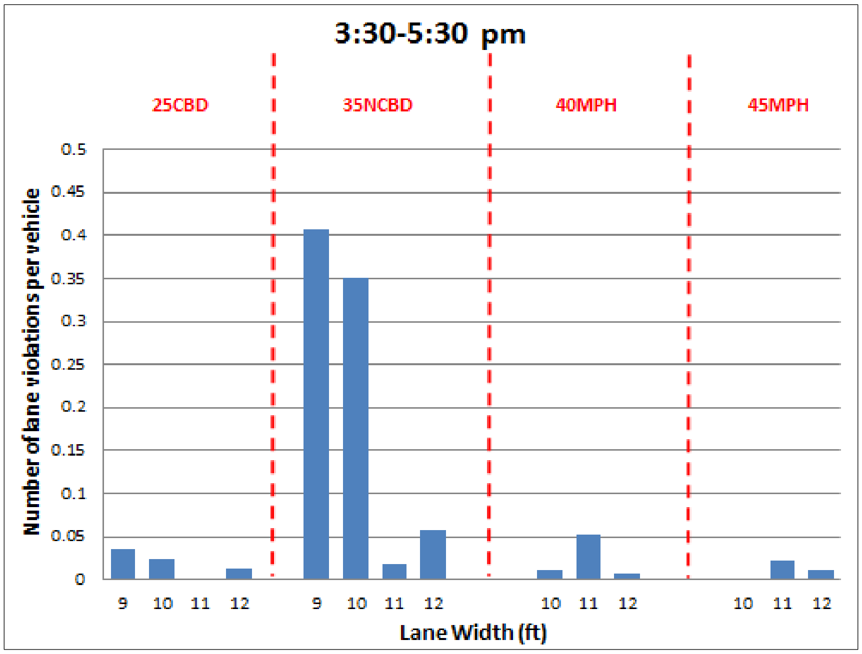


Figure 5.8 Number of lane violations per vehicle from 3:30 pm to 5:30 pm (SUV, pickup, van)

These figures reveal that a greater number of lane violations per vehicle happened in 9 ft and 10 ft lanes as opposed to 11 ft and 12 ft lanes for 25CBD and 35NCBD. Lanes 10 ft wide had a smaller number of lane violations per vehicle than 11 ft lanes, and lanes 10 ft and 12 ft wide had a similar number of lane violations per vehicle at 40MPH. Additionally, at 45MPH, a smaller number of lane violations per vehicle occurred in lanes 10 ft wide when compared to 11 ft and 12 ft lanes.

Considering the bus, truck, and RV analysis in figures 5.9 and 5.10, it is obvious that a greater number of lane violations per vehicle happened in the 9 ft and 10 ft lanes than in the 11 ft and 12 ft lanes at 25CBD and 35NCBD, and a larger number of lane violations per vehicle happened in 10 ft lanes than in lanes 11 ft and 12 ft wide at 40MPH and 45MPH.

Furthermore, buses, trucks, and RVs have the highest number of lane violations per vehicle compared to sedans, SUVs, pickups, and vans. Heavy vehicles appear to have a higher probability of committing lane violations.

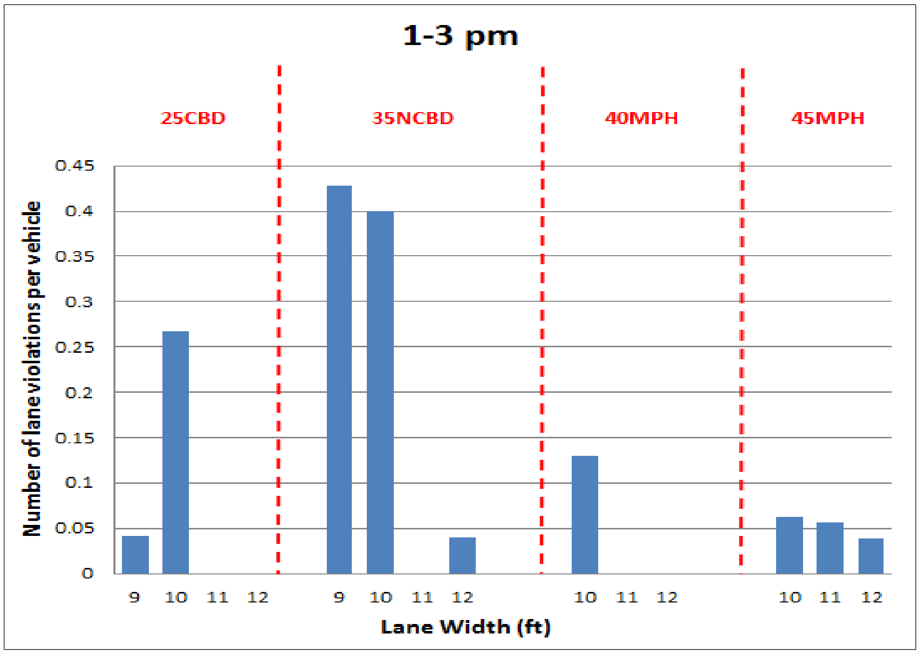


Figure 5.9 Number of lane violations per vehicle from 1:00 pm to 3:00 pm (truck, bus, RV)

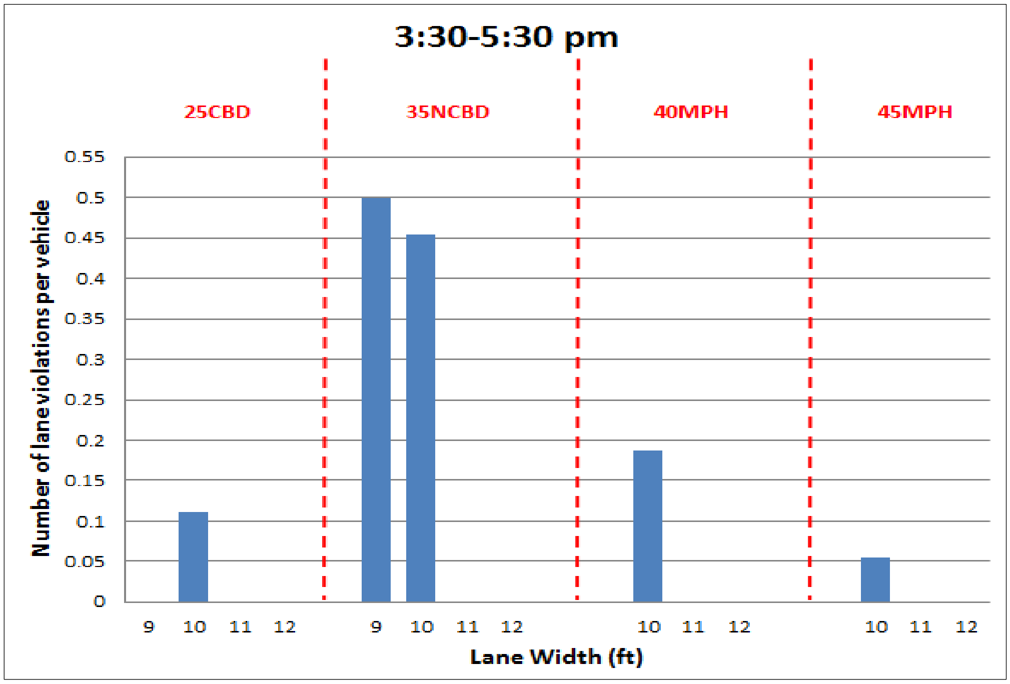


Figure 5.10 Number of lane violations per vehicle from 3:30 pm to 5:30 pm (truck, bus, RV)

5.3 Effects of Lane Width on Headway in the Queue at Intersection Approaches

The effects of lane width on headway in the queue at intersection approaches were tested using the Kolmogorov-Smirnov (K-S) test. The K-S test is a non-parametric test, which means that there is no assumption about the distribution of the tested variables. The K-S statistic quantifies a distance between the empirical distributions of two samples to test whether there is a significantly different cumulative distribution between two tested samples. In this research, the K-S test compared the empirical cumulative density function of the queue's discharged headway according to lane width combinations in different groups (25CBD, 30NCBD, 40MPH, 45MPH) and at different data collection times (1:00 pm to 3:00 pm, 3:30 pm to 5:30 pm). The vehicles in the queue were divided as follows: the first vehicle, the second vehicle, the third vehicle, the fourth vehicle, and the fifth and remaining vehicles in the queue.

The null hypothesis of the K-S test is that the cumulative distributions of a specific vehicle's headway by lane width combinations in the intersection approach are not significantly different. The alternative hypothesis is that there is a significant difference in the cumulative distributions of a specific vehicle's headway by lane width combinations. The confidence interval for the test is 95%. The variable $h=0$ means that the null hypothesis is accepted at the 95% confidence interval. The variable $h=1$ implies that the null hypothesis is rejected, which means the alternative hypothesis is accepted. The K-S test results are shown in figures 5.11 through 5.18.

Figure 5.11 shows that from 1:00 pm to 3:00 pm for 25CBD, there is a significant difference in the cumulative distributions of the first vehicle's headway between the combination of no left-turn lane and a narrowed through lane width (I0N) and the combination of no left-turn lane and a standard through lane width (I0S). In addition, there is no significant difference in the cumulative distributions of the other corresponding vehicles' headway in the queue between the combination of no left-turn lane and a narrowed through lane (I0N) and the combination of no left-turn lane and a standard through lane width (I0S) for 25CBD.

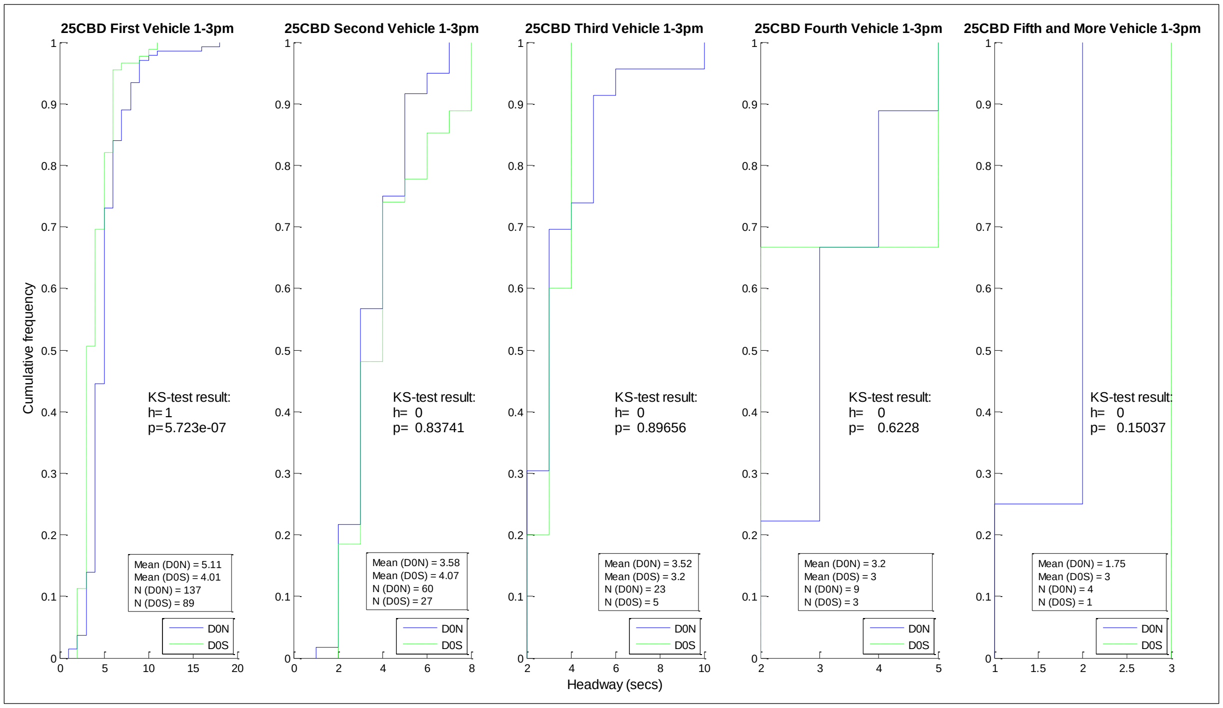


Figure 5.11 K-S test for headway in 25CBD (1:00 pm to 3:00 pm)

Figure 5.12 shows that for 35NCBD, there is a significant difference in the cumulative distributions of the first vehicle's headway between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a narrowed left-turn lane and a standard through lane width (INS). In addition, there is no significant difference in the cumulative distributions of all other corresponding vehicles' headway in the queue between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a narrowed left-turn lane and a standard through lane width (INS) for 35NCBD.

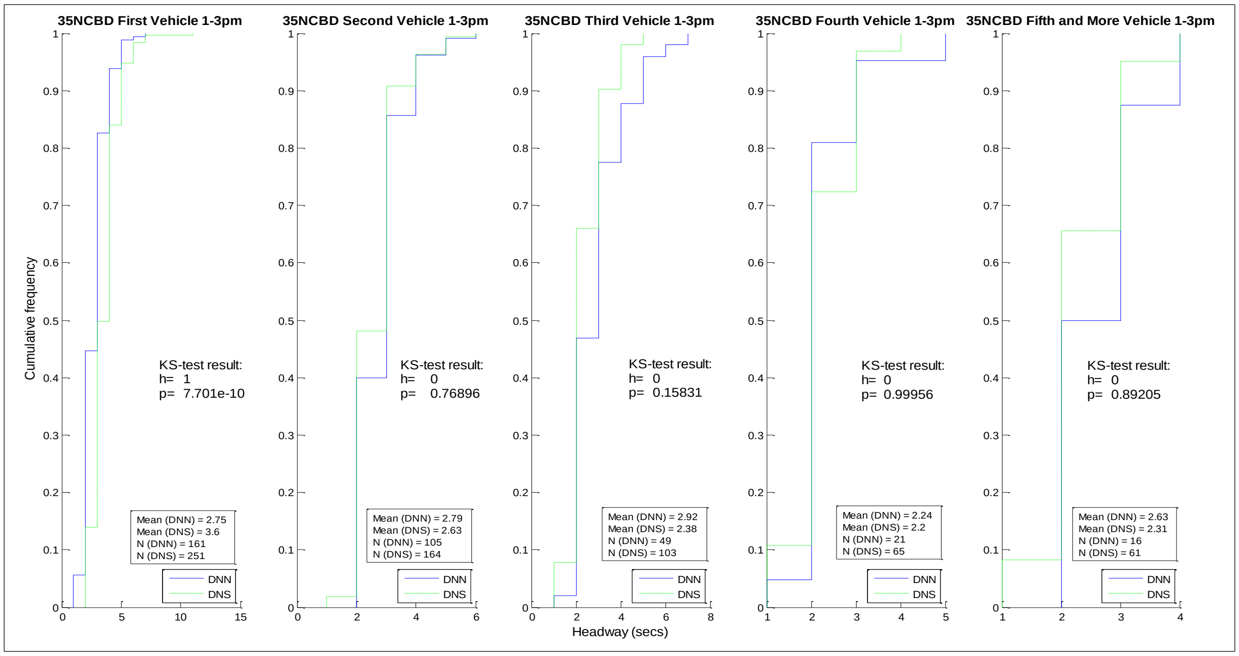


Figure 5.12 K-S test for headway in 35NCBD (3:30 pm to 5:30 pm)

Figure 5.13 shows that at 40MPH, there is a significant difference in the cumulative distributions of the first vehicle's headway between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a standard left-turn lane and standard through lane width (ISS). In addition, there is no significant difference in the cumulative distributions of all other corresponding vehicles' headway in the queue between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a standard left-turn lane and a standard through lane width (ISS) at 40MPH.

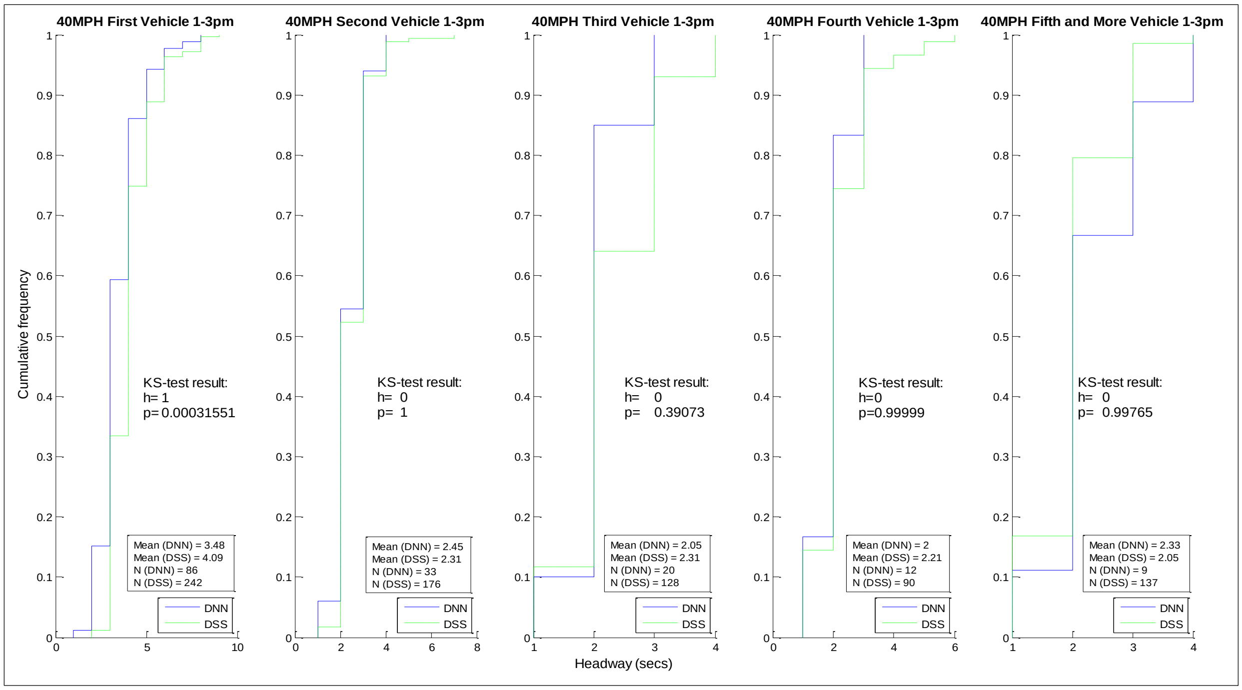


Figure 5.13 K-S test for headway at 40MPH (1:00 pm to 3:00 pm)

Figure 5.14 illustrates that at 45MPH there is no difference in the cumulative distributions of all the corresponding vehicles in the queue between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a standard left-turn lane and a standard through lane width (ISS).

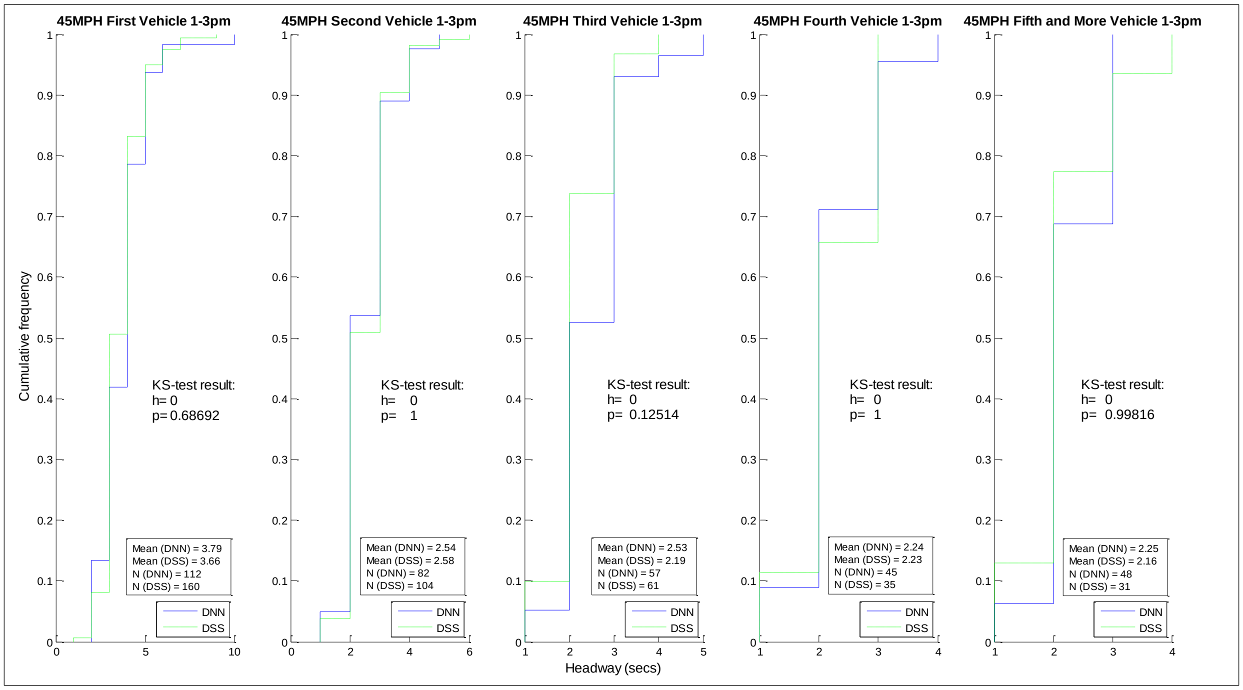


Figure 5.14 K-S test for headway at 45MPH (1:00 pm to 3:00 pm)

Figure 5.15 illustrates that for 25CBD from 3:30 pm to 5:30 pm, there was no significant difference in the cumulative distributions of all the corresponding vehicles in the queue between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a standard left-turn lane and a standard through lane width (ISS).

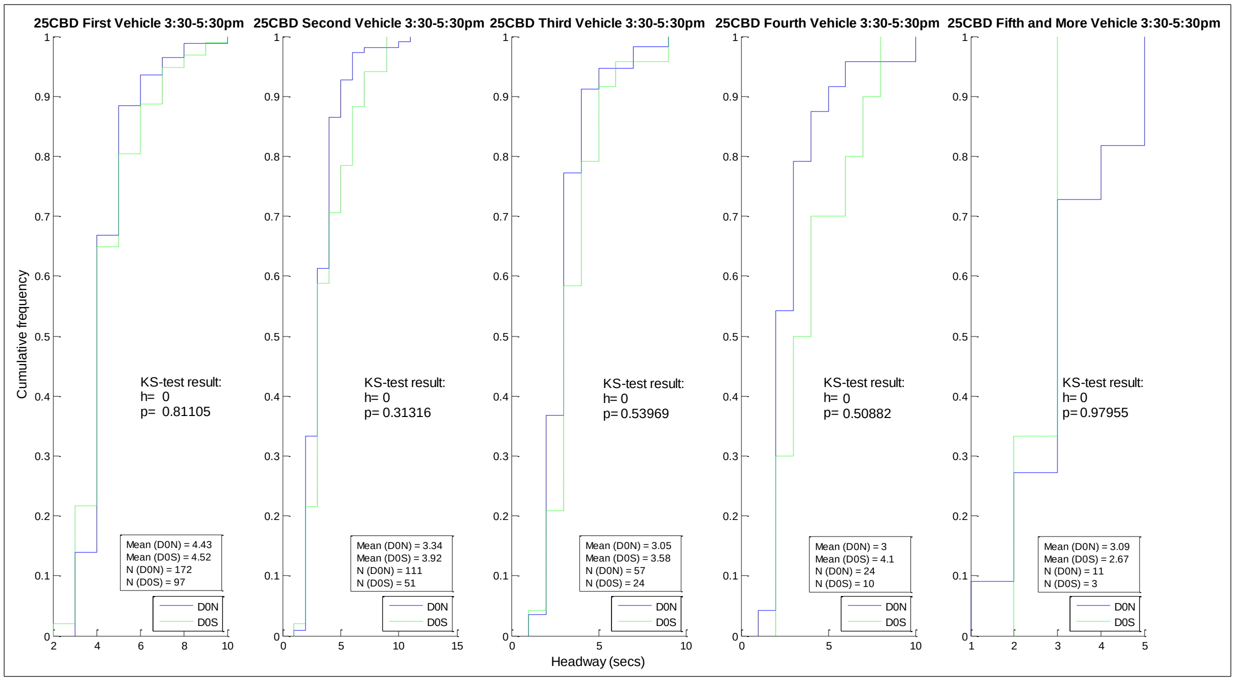


Figure 5.15 K-S test for headway in 25CBD (3:30 pm to 5:30 pm)

Figure 5.16 illustrates a significant difference in the cumulative distributions of the first vehicle's headway between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a narrowed left-turn lane and a standard through lane width (INS) for 35NCBD. In addition, there is no significant difference in the cumulative distributions of all other corresponding vehicles' headway in the queue between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a narrowed left-turn lane and a standard through lane width (INS) for 35NCBD.

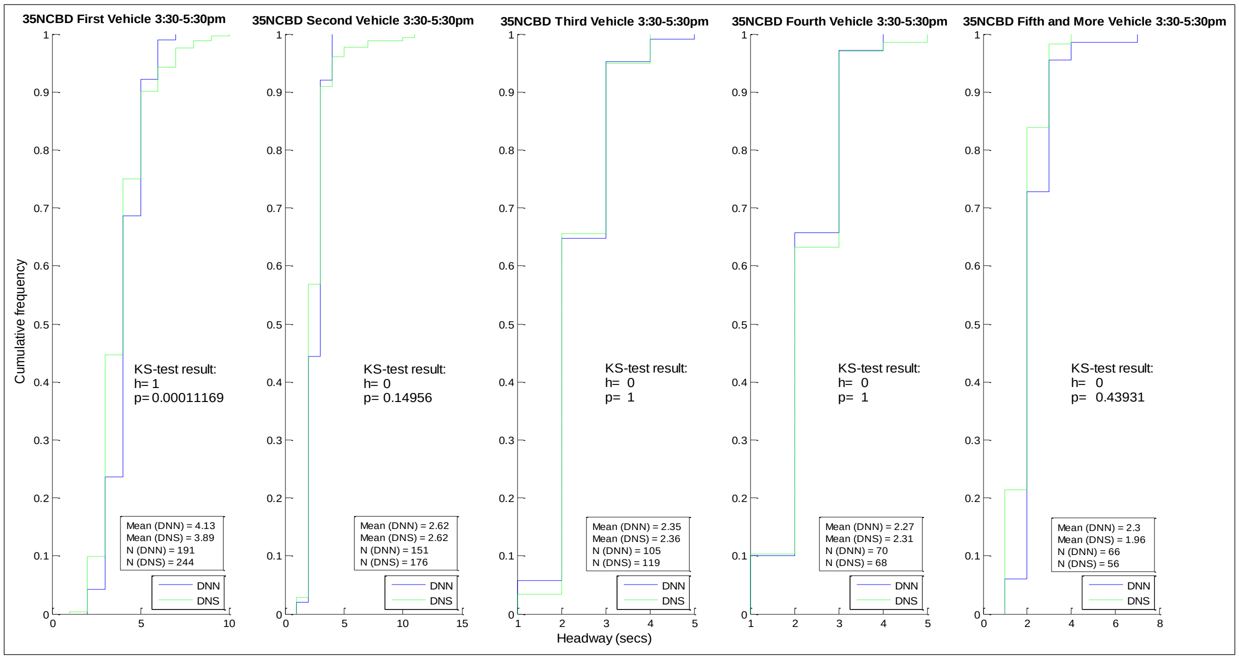


Figure 5.16 K-S test for headway in 35NCBD (3:30 pm to 5:30 pm)

In figures 5.17 and 5.18, there is no significant difference in the cumulative distributions of all of the corresponding vehicles' headway in the queue between the combination of a narrowed left-turn lane and a narrowed through lane (INN) and the combination of a standard left-turn lane and a standard through lane width (ISS) at both 40MPH and 45MPH.

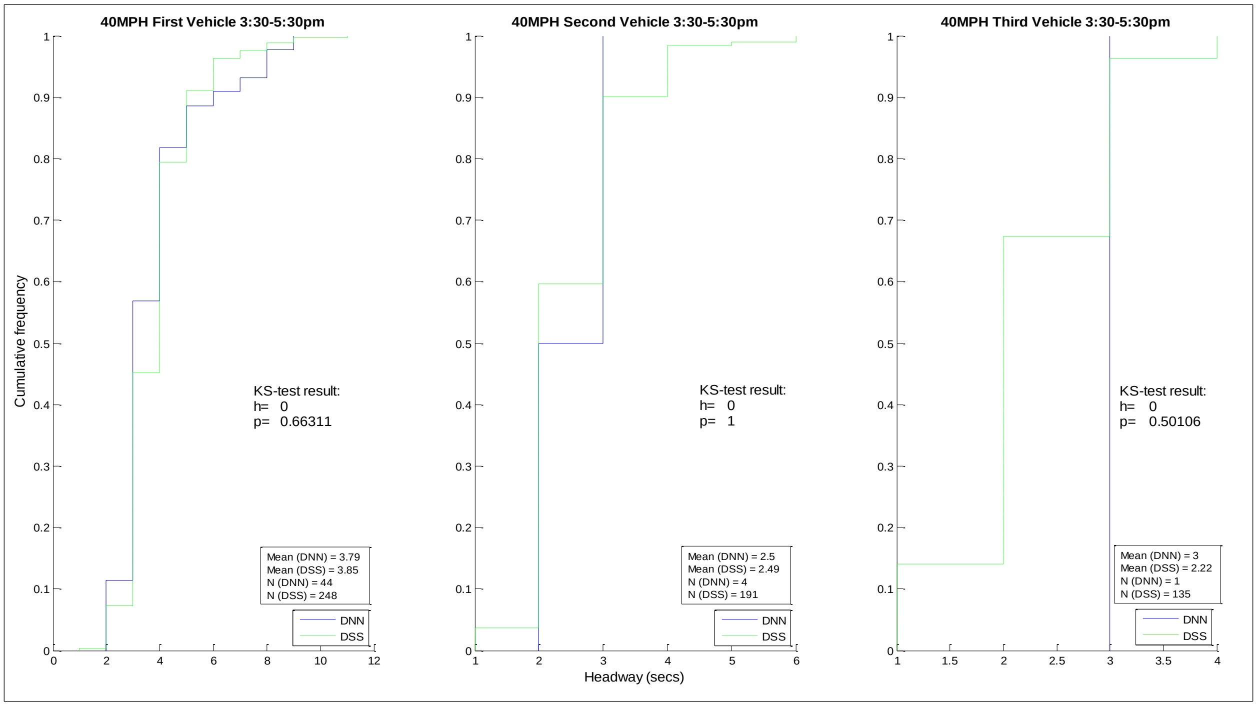


Figure 5.17 K-S test for headway at 40MPH (3:30 pm to 5:30 pm)

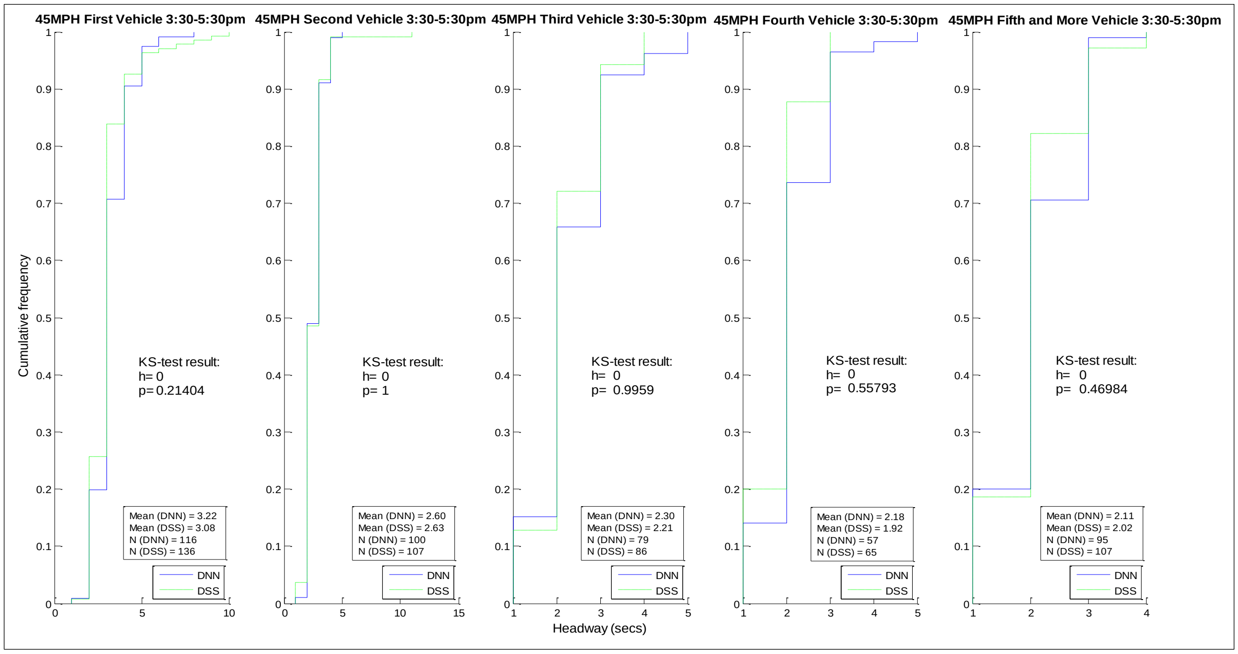


Figure 5.18 K-S test for headway at 45MPH (3:30 pm to 5:30 pm)

Based on the discussion above, we find that it is only in some groups that different combinations of lane widths have different cumulative distributions of the first vehicle's headway in the queue.

Figures 5.19 and 5.20 only included the K-S test results for the first vehicle's headway in the queue in different groups and different time periods, but the result for the first vehicle's headway is still not consistent. Therefore, we cannot find evidence to prove that lane width combinations have an effect on the queue discharge headway in intersection approaches.

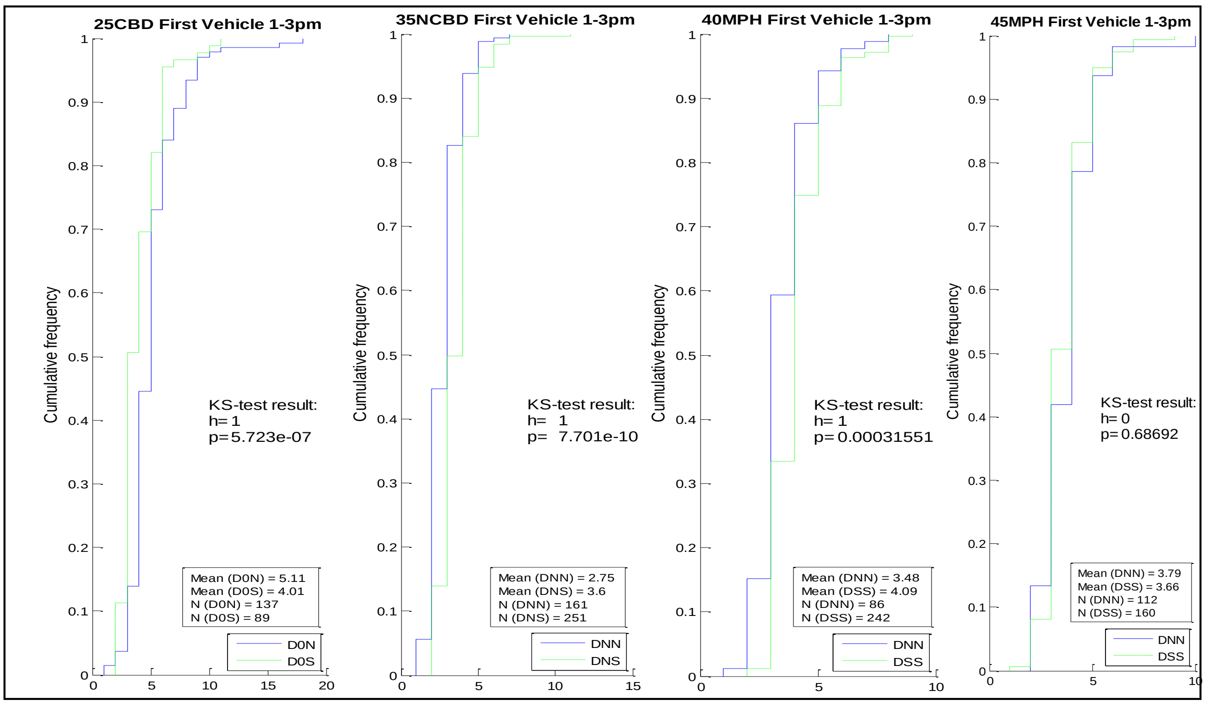


Figure 5.19 K-S test for first vehicle's headway (1:00 pm to 3:00 pm)

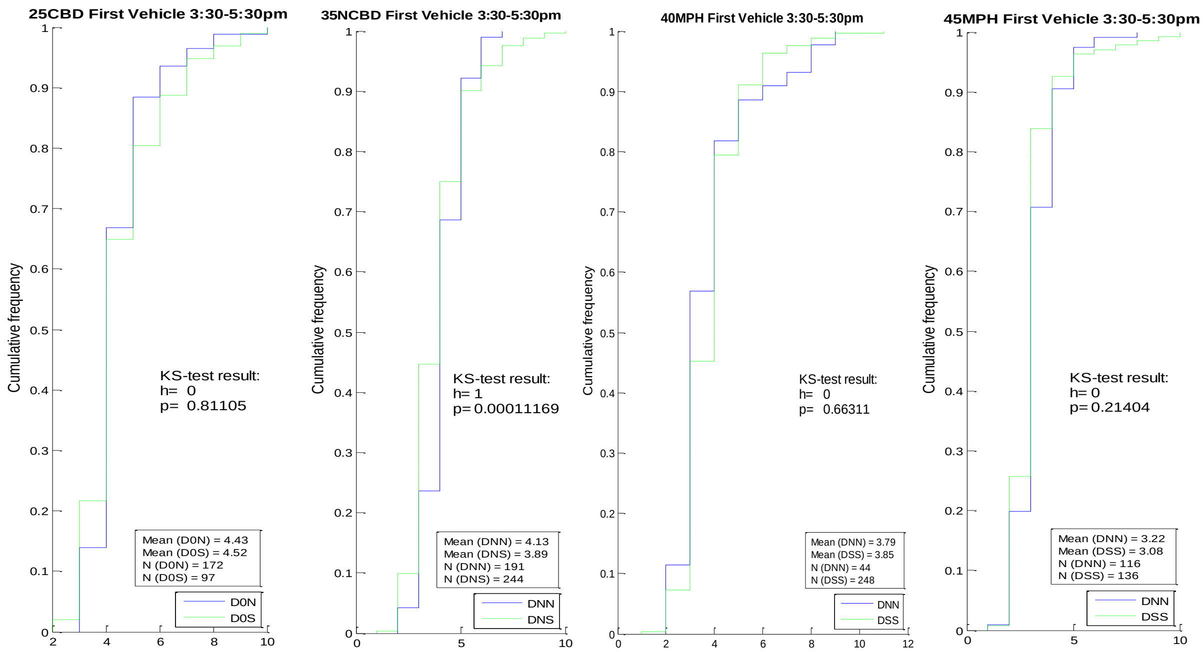


Figure 5.20 K-S test for first vehicle's headway (3:30 pm to 5:30 pm)

All the findings are consistent with our findings that narrow lane widths don't sufficiently reduce the speeds at lower speed limits of 30 to 35 mph per hour roads. This in association with more access density near CBD can lead to higher crash rates as observed in the crash analysis. Whereas reduction in speeds, for higher speed limit roads, along with the fact these roads are usually away from the business district thus have lower access density can lead to safer narrower roads. The dilemma though is usually the right of way also gets cheaper in the outer fringes of the cities thus there is less and less demand for narrowing the roads. It should be noted that the capacity of roadways was not systematically found to decrease with reduction in lane widths from standard widths to narrower widths.

Chapter 6 Conclusions

This research examined the safety and operational effects of lane width on mid-block segments between signalized intersections and on signalized intersection approaches in the urban environments of Lincoln and Omaha, Nebraska. The safety analysis used Poisson and negative binomial regressions with fixed or random parameters to evaluate the effects of lane width on annual crash frequency at mid-block segments between signalized intersections and on intersection approaches. The operational analysis used linear regressions and box plots to e-amine the effects of lane width on vehicles' traffic speed at mid-block segments. Bar graphs were used to represent the relationship between lane width and vehicles' lane violation at mid-block segments. The Kolmogorov-Smirnov test was implemented to explore the effects of lane width on vehicles' headway in the queue at the intersection approaches.

The results from the analysis of lanes 9 ft and 10 ft wide compared to lanes 11 ft and 12 ft wide in the mid-block segments illustrated that 10 ft lanes increase the crash frequency in areas outside of the central business district with speed limits of 30 mph and 35 mph in Omaha. Lanes 10 ft wide also had a random effect (decrease or increase) on crash frequency in the area outside of the central business district with a 30 mph speed limit in Lincoln. However, 10 ft lanes decreased or had a random effect on crash frequency in areas with 40 mph and 45 mph speed limits. A possible interpretation was that drivers were having higher work-load when driving on roads with lower speed limits, which are usually located near the center of the city, and crashes were more likely to happen in narrow lanes because there was less space between vehicles. It is possible that drivers were more careful while driving in high speed limit areas with narrowed lanes due to the combination of high traffic speeds and little space between vehicles. In addition, 9 ft and 10 ft lanes corresponded to higher vehicle traffic speeds in the central business district at

25 mph and areas outside of the central business district at 35 mph. Lanes 9 ft and 10 ft wide were related to a lower traffic speed in the areas with 40 mph and 45 mph speed limits. The hypothesized impacts were also observed in the safety surrogates, 9 ft and 10 ft lanes were associated with larger numbers of lane violations per vehicle for all types of vehicles in the central business district at 25 mph and areas outside of the central business district at 35 mph. Moreover, 10 ft wide lanes were related to a smaller number of lane violations per vehicle (except heavy vehicles) in 40 mph and 45 mph areas.

The dilemma though is usually the right of way also gets cheaper in the outer fringes of the cities thus there is less and less demand for narrowing the roads. Therefore, it is preferable to adopt 10 ft lanes in mid-block segments in higher speed limit areas (40 mph and 45 mph) due to these segments' lower crash frequencies, lower traffic speeds, and fewer lane violations per vehicle (except heavy vehicles) in comparison to 11 ft and 12 ft lane widths but there might be no demand for such reductions. Also, larger numbers of heavy vehicle–related lane violations per vehicle may be caused when 10 ft lanes are used at areas with 40 mph and 45 mph speed limits. In contrast, 11 ft and 12 ft lane widths should be considered to be adopted in 30-35 mph areas (especially near central business districts with a 35 mph speed limit) because of these segments' lower crash frequencies, lower traffic speeds, and fewer lane violations per vehicle compared to 9 ft and 10 ft lanes.

As for the effects of lane width on intersection approaches, the lane width combination of no left-turn lanes and narrowed (9 ft and 10 ft) through lanes decreased or had no effects on annual crash frequency when compared to the combination of no left-turn lanes and standard (11 ft and 12 ft) through lanes for intersection approaches located outside of the central business district with a 35 mph speed limit. The lane width combination of narrowed left-turn lanes and narrowed through lanes decreased or had no effect on crash frequency when compared to the combination of standard left-turn lanes and standard through lanes located outside of the central business district with a 35 mph speed limit or located at areas with 40 mph and 45mph speed limits. A possible reason for this effect was that a narrowed lane at an intersection approach could have forced drivers to concentrate on driving because they were allowed a smaller space when approaching the intersection. Additionally, the combination of narrowed left-turn lanes and standard through lanes increased the crash frequency when compared to the combination of standard left-turn lanes and standard through lanes at areas with a 45 mph speed limit. This effect may suggest that drivers were not comfortable approaching an intersection with unequal lane widths between the adjacent through lane and left-turn lane. In fact, this combination may cause more crashes. Therefore, the combination of narrowed left-turn lanes and narrowed through lanes would be a safer lane width combination for intersection approaches in the urban areas in Nebraska based on the evidence of the current research.

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Appendix A Survey Emails

The following pages contain the email correspondences between the researchers and survey respondents. The respondents include representatives from Kansas, Iowa, Missouri, Wyoming, and California.

Wyoming:

from:	**Paul Jones** <paul.jones@wyo.gov>
to:	Wei Li <weili0822@gmail.com>
date:	Thu, Jan 31, 2013 at 5:17 AM
subject:	Re: Questions about policy regarding the use of lane width in urban settings

Dear Paul Jones:

This is Wei Li, from Nebraska Transportation Center at University of Nebraska-Lincoln. Currently, we are conducting a research about the operational analysis of narrow lane widths (or road diet) in the urban environment. As a part of a survey, we are collecting the information about policies followed in the neighboring states in regards to the use of narrow lane widths in urban settings.

1. I would really appreciate if you could share any policy guidelines used by Wyoming or any research done in this area in your state/city.

A: Wydot typically uses 12 ft lane widths for urban sections. We do have 2 or 3 slow speed urban (20 to 30 mph) with 11 ft lane widths, but these are very much an exception.

2. If there is no written policy please let us know if there are any general principles that are used to decide feasibility of using a narrower lane width in an urban settings and the parameters taken into consideration while making this decision.

A: It is when we are out of right of way width to handle the cross section.

3. Also, please let us know the current range of lane widths that has been implemented in your urban areas.

A: See above

4. Are there any situations you would implement unequal lane widths in your state/city.

A: A right turn auxiliary lane if cross section width is unavailable.

If you are not familiar with this part, could you provide the contact information to the person who is responsible for this area, or forward this email to him/her?

Thank you very much for your time and help. Looking forward to hearing from you.

Wei Li

from:	**Jeffery Mellor** <jeffery.mellor@wyo.gov>
to:	weili0822@gmail.com
date:	Tue, Feb 5, 2013 at 2:58 AM
subject:	Re: Questions about policy regarding the use of lane width in urban settings

Wei Li

We strive for 12 ft lanes whenever possible. The minimum we have narrowed down to is 11 ft. Isolated left-turn lanes have been narrowed to 10 ft at intersections.

Jeffery Mellor, P.E.
Geometrics & Markings
WYDOT Traffic Program
5300 Bishop Blvd.
Cheyenne, WY 82009

Missouri:

from:	**Jonathan.Nelson@modot.mo.gov**
to:	Wei Li <weili0822@gmail.com>
cc:	Jeanne.Olubogun@modot.mo.gov, Joseph.Jones@modot.mo.gov, John.P.Miller@modot.mo.gov, Jason.Sims@modot.mo.gov
date:	Wed, Jan 30, 2013 at 10:36 PM
subject:	Re: Questions about policy regarding the use of lane width in urban settings

Wei,

We do not have a lot of information regarding this practice. We have converted some freeways in the St. Louis area to narrower lane widths in order to provide some additional capacity. For e-ample, we recently added a lane to a section of I-270 NB, south of I-44. To allow for this lane addition, lane widths in the area were converted from standard 12' lanes to 11' lanes. We don't have a lot of written policy on this issue, but here is a brief link to an article in our Engineering Policy Guide (EPG):

http://epg.modot.mo.gov/index.php?title=231.3_Lane_Width

This type of conversion is usually done as a result of right of way limitations, especially in the urban areas. We have done similar conversions (12' lanes to 11' lanes) on I-44 as well as other locations during major construction projects. I am not aware of any locations with unequal lane widths.

I've copied in a few others that might know more about our practices in case they should have any additional information to add.

Thanks.

Jon Nelson, P.E.
Traffic Management and Operations Engineer
Traffic and Highway Safety Division
Missouri Department of Transportation

from:	**Jeanne.Olubogun@modot.mo.gov**
to:	Wei Li <weili0822@gmail.com>
cc:	John.P.Miller@modot.mo.gov, Jonathan.Nelson@modot.mo.gov
date:	Sat, Feb 2, 2013 at 12:49 AM
subject:	Re: Questions about policy regarding the use of lane width in urban settings

Wei,

We do have an upcoming project where we are converting a current 5 lane section to a three lane typical, with specific turn lanes (not a two way left-turn lane). This was identified during a study called Great Streets Initiative, and is really a road diet project. This is on Natural Bridge Road (MO 115) east of I-170 to the City Limits of St. Louis.

In the St. Louis area, there has been one other road diet implemented, first as a trial, and now as a permanent solution. This is on Grand Ave. in St. Louis, between Arsenal Street and Cherokee Streets. This is maintained by the City of St. Louis and not a MoDOT road.

As Jon stated, we don't really have a policy for these decisions, but they are managed on a case by case basis.

Best of success on your research!!

Jeanne Fuchs Olubogun, P.E.
District Traffic Engineer - St. Louis Metro District
Missouri Department of Transportation
Mailing address: 1590 Woodlake Dr., Chesterfield, MO 63017
Delivery address: 14301 South Outer Forty, Chesterfield, MO 63017
Phone: (314)-275-1536 Cell: (314)-566-8812 (NEW) Fax: (573)-522-6491
Jeanne.Olubogun@modot.mo.gov

Iowa:

from:	**Simodynes, Tim [DOT]** <Tim.Simodynes@dot.iowa.gov>
to:	Anuj Sharma <asharma3@unl.edu>
cc:	"weili0822@gmail.com" <weili0822@gmail.com>, "Mike Ring (MPRing@dmgov.org)" <MPRing@dmgov.org>, "Smith, Brian [DOT]" <Brian.Smith@dot.iowa.gov>, "Vortherms, Jeremey [DOT]" <Jeremey.Vortherms@dot.iowa.gov>, "Jia, Yanxiao [DOT]" <Yanxiao.Jia@dot.iowa.gov>
date:	Wed, Feb 6, 2013 at 12:37 AM
subject:	RE: A side question on road diet program

Hi Anuj,

I assume you are asking about urban arterials and not urban freeways.
I am not certain about our written policies or flexibility with using narrower lane widths on urban arterials, but you can try checking our design manual:
www.iowadot.gov/design/dmanual/manual.html
(try chapter 1C-1)

When I was in safety we assisted with many projects that converted 4-lane, undivided roadways into 3-lane roadways (with a center two-way, left-turn lane). I have heard those labeled as *Road Diets* in the sense that the number of lanes were reduced.
InTrans at Iowa State University helped us evaluate their effectiveness:
http://www.ctre.iastate.edu/research/4laneto3lane.htm

In the past, the DOT has also assisted the City of Des Moines with lane width reductions that allowed them to add center turn lanes. I think at least one of those may have been a 4-lane to 5-lane conversion with narrower lanes.

From my experience, I would be reluctant to form a rigid policy since so many factors are involved such as traffic volumes, number of large trucks, truck turning movements, traffic speeds, crash history, left-turn related crash history, bicycle presence, on-street parking, gutter shape, etc.

I have cc'd a few people who may be able to help answer more of your questions below, including Mike Ring at the City of Des Moines.

Tim Simodynes, PE

ITS Engineer, Iowa DOT

Kansas:

from:	**Brian Gower** <Gower@ksdot.org>
to:	Wei Li <weili0822@gmail.com>
date:	Fri, Mar 15, 2013 at 9:43 PM
subject:	RE: Questions about policy regarding the use of lane width in urban settings

WL:

As a Department of Transportation, we support 12 ft lanes.

When working with communities, our practice in order of preference:

1. Support 12 ft lanes

2. 11 ft lanes are acceptable due to constraints mainly to ROW; (we suggest turn lanes be 12 ft with thru lanes being 11 ft)

3. In rare instances, we may allow 10 ft lanes due to ROW constraints

Thx.

BDG

California:

from:	**Ahmad Rastegarpour** <ahmad.rastegarpour@dot.ca.gov>
to:	Wei Li <weili0822@gmail.com>
date:	Fri, Feb 1, 2013 at 3:07 AM
subject:	Re: Questions about policy regarding the use of lane width in urban settings

Hello Mr. Li,

I have requested my colleagues to review your email and so far I been able to get answers to some parts of your questions below.

The Caltrans Highway Design Manual (HDM) allows 11 ft lanes on conventional State highways in urban, city or town centers (rural main streets) in specified conditions as a standard, where previous to May 7, 2012, 12 ft was the mandatory standard. This was part of our "Complete Streets" update that revised design guidance throughout the HDM with opportunities to enhance multi-modal traffic. The revision did not target narrow lanes as a "road diet" operations focus.

I will send you additional information as I get them from my colleagues.

Thanks,

Ahmad Rastegarpour, P.E.

Division of Traffic Operations

California Department of Transportation

South Dakota:

from:	**Kinniburgh, Doug** <Doug.Kinniburgh@state.sd.us>
to:	Wei Li <weili0822@gmail.com>
date:	Sat, Mar 23, 2013 at 3:59 AM
subject:	RE: Questions about policy regarding the use of lane width in urban settings

Wei,

Here is the link to our design guidelines for local roads and within the manual, it also has the link to the State's Road Design Manual in which you can obtain their data for the state and federal routes.

http://www.sddot.com/business/local/docs/localroadsplan.pdf

Thanks,

Doug Kinniburgh

Local Government Engineer
Office of Local Government Assistance, SDDOT
700 E. Broadway, Pierre, SD 57501

Deadline for submission of results and short paper: November 30th, 2014 (11:59 PM, Central Time). Please check the website regularly to see if there are any updates or comments/clarification on the dataset. Please direct all questions to Anuj Sharma (anujpals@gmail.com) or Linda Ng Boyle (linda@uw.edu).We will post responses to all questions on the website (we will NOT provide individual responses). Please note that we WILL NOT answer any questions on what the best model is, what is the right goodness of fit test, what are the model assumptions, how to compute
X, Y or Z, etc.

Data Description

Data Excel Sheet summarizes 10 years of crash data at midblock segment of arterial roads (urban collectors, urban minor arterial, urban principal arterial-other non-connecting link, and urban principal arterial-other connecting link) in 4 cities of Nebraska. The data set contains segment details measured using Google Earth, such as, lane width, speed limit, presence of shoulders, etc., and the yearly crash frequency reported for different categories, such as, crash severity, driver age etc.

Competition Objective

Develop an exploratory, analytical or statistical model using the data available in "TRB2015-DataSet.xlsx" to assess the impact of Narrow Lane Width on safety of the arterial roads. You can use any statistical/analytical software program. Your results along with a SHORT write up should be NO MORE than 6 pages total (this includes figures, tables, and references). It needs to include your Last Name and First Name in the filename (e.g, Sharma_Anuj.pdf). Send your results to anujpals@gmail.com. The file should contain the following

a. Your name and affiliation
b. Your problem formulation
c. Your model and justification for your approach
d. Model adequacy check: How do you know you have a good fitting model?
e. Your solution
f. Your assumptions
g. The software used (and corresponding program or functions/call out procedure)
h. The level that you reduce/aggregate the data for analysis (if any)
i. The limitations in the dataset (including what variables you wish you had).
j. A critical review of your solution process in terms of strengths and weaknesses

NOTE: We have received many requests for the data. Hence, we will NOT review those documents that do not adhere to the submission requirements.