Rumble Strips in North Dakota:
A Comparison of Road Segments, Safety, and Crash Patterns

Prepared for

North Dakota Department of Transportation and Federal Highway Administration – ND Division

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ABSTRACT

Rumble strips and rumble stripes are a recommended strategy for crash reduction. The North Dakota Department of Transportation initiated rumble strip use in the 1970's and greatly expanded application of rumble stripes through a statewide initiative in recent years. This study of four intervention and two control road segments shows positive results with regard to crash incidence in before and after comparisons. The crash rates comparison considers crash severity, vehicle type, roadway factors, crash type, and contributing factors. A reduction in all crashes and crash severity, in terms of the most serious fatal crashes, is found in comparing crash rates per 100 million VMT in times periods before and after the installation occurred. Note that on some road segments, confounding factors such as impaired driving, appear to be significant factors in the crash rates so the safety benefit attributable to the rumble strips/stripes cannot be easily assessed. In addition, results should be used with caution – especially those for fatal crashes – because of the limited number of observations. Future studies may produce more robust results as additional road segment and crash rate data can be incorporated.

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1. LITERATURE REVIEW

Rumble strips and rumble stripes are two safety strategies commonly used on roadways. The Federal Highway Administration (2011) defines rumble strips as "a longitudinal design feature installed on a paved roadway shoulder near the travel lane. It is made of a series of indented or raised elements intended to alert inattentive drivers through vibration and sound that their vehicles have left the travel lane." Rumble stripes are a subset of rumble strips that "are painted with a retroreflective coating to increase the visibility of the pavement edge at night and during inclement weather conditions" (Federal Highway Administration 2011). Rumble strips and rumble stripes can be placed on the shoulder, centerline, or both.

In North Dakota, the first shoulder rumble strip was placed on Interstate 29 just south of Fargo in 1973. It was approximately one mile in length on the stretch of highway between Prairie Rose and Frontier. Although shoulder rumble strips became more common across the state, it was not until 2008 that the first centerline rumble strip was placed on North Dakota Highway 1806 just south of Mandan.

This study assesses the success of rumble strips and rumble stripes as a road safety strategy. It examines crash rates on road segments before and after rumble strips and rumble stripes were put on the roads. Because the state of North Dakota does not distinguish between "strip" and "stripe" in datasets and reports, in this study both rumble strips and rumble stripes will be referred to as "rumble strips" collectively. The remainder of this literature review will focus on five key areas: general information about rumble strips and the need for them, the effectiveness of rumble strips, the retroreflectivity of rumble strips during dry or wet conditions, the durability of rumble strips, and the rising prevalence of rumble strips in North Dakota.

1.1 General Information about Rumble Strips

Various risk factors contribute to accidents caused by drivers crossing the edge or centerline of a roadway. These factors include poor visibility, slippery road surfaces due to weather, and the condition of the driver. According to the U.S. Department of Transportation, installing rumble strips helps reduce accidents because the contour of the rumble strip is better at draining water and also improves visibility at night when adverse weather conditions may render normal pavement markings nonfunctional. This is especially important considering that run-off-the-road crashes account for 50% of all fatal crashes (Toole 2009). Furthermore, when considering that about half of all run-off-the-road crashes occur at night, it becomes evident that rumble strips can be a powerful tool for saving lives (Taylor 2005). Moreover, current research suggests that rumble strips not only help prevent run-off-the-road crashes, but are also effective in reducing head-on crashes, opposite direction sideswipe crashes, and rollovers (Ziegler 2010).

1.2 Effectiveness of Rumble Strips

A study by Hallmark et al. (2009) revealed that the number of vehicles within 1 and 2 feet of the driving lane edge decreased by approximately 2% and 7%, respectively, after rumble strips were installed in rural Iowa. Similarly, a study by Potts et al. (2009) indicated that the benefit-to-cost ratio of centerline and edgeline rumble strips in Missouri equaled 59. Clearly, there are a number of benefits that can be realized when rumble strips are utilized on roadways.

There has been some concern, however, over the effectiveness of rumble strips during adverse weather conditions. A study by Torbic et al. (2009) found that when snow, salt, sand, or debris collected in the grooves of the rumble strips, pavement markings were difficult to see. This sentiment was reiterated by Outcalt (2001) who concluded that – above and beyond visibility problems – the sand which collects within the groove of the strip can obscure the paint stripe, and thus the strips appear to have a negative effect on the life of the yellow centerline paint.

1.3 Retroreflectivity of Rumble Strips

Pike et al. (2011) concluded that rumble strips do provide at least twice the wet-night retroreflectivity compared to their flat thermoplastic counterpart. Like Pike et al., Carlson et al. (2005) found that rumble strips provide better preview times during wet-night conditions and also provide improved wet-night detection distance. Lindly and Narci (2006) contend that, because rumble strips provide such a high benefit-to-cost ratio due to their retroreflectivity, rumble strips should be implemented wherever shoulders are constructed, reconstructed, or overlaid. As a whole, the literature suggests that rumble strips provide safer driving conditions in terms of visibility, particularly during nighttime driving.

1.4 Durability of Rumble Strips

Although rumble strips are a viable safety tool, they are often damaged during long-term use in cold climates. Henrichs and Luger (2008) explain that this is due to the abrasive action of snow plows and the damages they cause to rumble strips during plowing season. This idea is reiterated by Abernathy (2009) who discovered that – beyond the damage snow plows can cause to rumble strips – the collection of sediment within the recess of the rumble strip can also deteriorate the strip rapidly. These findings suggest that although rumble strips are a viable road safety tool with many benefits, they should not be viewed as a long-term permanent solution to traffic safety issues.

1.5 Rumble Strips in North Dakota

Although rumble strips were used along the shoulder and edgelines of North Dakota roads as early as 1973, centerline rumble strips were not utilized in North Dakota until 2008 (Bismarck Tribune 2008) when they were placed on Highway 1806 from Fort Lincoln State Park to Cannon Ball (North Dakota Department of Transportation 2008).

As time progressed, centerline rumble strips were implemented on Highway 23 near New Town, Plaza, and Stanley (Ogden 2009), Highway 83 near Watford City (Minot Daily News 2009), Highway 8 in Stark and Dunn counties (North Dakota Department of Transportation 2009), and in many southwest and western portions of the state (North Dakota Department of Transportation 2011).

1.6 Crash Rate Analysis

Crash rate analysis is an effective tool not only to measure, but also to compare performance of particular locations in traffic safety analysis (Federal Highway Administration 2012). In this study, crash rate analysis is used when determining how rumble stripes perform. The crash rate used in this study is "crashes per 100 million vehicle miles traveled." This rate is a combination of crash frequency (number of crashes) and traffic volume, for a given period of time. The formula for calculating the crash rate is presented below (Federal Highway Administration 2012).

$$R = \frac{100{,}000{,}000 * C}{V * D * L}$$

The variable in this equation are:
R: Crash rate, crashes per 100 million vehicle-miles of travel
D: Study period (in days)
C: Total number of crashes in the study period
V: Average annual daily traffic (AADT) volume
L: Length of the road segment in miles

1.7 Gaps in the Literature

Although some studies have assessed costs, benefits, and crash rates after implementation of rumble strips, none have directly compared segments of North Dakota roads to determine how crash rates differ once rumble strips have been put in place. Furthermore, none have examined crash rates on North Dakota roads before and after centerline rumble strips were first installed in 2008. This study will analyze how crash rates differed when rumble strips were utilized in oil counties with rapidly increasing traffic rates and on centerline road segments by comparing these groups to control road segments with similar AADT counts and no rumble strips installed.

2. ANALYSIS

The following section will analyze crash rates on selected North Dakota road segments (Figure 2.1). Two groups of segments were analyzed for this study. The first group (ND-15, ND-23, ND-49, ND-1806) looks at crash rates on road segments where centerline and shoulder rumble strips were installed and compares them to similar roads without rumble strips. The second group (ND-2 Stanley, ND-2 Ray, ND-8) examines crash rates on road segments that have substantially increased AADT due to oil development.

Figure 2.1 Road Segments of ND Studied

For all road segments studied, before-and-after data is presented in terms of crash rates per 100,000,000 vehicle miles traveled (VMT). These comparisons provide a baseline for understanding how rumble strips influence various safety measures. Although the goal of this project is to address the effectiveness of rumble strips as a safety tool on North Dakota roadways, it should be emphasized that there are always external variables that may play a role in altering the safety of a given road segment. Some variables are capable of being controlled by drivers; others may be impossible for drivers to control. These external variables include driver impairment, driver conditions, contributing factors such as driver distractions, speeding, weather conditions, and road surface conditions, and many others. Tables highlighting before-and-after data provide information about some of these external variables.

One external variable, impaired driving was addressed in detail in this study. North Dakota consistently ranks among the worst states in terms of automobile crashes involving impaired drivers. Thus, there was a need for this project to distinguish safety on the road segments that were examined: are road segments safe because rumble strips were used or are road segments dangerous because of impaired drivers? To help separate the benefits of rumble strips and the drawbacks of impaired driving, crash data were recoded into dichotomous nominal level scales. Table 2.1 provides the quantitative scale definitions used for impaired driving statistics.

Table 2.1 Quantitative Scale Definitions for Impaired Crash Statistics

Crash Statistic	Scale	Conversion Values
Rumble Strips	0-1	0=No Rumble Strips, 1=Rumble Strips
Impairment	0-1	0=No Impairment, 1=Alcohol, Drugs, or Both
Multiple Vehicles	1-2	1=One Vehicle Involved, 2=Multiple Vehicles Involved
Fatal Crashes	0-1	0=Nonfatal Crash, 1=Fatal Crash
Harmful Crashes	0-1	0=Non-harmful Crash, 1=Injury or Fatal Crash

2.1 Centerline and Shoulder Rumble Strips

Centerline rumble strips are relatively new in North Dakota and have only been in use since October of 2008. Centerline rumble strips are designed to alert drivers that they are drifting outside of their lane and into oncoming traffic. Four road segments with similar length, location, AADT, and function were studied: two (North Dakota Highway 1806 and North Dakota Highway 49) had centerline and shoulder rumble strips and two (North Dakota Highway 15 and North Dakota Highway 23) did not. Crash rates before and after rumble strip implementation were compared to the control group road segments to help identify the effectiveness of centerline and shoulder rumble strips as a road safety strategy.

2.1.1 ND-1806 Compared to ND-15: Background and Crash Statistics

North Dakota Highway 1806 (ND-1806) was the first to receive centerline rumble strips. The road segment studied begins just south of Mandan, at Fort Lincoln State Park, and extends to the southern border of Morton County (Figure 2.2). The ND-1806 road segment that was studied is 31.9 miles in length and is the primary route to a casino. Table 2.2 summarizes the total number of crashes on this road segment before and after the rumble strips were put in place.

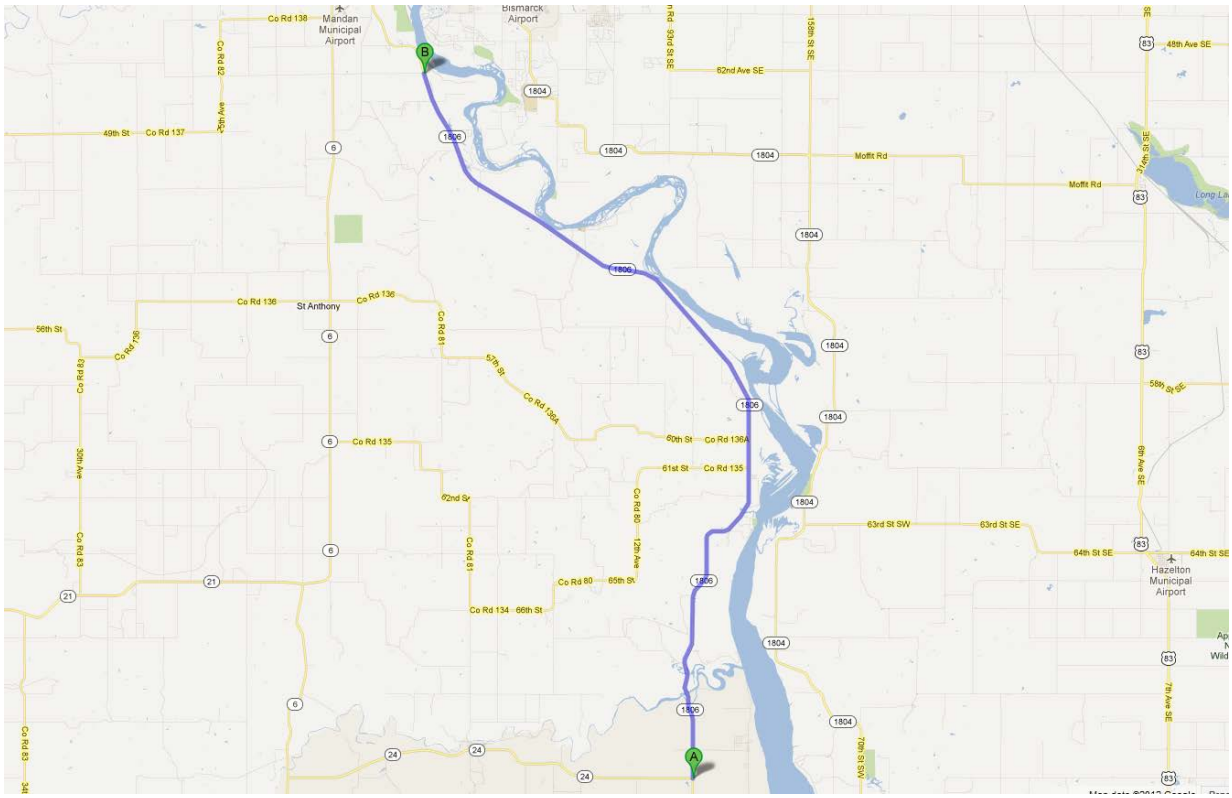

Figure 2.2 Segment of ND-1806 Studied, Centerline and Shoulder Rumble Strips

Table 2.2 Crashes Occurring on ND-1806

Date	**Crashes**	**Impairment**	**Crash Severity**	**Rumble Strips**
Before From: 10/01/2006 To: 10/01/2008	105 (6 multi-car)	Under influence: 1 No impairment: 104	Fatality: 1 Injury: 4 PDO: 100	No
After From: 10/01/2008 To: 10/01/2010	129 (4 multi-car)	Under influence: 2 No impairment: 127	Fatality: 1 Injury: 11 PDO: 117	Yes

The segment of North Dakota Highway 15 (ND-15) studied is comparable to ND-1806. The segment of the road studied stretches from just south of Logan Center to Thompson, near Interstate 29 (Figure 2.3), and 31.9 miles in length. ND-15 is similar to ND-1806 in every way with two exceptions: first, the road was never given rumble strips; and, second, over the identical timeframe, the road had significantly fewer crashes (Table 2.3).

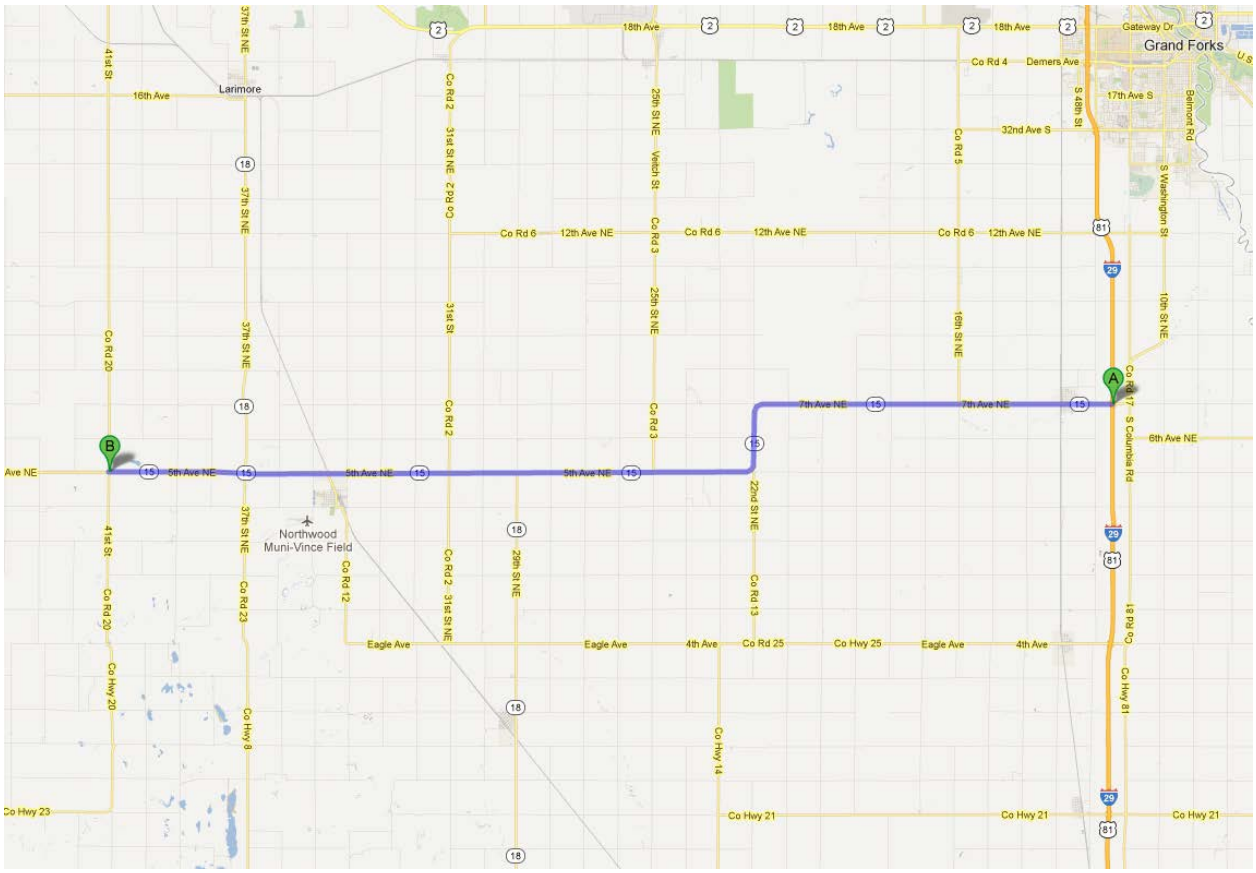

Figure 2.3 Segment of ND-15 Studied, No Rumble Strips

Table 2.3 Crashes Occurring on ND-15

Date	Crashes	Impairment	Crash Severity	Rumble Strips
Before From: 10/01/2006 To: 10/01/2008	43 (11 multi-car)	Under influence: 2 No impairment: 41	Fatality: 0 Injury: 5 PDO: 38	No
After From: 10/01/2008 To: 10/01/2010	53 (9 multi-car)	Under influence: 2 No impairment: 51	Fatality: 0 Injury: 8 PDO: 45	No

The before-and-after crash rates per 100 million vehicle miles traveled (VMT) for segments of ND-1806 and ND-15 studies are summarized in Table 2.4.

Table 2.4 A Comparison of Crash Rates per 100 Million VMT for ND-1806 and ND-15

	ND 1806		ND 15		% Change in	
	Before	**After***	**Before**	**After**	**ND**	**ND 15**
All Crashes						
All Crashes	288.2	339.3	125.7	153.8	**17.7%**	22.3%
Impairment						
**ADI	2.7	5.3	5.8	5.8	91.6%	-0.7%
Normal	285.4	334.0	119.9	148.0	**17.0%**	23.5%
Injury Class						
Serious Injuries	2.7	7.9	0.0	0.0	187.5%	N/A
Other Injuries	285.4	331.4	125.7	153.8	**16.1%**	22.3%
Crash Severity						
Fatal Crashes	2.7	2.6	0.0	0.0	**-4.2%**	N/A
Injury Crashes	11.0	28.9	14.6	23.2	163.5%	58.8%
Property-Damage Only	274.5	307.7	111.1	130.6	**12.1%**	17.5%
Crashes Involving Large Trucks						
Total	2.7	0.0	5.8	0.0	**-100.0%**	-100.0%
Single-Vehicle	2.7	0.0	0.0	0.0	**-100.0%**	N/A
Multi-vehicle	0.0	0.0	5.8	0.0	N/A	-100.0%
Crashes Not Involving Large Trucks						
Total	285.4	339.3	119.9	153.8	**18.9%**	28.3%
Single-Vehicle	269.0	328.7	93.6	127.7	**22.2%**	36.5%
Multi-vehicle	16.5	10.5	26.3	26.1	**-36.1%**	-0.7%
Relationship to Roadway						
Run off road	24.7	31.6	23.4	17.4	27.8%	-25.6%
On Roadway	263.5	307.7	102.3	136.4	**16.8%**	33.3%
Rollover						
Rollover	8.2	26.3	17.5	14.5	219.4%	-17.3%
Lane Departures						
Head On	0.0	2.6	0.0	0.0	100.0%	N/A
Sideswipe Same D.	5.5	0.0	8.8	2.9	**-100.0%**	-66.9%
Sideswipe Opposite D.	2.7	0.0	0.0	0.0	**-100.0%**	N/A
Road Geometry						
Curve	5.5	15.8	2.9	8.7	**187.5%**	197.8%
Hill	11.0	23.7	2.9	8.7	**115.6%**	197.8%
Driver Condition						
Drowsy	2.7	0.0	0.0	0.0	**-100.0%**	N/A
Contributing Factors						
Distracted	5.5	2.6	8.8	11.6	**-52.1%**	32.3%
Speed	16.5	13.1	17.5	23.2	**-20.2%**	32.3%
Improper Overtaking	0.0	2.6	0.0	2.9	100.0%	100.0%
Light						
Daylight	38.4	55.2	52.6	49.3	43.7%	-6.3%
Dawn, Dusk, or Dark	249.8	284.0	73.1	104.5	**13.7%**	42.9%
Weather						
Clear or Cloudy	277.2	320.8	108.2	150.9	**15.7%**	39.5%
Other	11.0	18.4	17.5	2.9	67.7%	-83.5%

** Center and shoulder rumble strips/rumble stripes were installed.*

*** ADI: alcohol or other drug-impaired, Normal: no impairment*

2.1.2 ND-1806 Compared to ND-15: Comparative Analysis

A before-and-after comparison of ND-1806 and ND-15 provides initial insight into the effectiveness of rumble strips on the roadway. After rumble strips were placed on ND-1806, the rate of fatal crashes on that road segment decreased 4.2%. Crash rates for distracted drivers on ND-1806 decreased by 52.1%. Rumble strips may be directly related to this improvement: drivers that otherwise would not have been alerted that they were drifting into oncoming traffic may have been warned by the vibrations from the rumble strips in the midst of their distraction. Although the crash rates for all types of crashes increased 17.7% on ND-1806 during the time frame studied, it should be emphasized that the control road segment actually outpaced ND-1806 and had an increase in 22.3% of all crash types during the same time period. On the control road segment, alcohol was not a factor in determining fatalities (there were none during the study period) and there was no statistical relationship between impaired drivers and the likelihood of a crash resulting in an injury (Chi-Sq.=0.715, df=1, p=0.398). The change in crash statistics may be due to increased volumes of traffic or changes in driver behaviors. Nonetheless, the fact that the crash rates on the road segment with rumble strips were outpaced by the road segment without rumble strips should be viewed as a successful use of this particular safety tool.

For this segment of ND-1806, impaired driving was not a determinant of fatal crashes. There was no relationship between impaired driving and crashes that resulted in a fatality (Chi-Sq.=0.013, df=1, p=0.987). There were two fatalities on this road segment during the study period. On this particular roadway, the one recorded fatality did not have any impairment. (It was unknown if the other fatality resulted from impaired driving.) There was, however, a distinct relationship between driver impairment and crashes that resulted in either a fatality or an injury (Chi-Sq.=19.324, df=1, p<0.001). Whereas only 5.3% (12 of 225) of sober drivers involved in crashes on this segment had a crash that resulted in either an injury or fatality, 66.7% (2 of 3) of all impaired drivers involved in crashes on this segment had a crash that ended in either an injury or a fatality. Thus, the following conclusions can be made about this particular road segment. In terms of all crashes, rumble strips were an effective safety tool: crash rates were curtailed compared to a control road segment. With regard to fatalities, no decisive conclusions can be made concerning rumble strips. On this road segment, alcohol was not a factor in determining if a fatality occurred. However, there is also no conclusive relationship between the presence of rumble strips and the chance of a fatality: 1.0% of all crashes on ND-1806 prior to rumble strips resulted in a fatality and 0.8% of all crashes on the road with rumble strips resulted in a fatality (Chi-Sq.=0.21, df=1, p=0.884). It can be concluded that there was a distinct relationship between driver impairment and the likelihood of the crash resulting in either an injury or fatality. Again, however, there was no conclusive relationship between the presence of rumble strips affecting the chance of a crash resulting in either an injury or a fatality (Chi-Sq.=1.771, df=1, p=0.183). Rumble strips on ND-1806 likely reduced crash rates, but did not play a statistically significant role in determining (and subsequently reducing) crash severity. As with other analysis of fatal crashes in this report, results should be used with caution due to the limited number of observations.

2.1.3 ND-49 Compared to ND-23: Background and Crash Statistics

This project studied a segment of North Dakota Highway 49 (ND-49) stretching from just south of Beulah to the southern border of Mercer County (Figure 2.4). This segment is 18.8 miles in length. Centerline and shoulder rumble strips were installed on ND-49 on October 1, 2009 (Table 2.5). The before-and-after results show signs that the road segment became safer after rumble strips were installed.

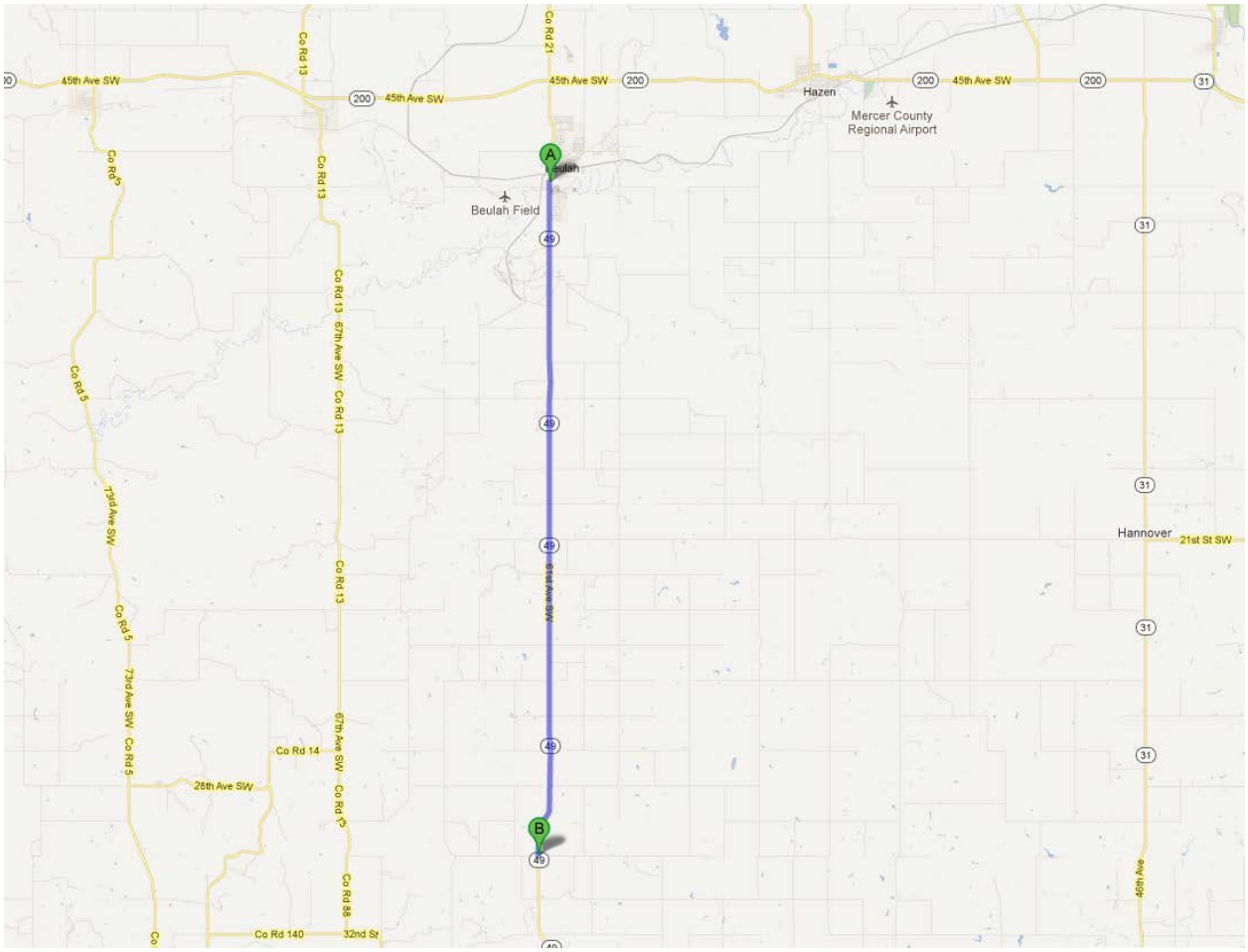

Figure 2.4 Segment of ND-49 Studied, Centerline and Shoulder Rumble Strips

Table 2.5 Crashes Occurring on ND-49

Date	Crashes	Impairment	Crash Severity	Rumble Strips
Before From: 10/01/2007 To: 10/01/2009	35 (2 multi-car)	Under influence: 0 No impairment: 35	Fatality: 1 Injury: 7 PDO: 27	No
After From: 10/01/2009 To: 10/01/2011	30 (7 multi-car)	Under influence: 1 No impairment: 29	Fatality: 0 Injury: 5 PDO: 25	Yes

North Dakota Highway 49 was compared to North Dakota Highway 23 (ND-23), a comparable road segment that does not have any rumble strips (Figure 2.5). The portion of ND-23 studied for this project stretches from North Dakota Highway 83 to the east to County Road 9/338th St. SW to the west, and 18.8 miles in length.

Figure 2.5 Segment of ND-23 Studied, No Rumble Strips

During the study period, ND-23 had mixed results. From 2007-2009 the road segment had 24 total crashes, 3 of which resulted in injuries. During 2009-2011, the same stretch of road had a comparable number of total crashes—there were 26 during this time—yet the number of crashes resulting in fatalities and injuries rose significantly (Table 2.6).

Table 2.6 Crashes Occurring on ND-23

Date	**Crashes**	**Impairment**	**Crash Severity**	**Rumble Strips**
Before From: 10/01/2007 To: 10/01/2009	24 (3 multi-car)	Under influence: 2 No impairment: 22	Fatality: 0 Injury: 3 PDO: 21	No
After From: 10/01/2009 To: 10/01/2011	26 (7 multi-car)	Under influence: 2 No impairment: 24	Fatality: 4 Injury: 7 PDO: 15	No

ND-49, with rumble strips installed, saw a decrease in the number of fatal and injury crashes but ND 23, without rumble strips installed, saw a dramatic increase in serious crashes. Table 2.7 summarizes crash rates per 100 million vehicle miles traveled (VMT) for segments of ND-49 and ND-23 studied in this project.

Table 2.7 A Comparison of Crash Rates per 100 Million VMT on ND-49 and ND-23

	ND 49		ND 23		% Change in	
	Before	**After***	**Before**	**After**	**ND 49**	**ND 23**
All Crashes						
All Crashes	209.2	154.5	130.1	107.3	**-26.2%**	-17.5%
Impairment						
**ADI	0.0	5.1	10.8	8.3	100.0%	-23.9%
Normal	209.2	149.3	119.2	99.0	**-28.6%**	-16.9%
Injury Class						
Serious Injuries	0.0	0.0	10.8	4.1	N/A	-61.9%
Other Injuries	209.2	154.5	119.2	103.1	**-26.2%**	-13.5%
Crash Severity						
Fatal Crashes	6.0	0.0	0.0	16.5	**-100.0%**	100.0%
Injury Crashes	41.8	25.7	16.3	28.9	**-38.5%**	77.6%
Property-Damage Only	161.4	128.7	113.8	61.9	-20.2%	-45.6%
Crashes Involving Large Trucks						
Total	0.0	15.4	5.4	16.5	100.0%	204.5%
Single-Vehicle	0.0	5.1	0.0	8.3	100.0%	100.0%
Multi-vehicle	0.0	10.3	5.4	8.3	100.0%	52.3%
Crashes Not Involving Large Trucks						
Total	209.2	139.0	124.6	90.8	**-33.6%**	-27.2%
Single-Vehicle	197.2	113.3	113.8	70.1	**-42.6%**	-38.4%
Multi-vehicle	12.0	25.7	10.8	20.6	115.3%	90.3%
Relationship to Roadway						
Run off road	65.7	20.6	48.8	33.0	**-68.7%**	-32.3%
On Roadway	143.4	133.9	81.3	74.3	-6.7%	-8.6%
Rollover						
Rollover	12.0	10.3	37.9	33.3	**-13.9%**	-13.0%
Lane Departures						
Head On	0.0	0.0	0.0	0.0	N/A	N/A
Sideswipe Same D.	0.0	0.0	0.0	4.1	N/A	100.0%
Sideswipe Opposite D.	0.0	5.1	5.4	0.0	100.0%	-100.0%
Road Geometry						
Curve	12.0	10.3	27.1	12.4	-13.9%	-54.3%
Hill	17.9	30.9	21.7	20.6	72.3%	-4.8%
Driver Condition						
Drowsy	6.0	0.0	5.4	4.1	**-100.0%**	-23.9%
Contributing Factors						
Distracted	12.0	0.0	0.0	0.0	**-100.0%**	N/A
Speed	35.9	20.6	27.1	37.1	**-42.6%**	37.0%
Improper Overtaking	6.0	5.1	0.0	0.0	**-13.9%**	N/A
Light						
Daylight	53.8	56.6	54.2	66.0	**5.3%**	21.8%
Dawn, Dusk, or Dark	155.4	97.8	75.9	41.3	-37.1%	-45.6%
Weather						
Clear or Cloudy	179.3	133.9	108.4	74.3	-25.3%	-31.5%
Other	29.9	20.6	21.7	33.0	**-31.1%**	52.3%

** Center and shoulder rumble strips/rumble stripes were installed.*

*** ADI: alcohol or other drug-impaired, Normal: no impairment*

2.1.4 ND-49 versus ND-23: A Comparative Analysis

Rumble strips appear to have been effective in reducing overall crash rates. The crash rate per 100 million VMT decreased by 26.2% for ND-49 during the study period. In comparison, the crash rate for the control road segment only decreased by 17.5% during the same time frame. This implies that driving conditions were safer on the road with rumble strips than the control road segment. Once the installation of rumble strips on ND-49 was complete, crash rates for fatal crashes, injury crashes, and property-damage-only crashes decreased. This suggests that rumble strips are an effective countermeasure for crashes on this particular road segment. There were no statistically significant links between rumble strips and a reduction in crash severity for fatal crashes and crashes that resulted in either an injury or fatality (Chi-Sq.=0.871, df=1, p=0.351; Chi-Sq.=0.387, df=1, p=0.534). Contributing factors such as distracted driving, speeding, and improper overtaking were all greatly reduced when comparing before-and-after results from ND-49.

Alcohol was not an external factor explaining all crash patterns on ND-49. Of the nine multi-vehicle collisions that occurred on ND-49 during the before-and-after study period, none involved impaired drivers. Thus, there was no statistically significant link between the likelihood of a multi-vehicle crash involving alcohol (Chi-Sq.=0.163, df=1, p=0.686). Impaired driving also was not a factor in explaining the likelihood that the crash resulted in a fatality (Chi-Sq.=0.016, df=1, p=0.900). The only fatality to occur on this road segment involved a sober driver. There was, however, a distinct relationship between impaired driving and the crash resulting in either an injury or a fatality. This relationship was statistically significant at the 5% level (Chi-Sq.=4.063, df=1, p=0.044). As a result, conclusions made about this road segment arguing that rumble strips helped reduce the rate of crashes that result in injuries cannot be considered definitive. Although the overall rate of injury crashes did in fact decrease, there is a clear link between impairment and the propensity for a crash to result in an injury. For this particular road segment, injury crash rates may be better explained by impaired driving than by the installation of rumble strips. Nonetheless, the fact that injury rates decreased even with a clear relationship between injury crashes and impairment suggests that conditions on this road may be safer with rumble strips in place.

Like ND-49, alcohol was not a determinant of crashes on the control road segment, ND-23. There was no statistically significant relationship between alcohol and the likelihood of a crash involving multiple vehicles (Chi-Sq.=2.348, df=1, p=0.125). Similarly, alcohol was not connected with the chance of a crash resulting in a fatality (Chi-Sq.=0.387, df=1, p=0.534). All of the fatalities on this road segment involved sober drivers. Moreover, there was no clear relationship between impaired driving and the probability of a crash resulting in an injury (Chi-Sq.=0.027, df=1, p=0.869). The fact that impaired driving is not an external variable at work on this road segment, justifies why these two road segments can be compared.

2.2 Rumble Strips on Roads with High AADT Change

Thus far this paper has examined rumble strips on North Dakota road segments that have comparable length, AADT, and function. It is important to understand that not all road segments in North Dakota have had these variables remain constant over time and thus are not easily capable of being compared with one another. In western North Dakota, an expanding energy industry focused on oil development and extraction has created a dramatic shift in driving conditions and the safety of various road segments. In this portion of the state, AADT on many roads has increased drastically. Because of these rapidly changing road conditions, three road segments in the western North Dakota oil region were studied. These road segments shared two important qualities. First, they had a substantial increase in AADT. Second, they all had rumble strips installed recently.

2.2.1 Centerline and Shoulder Rumble Strips on ND-8

The section of ND-8 running from just south of Stanley near Highway 2 to its junction with ND-23 was studied (Figure 2.6). This road segment is 23.8 miles in length. The road segment was observed on two separate occasions between 2007 and 2011. During this time oil traffic increased significantly on this road, resulting in a substantially higher AADT over the five years observed. The AADT of the study periods increased from 1,071 in 2007 to 2,898 in 2011, a 170.6% increase. There was substantial change in total number of crashes between the two study periods: higher AADT significantly increased the total number of crashes and multi-car crashes injuries that took place on this road despite the installation of rumble strips (Table 2.8).

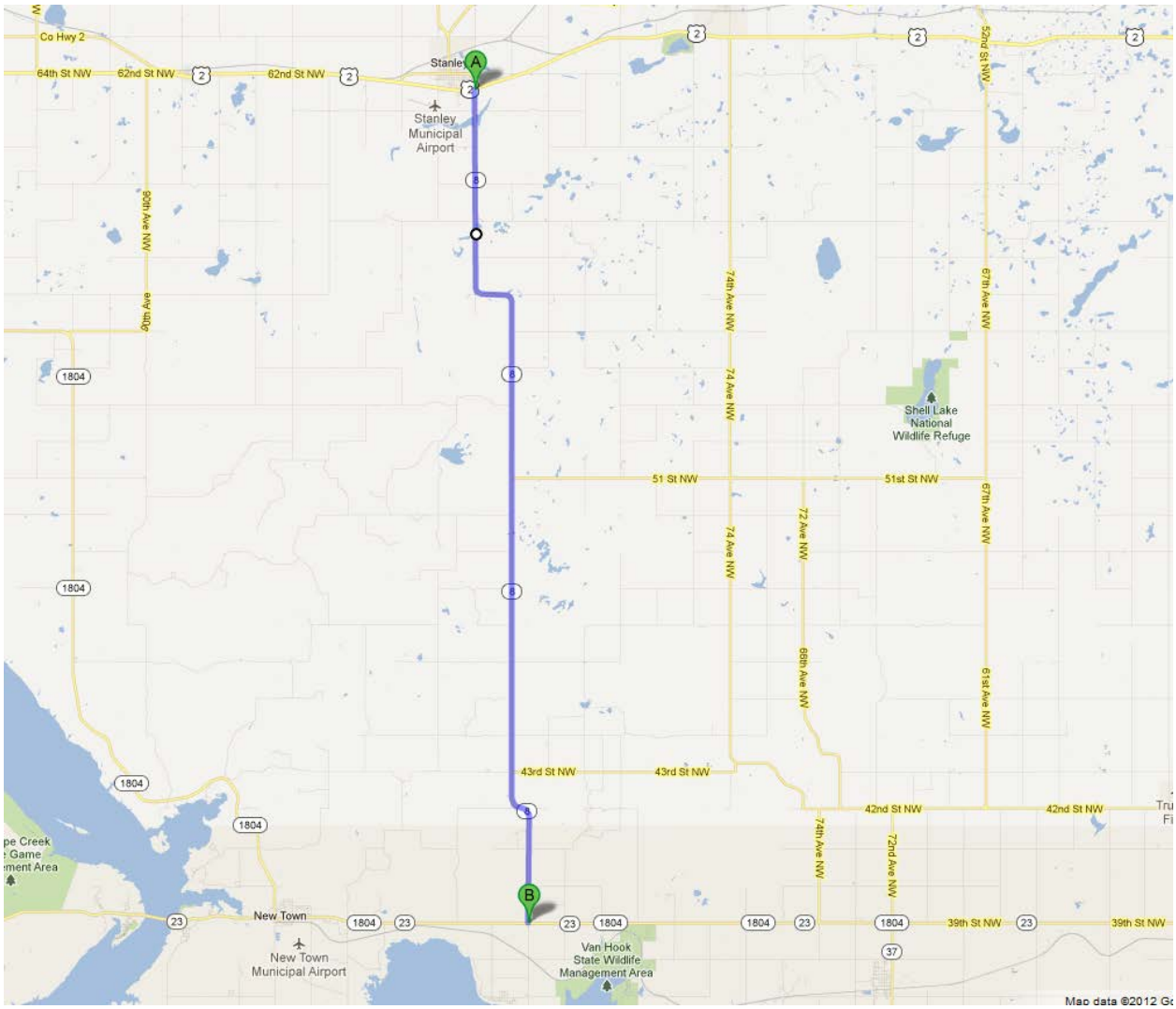

Figure 2.6 Segment of ND-8 Studied, Centerline and Shoulder Rumble Strips

Table 2.8 Crashes Occurring on ND-8

Date	**Crashes**	**Impairment**	**Crash Severity**	**Rumble Strips**
Before From: 10/01/2007 To: 10/01/2009	44 (9 multi-car)	Under influence: 3 No impairment: 41	Fatality: 1 Injury: 11 PDO: 32	No
After From: 10/01/2009 To: 10/01/2011	58 (29 multi-car)	Under influence: 8 No impairment: 50	Fatality: 1 Injury: 16 PDO: 41	Yes

Crash rates per 100 million vehicle miles traveled (VMT) for the ND-8 road segment are summarized in Table 2.9 factoring for crash statistics both prior to and after the installation of rumble strips.

Table 2.9 Crash Rates per 100 Million VMT Before and After Rumble Strips on ND-8

	ND 8		% Change in
	Before	**After***	**ND 8**
All Crashes			
All Crashes	131.9	123.8	**-6.1%**
Impairment			
**ADI	9.0	17.1	90.0%
Normal	122.9	106.8	**-13.1%**
Injury Class			
Serious Injuries	3.0	14.9	398.7%
Other Injuries	128.9	108.9	**-15.5%**
Crash Severity			
Fatal Crashes	3.0	2.1	**-28.8%**
Injury Crashes	33.0	34.2	3.6%
Property-Damage Only	95.9	87.5	**-8.7%**
Crashes Involving Large Trucks			
Total	21.0	36.3	73.0%
Single-Vehicle	12.0	8.5	**-28.8%**
Multi-vehicle	9.0	27.8	208.7%
Crashes Not Involving Large Trucks			
Total	110.9	87.5	**-21.1%**
Single-Vehicle	92.9	53.4	**-42.5%**
Multi-vehicle	18.0	34.2	90.0%
Relationship to Roadway			
Run off road	48.0	32.0	**-33.2%**
On Roadway	83.9	91.8	9.4%
Rollover			
Rollover	24.0	27.8	15.8%
Lane Departures			
Head On	3.0	0.0	**-100.0%**
Sideswipe Same D.	0.0	6.4	100.0%
Sideswipe Opposite D.	3.0	10.7	256.2%
Road Geometry			
Curve	15.0	8.5	**-43.0%**
Hill	48.0	38.4	**-19.9%**
Driver Condition			
Drowsy	0.0	2.1	100.0%
Contributing Factors			
Distracted	6.0	10.7	78.1%
Speed	18.0	27.8	54.4%
Improper Overtaking	3.0	2.1	**-28.8%**
Light			
Daylight	59.9	49.1	**-18.1%**
Dawn, Dusk, or Dark	71.9	74.7	3.9%
Weather			
Clear or Cloudy	98.9	74.7	**-24.4%**
Other	33.0	49.1	49.0%

** Center and shoulder rumble strips/rumble stripes were installed.*

*** ADI: alcohol or other drug-impaired, Normal: no impairment*

2.2.2 ND-8 Crash Analysis

A before-and-after comparison of crash rates on ND-8 reveals that the overall crash rate declined by 6.1% between 2007 and 2011. After the installation of rumble strips on ND-8, fatal crash rates and property-damage-only crash rates decreased by 28.8% and 8.7%, respectively. However, there was a 3.3% increase in injury crash rate. Crashes involving large trucks increased considerably over the study period. This can likely be linked to the increased truck traffic that occurred due to oil development in the region. Crashes involving multiple vehicles increased substantially for both those that involved trucks and those that did not. Contributing factors such as distracted driving and speeding increased 78.1% and 54.4%, respectively, during the study period.

A multiple-vehicle crash was more likely to occur on ND-8 after rumble strips had been installed (Chi-Sq.=9.343, df=1, p=0.002). This is counterintuitive to the design and functionality of rumble strips: they are intended to prevent head-on collisions and alert drivers of potentially dangerous situations. Although this may be attributed to the large increase in AADT on this road segment, the model used in crash rate analysis captures such increases. Thus, the 208.7% increase in multiple-vehicle crashes involving large trucks and the 90.0% increase in multiple-vehicle crashes not involving large trucks should be considered a serious issue on ND-8. There was no statistical correlation between the use of rumble strips on the road segment and the chance of a crash resulting in either a fatality or an injury/fatality (Chi-Sq.=0.039, df=1, p=0.843; Chi-Sq.=0.051, df=1, =0.821).

On this particular road segment, alcohol was a determinant of crashes resulting in either fatalities or injuries and fatalities. Fatalities on ND-8 were more likely to occur if the driver was operating the vehicle while impaired (Chi-Sq.=8.791, df=1, p=0.003). Similarly, the rate of impaired drivers that had a crash resulting in either an injury or a fatality far exceeded the rate of sober drivers that had a crash ending in either an injury or a fatality. This difference was statistically significant at the 5% level (Chi-Sq.=5.742, df=1, p=0.017). Thus, on this stretch of ND-8 it can be concluded that the presence of impaired drivers is a better determinant of road safety than is the presence of rumble strips. Nonetheless, given the decrease in crash rates in light of the increase in AADT, it appears as though rumble strips have made this segment moderately safer among the non-impaired driver group.

2.2.3 Shoulder Rumble Strips on ND-2 Ray

A portion of Highway 2 was examined from 2005 to 2009. The road segment stretched from just west of Ray, to North Dakota Highway 85 (Figure 2.7). The road segment is 20.8 miles in length. Like ND-8, the western North Dakota oil boom resulted in increasing AADT on this road segment.

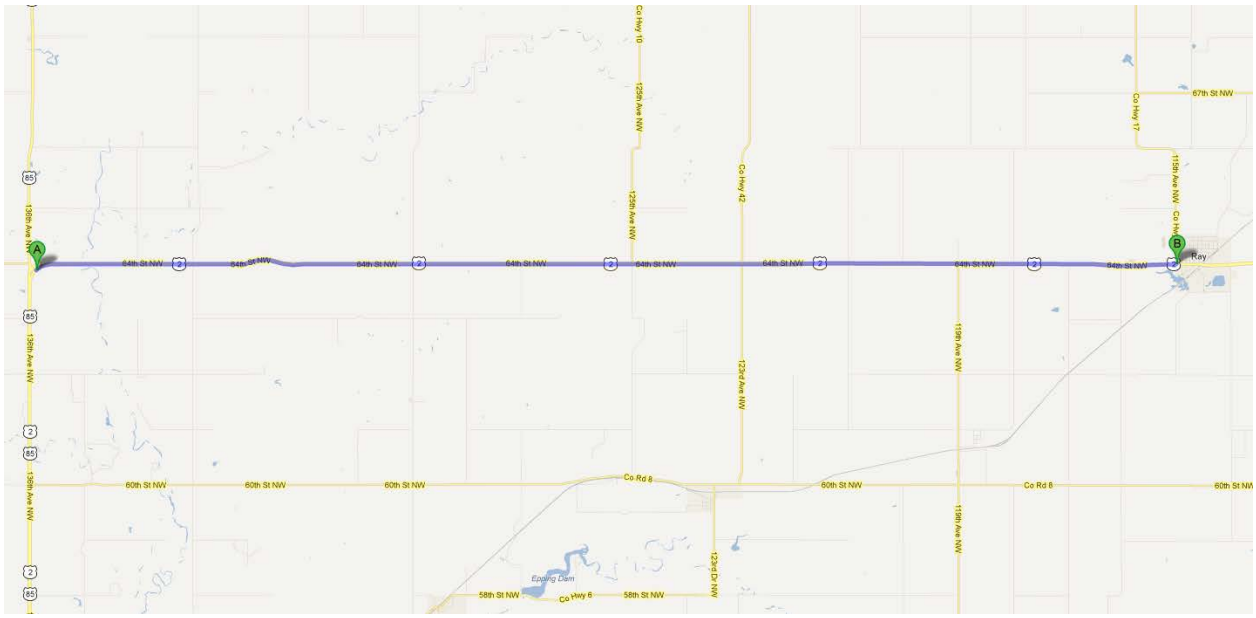

Figure 2.7 Segment of ND-2 Ray Studied, Shoulder Rumble Strips

During the study periods, the total number of crashes decreased by one, from 21 to 20 (Table 2.10). However, there was a considerable increase in injury crashes, from one between 2005 and 2007 to five in the 2007 to 2009 study period. Although the number of injury crashes increased from one to five, the number of fatality crashes decreased to 0. Rumble strips may play a role in preventing collisions that have greater crash severity. Table 2.11 summarizes crash rates per 100 million vehicle miles traveled (VMT) for this segment of ND-2 from Ray to ND-85.

Table 2.10 Crashes Occurring on the Segment of ND-2 Near Ray, North Dakota

Date	**Crashes**	**Impairment**	**Crash Severity**	**Rumble Strips**
Before From: 10/01/2005 To: 10/01/2007	21 (3 multi-car)	Under influence: 2 No impairment: 19	Fatality: 1 Injury: 1 PDO: 19	No
After From: 10/01/2007 To: 10/01/2009	20 (3 multi-car)	Under influence: 0 No impairment: 20	Fatality: 0 Injury: 5 PDO: 15	Yes

Table 2.11 Before-and-After Crash Rates per 100 Million VMT for ND-2 Near Ray, ND

	ND 2 Ray		% Change in
	Before	**After***	**ND 2 Ray**
All Crashes			
All Crashes	115.2	94.5	**-18.0%**
Impairment			
**ADI	11.0	0.0	**-100.0%**
Normal	104.2	94.5	**-9.3%**
Injury Class			
Serious Injuries	11.0	4.7	**-56.9%**
Other Injuries	104.2	89.7	**-13.9%**
Crash Severity			
Fatal Crashes	5.5	0.0	**-100.0%**
Injury Crashes	5.5	23.6	330.6%
Property-Damage Only	104.2	70.9	**-32.0%**
Crashes Involving Large Trucks			
Total	11.0	9.4	**-13.9%**
Single-Vehicle	0.0	0.0	N/A
Multi-vehicle	11.0	9.4	**-13.9%**
Crashes Not Involving Large Trucks			
Total	104.2	85.0	**-18.4%**
Single-Vehicle	98.7	80.3	**-18.7%**
Multi-vehicle	5.5	4.7	**-13.9%**
Relationship to Roadway			
Run off road	21.9	23.6	7.6%
On Roadway	93.2	70.9	**-24.0%**
Rollover			
Rollover	11.0	9.4	**-13.9%**
Lane Departures			
Head On	0.0	0.0	N/A
Sideswipe Same D.	5.5	4.7	**-13.9%**
Sideswipe Opposite D.	0.0	0.0	N/A
Road Geometry			
Curve	5.5	0.0	**-100.0%**
Hill	32.9	18.9	**-42.6%**
Driver Condition			
Drowsy	0.0	0.0	N/A
Contributing Factors			
Distracted	5.5	0.0	**-100.0%**
Speed	21.9	18.9	**-13.9%**
Improper Overtaking	0.0	0.0	N/A
Light			
Daylight	27.4	37.8	37.8%
Dawn, Dusk, or Dark	87.8	56.7	**-35.4%**
Weather			
Clear or Cloudy	98.7	61.4	**-37.8%**
Other	16.5	33.1	100.9%

** Shoulder rumble strips/rumble stripes were installed.*

*** ADI: alcohol or other drug-impaired, Normal: no impairment*

2.2.4 ND-2 Ray Crash Analysis

After the installation of rumble strips, the overall crash rate on this road segment decreased 18.0%, a positive sign considering the shift in AADT. Multiple-vehicle collisions involving large trucks and multiple-vehicle collisions involving all other vehicle types decreased nearly 14%. Similarly, contributing factors such as distracted driving or speeding decreased by 100% and 13.9%, respectively. The decrease in several crash rates is promising for this road segment, but it should be noted that there was not a significant decrease in the total number of crashes when examining before-and-after study periods. The difference in pre-rumble-strip crash rates and post-rumble-strip crash rates may be related to the change in traffic volume.

There were no statistical differences between before-and-after crash patterns when factoring for multiple-vehicle collisions (Chi-Sq.=0.004, df=1, p=0.948). Likewise, there were no statistically significant differences concerning the relationships between the presence of rumble strips and the likelihood of a crash resulting in a fatality (Chi-Sq.=0.976, df=1, p=0.323). In addition, the probability of a crash resulting in either an injury or a fatality was not directly related to whether or not the road segment had rumble strips (Chi-Sq.=1.733, df=1, p=0.188).

Alcohol was a factor in explaining fatalities on this road segment. The relationship between alcohol and the likelihood of a crash resulting in a fatality was statistically significant at the 1% level (Chi-Sq.=18.486, df=1, $p<0.001$). There was no statistically significant relationship between impaired driving and the chance of a crash on ND-2 involving more than one vehicle (Chi-Sq.=2.508, df=1, p=0.113). Similarly, there was no significant relationship between impaired driving and the probability of the crash resulting in either an injury or a fatality (Chi-Sq.=1.401, df=1, p=0.237).

2.2.5 Shoulder Rumble Strips on ND-2 Stanley

The final road segment studied that had a significant increase in AADT is a second portion of Highway 2 that stretches from just west of Stanley, to the western border of Mountrail County (Figure 2.8). This segment is 21.2 miles in length. Like the other road segments studied in this section, Highway 2 from Stanley to the western Mountrail County border has experienced heavier traffic flow due to oil development.

Between the two study periods in which the road was observed, there was no change in the number of crashes; 19 crashes took place in both study periods (Table 2.12). Similarly, neither of the study periods had a crash result from impaired driving. There were zero injuries and zero fatalities during the four years that this road segment was studied.

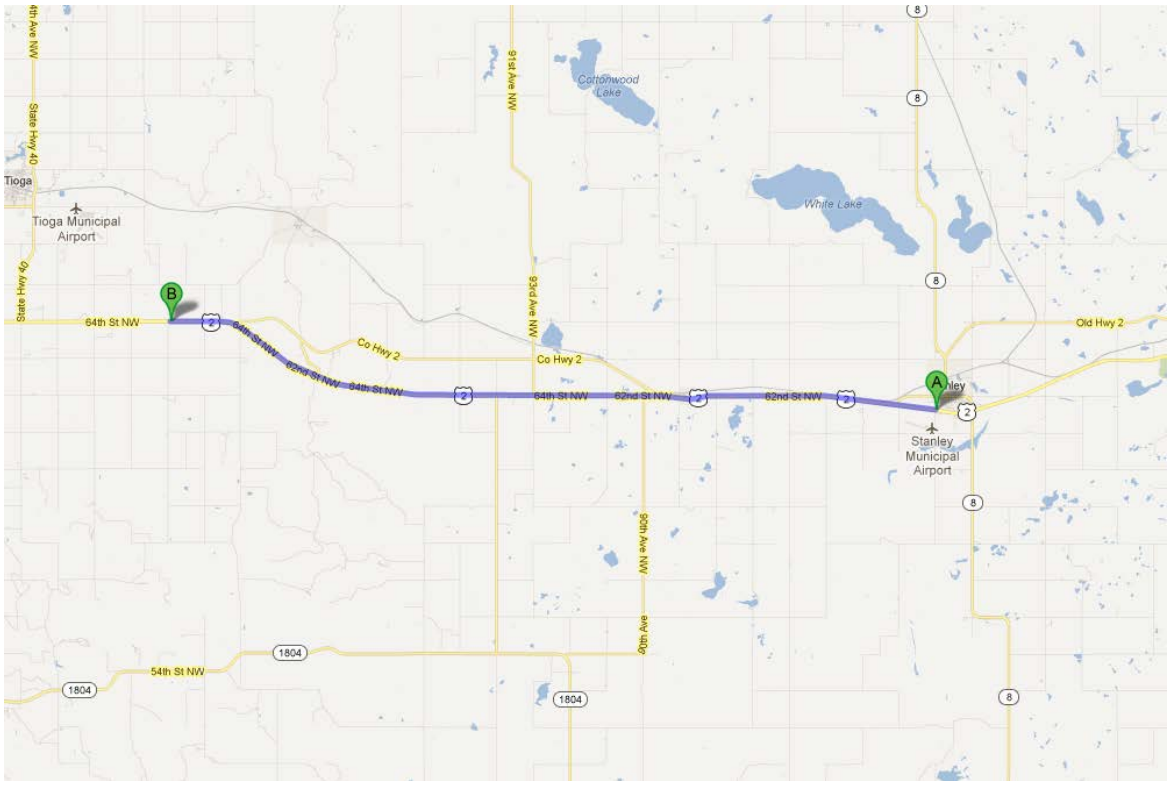

Figure 2.8 Segment of ND-2 Stanley Studied, Shoulder Rumble Strips

Table 2.12 Crashes Occurring on the Segment of ND-2 Near Stanley, North Dakota

Date	**Crashes**	**Impairment**	**Crash Severity**	**Rumble Strips**
Before From: 10/01/2004 To: 10/01/2006	19 (1 multi-car)	Under influence: 0 No impairment: 19	Fatality: 0 Injury: 0 PDO: 19	No
After From: 10/01/2006 To: 10/01/2008	19 (2 multi-car)	Under influence: 0 No impairment: 19	Fatality: 0 Injury: 0 PDO: 19	Yes

Table 3.6 summarizes the crash rates per 100 million vehicle miles traveled (VMT) for the segment of ND-2 studied in this project. Preliminary findings from the crash rate summary table suggest that driving conditions were safer after the installation of rumble strips.

Table 2.13 Before-and-After Crash Rates per 100 Million VMT for ND-2 Near Stanley, ND

	ND 2 Stanley		% Change in
	Before	**After***	**ND 2 Stanley**
All Crashes			
All Crashes	90.4	80.0	**-11.4%**
Impairment			
**ADI	0.0	0.0	N/A
Normal	90.4	80.0	**-11.4%**
Injury Class			
Serious Injuries	0.0	0.0	N/A
Other Injuries	90.4	80.0	**-11.4%**
Crash Severity			
Fatal Crashes	0.0	0.0	N/A
Injury Crashes	0.0	0.0	N/A
Property-Damage Only	90.4	80.4	**-11.4%**
Crashes Involving Large Trucks			
Total	0.0	4.2	100.0%
Single-Vehicle	0.0	0.0	N/A
Multi-vehicle	0.0	4.2	100.0%
Crashes Not Involving Large Trucks			
Total	90.4	75.8	**-16.1%**
Single-Vehicle	85.6	71.6	**-16.4%**
Multi-vehicle	4.8	4.2	**-11.4%**
Relationship to Roadway			
Run off road	0.0	16.9	N/A
On Roadway	90.4	63.2	**-30.1%**
Rollover			
Rollover	0.0	8.4	100.0%
Lane Departures			
Head On	0.0	0.0	N/A
Sideswipe Same D.	4.8	4.2	**-11.4%**
Sideswipe Opposite D.	0.0	0.0	N/A
Road Geometry			
Curve	0.0	0.0	N/A
Hill	0.0	0.0	N/A
Driver Condition			
Drowsy	0.0	0.0	N/A
Contributing Factors			
Distracted	0.0	4.2	100.0%
Speed	0.0	16.9	100.0%
Improper Overtaking	4.8	0.0	**-100.0%**
Light			
Daylight	23.8	16.9	**-29.2%**
Dawn, Dusk, or Dark	66.6	63.2	**-5.1%**
Weather			
Clear or Cloudy	90.4	80.0	**-11.4%**
Other	0.0	0.0	N/A

** Shoulder rumble strips/rumble stripes were installed.*

*** ADI: alcohol or other drug-impaired, Normal: no impairment*

2.2.6 ND-2 Stanley Crash Analysis

After rumble strips were installed on this road segment, crash rates per 100 million VMT decreased 11.4%. For crashes that did not involve a large truck, the crash rate per 100 million VMT decreased by 16.4% for single-vehicle collisions and by 11.4% for crashes involving more than one vehicle.

There are a few dangerous trends that emerged after the rumble strips were placed on the roadway. Whereas there were zero crashes involving a large truck prior to the installation of rumble strips, there were 4.2 crashes involving a large truck per 100 million VMT after rumble strips were placed on the roadway. This is likely attributed to the traffic mix related to growing oil activity than the actual implementation of rumble strips. Furthermore, whereas there were no crashes that resulted from distracted driving or speeding prior to the use of rumble strips, those two contributing factors were present once rumble strips were used on this stretch of roadway. Although this stems from driver behavior and likely does not correlate to rumble strips, it is encouraging that overall crash rates decreased in light of the fact that dangerous driver behaviors increased over the same time period.

Like the ND-2 road segment studied near Ray, the decrease in several crash rates is promising for this portion of ND-2. However, it should be noted that there was no decrease in the total number of crashes when comparing before-and-after crash results. The difference in crash rates is attributable to the change in traffic volume as captured by the model.

Only one statistical analysis was possible due to the limited number of crashes and the crash characteristics for this roadway. There was no statistically significant relationship between the use of rumble strips as a determinant of a crash involving more than one vehicle (Chi-Sq.=0.487, df=1, p=0.485). Because there were no impaired drivers, fatalities, or injuries on this road segment, it is impossible to perform Chi-Square analyses when a variable is constant. Nonetheless, knowing that alcohol was not a factor in the two study periods eliminates impaired driving as a confounding variable that may explain road safety on ND-2 better than rumble strips. Moreover, because there were no injuries or fatalities in either study period, it validates the model's applicability in this research project and helps support the claim that rumble strips do in fact improve safety on roads. This road segment was perhaps the most useful when analyzing the usefulness of rumble strips: a key external variable (impairment) was constant during both study periods, crash severity was constant in both study periods, the total number of crashes was constant in both study periods, and the model was able to capture changes in AADT to analyze crash rates per 100 million VMT. The ND-2 road segment near Stanley should serve as an example that, when most variables are held constant, rumble strips do appear to be a factor in making the roadway safer.

3. CONCLUSION

Overall, it appears as though rumble strips play a role in reducing crash rates for overall crashes, multi-vehicle collisions, crash severity, rates of injuries and fatalities, or a combination of the four crash statistics analyzed throughout this study (Table 3.1). Before-and-after comparisons of roads with and without rumble strips reveal that roads are generally safer after the installation of rumble strips. For roads that have experienced significantly higher AADT levels in recent years, it can be argued that, in general, rumble strips are an effective strategy that can keep crash rates below levels that are proportionate to the increased rate of AADT.

Note that this project only looked at rumble strip data on road segments by comparing various crashes statistics once they had occurred. It is undeniable that rumble strips likely prevented many crashes from happening by alerting drivers and allowing them to take a preventative action. Thus, although impossible to integrate into this study for statistical purposes, there were likely many instances when rumble strips helped make the roads safer even though those instances were not capable of being measured.

There are a variety of factors at play when attempting to make roads safer. Because conditions on many roads in North Dakota are rapidly changing – especially in the western part of the state – it is especially important to monitor crash rate trends as traffic is only expected to increase in the future. It will be important to revisit this study to understand the dangers on North Dakota's roadways and strategies that can be utilized to make them safer in the future.

Table 3.1 Before-and-After Crash Rates per 100 Million VMT, by Rumble Strip Type

	Center & Shoulder		Shoulder Only		No Rumbles		% Change in		
	Before	After*	Before	After**	Before	After	C&S	S	No
All Crashes									
All Crashes	212.6	208.1	101.9	86.8	127.2	134.6	**-2.1%**	**-14.8%**	5.8%
Impairment									
***ADI	4.6	10.5	5.1	0.0	7.6	6.8	128.2%	**-100%**	-10.3%
Normal	208.0	197.5	96.8	86.8	119.6	127.8	**-5.0%**	**-10.3**	6.8%
Injury Class									
Serious Injuries	2.3	9.6	5.1	2.2	3.8	1.7	314.9%	**-56.3%**	-55.1%
Other Injuries	210.3	198.5	96.8	84.6	123.4	132.9	**-5.6%**	**-12.6%**	7.6%
Crash Severity									
Fatal Crashes	3.5	1.9	2.5	0.0	0.0	6.8	**-44.7%**	**-100%**	100%
Injury Crashes	25.4	30.7	2.5	11.1	15.2	25.6	**20.7%**	337.0%	68.2%
PDO	183.8	175.5	96.8	75.7	112.0	102.2	-4.5%	**-21.8%**	-8.8%
Crashes Involving Large Trucks									
Total	9.2	19.2	5.1	6.7	5.7	6.8	107.4%	31.1%	19.6%
Single-Vehicle	5.8	4.8	0.0	0.0	0.0	3.4	**-17.0%**	N/A	100%
Multi-vehicle	3.5	14.4	5.1	6.7	5.7	3.4	314.9%	31.1%	-40.2%
Crashes Not Involving Large Trucks									
Total	203.4	188.9	96.8	80.2	121.5	127.8	**-7.1%**	**-17.2%**	5.1%
Single-Vehicle	187.2	164.9	91.7	75.7	100.7	103.9	**-11.9%**	**-17.5%**	3.2%
Multi-vehicle	16.2	24.0	5.1	4.5	20.9	23.9	48.2%	**-12.6%**	14.2%
Relationship to Roadway									
Run off road	41.6	29.7	10.2	20.0	32.3	23.9	**-28.5%**	96.7%	-26.1%
On Roadway	171.0	178.4	91.7	66.8	95.0	110.7	**4.3%**	**-27.2%**	16.6%
Rollover									
Rollover	15.0	24.0	5.1	8.9	24.7	22.1	59.6%	74.8%	-10.3%
Lane Departures									
Head On	1.2	1.0	0.0	0.0	0.0	0.0	-17.0%	N/A	N/A
Sideswipe Same D.	2.3	2.9	5.1	4.5	5.7	3.4	24.5%	-12.6%	-40.2%
Sideswipe Opposite D.	2.3	5.8	0.0	0.0	1.9	0.0	148.9%	N/A	-
Road Geometry									
Curve	10.4	11.5	2.5	0.0	11.4	10.2	10.6%	**-100%**	-10.3%
Hill	26.6	31.6	15.3	8.9	9.5	13.6	**19.1%**	**-41.7%**	43.5%
Driver Condition									
Drowsy	2.3	1.0	0.0	0.0	1.9	1.7	**-58.5%**	N/A	-10.3%
Contributing Factors									
Distracted	6.9	5.8	2.5	2.2	5.7	6.8	**-17.0%**	**-12.6%**	19.6%
Speed	20.8	21.1	10.2	17.8	20.9	29.0	**1.4%**	74.8%	38.6%
Improper Overtaking	2.3	2.9	2.5	0.0	0.0	1.7	**24.5%**	**-100%**	100%
Light									
Daylight	49.7	52.7	25.5	26.7	53.2	56.2	6.1%	**4.9%**	5.7%
Dawn, Dusk, or Dark	163.0	155.4	76.4	60.1	74.1	78.4	**-4.7%**	**-21.3%**	5.8%
Weather									
Clear or Cloudy	189.5	175.5	94.3	71.3	108.3	119.3	**-7.4%**	**-24.4%**	10.2%
Other	23.1	32.6	7.6	15.6	19.0	15.3	41.1%	103.9%	-19.3%

** Center and shoulder rumble strips/rumble stripes were installed. ;** Shoulder rumble strips/rumble stripes were installed.; ** ADI: alcohol or other drug-impaired, Normal: no impairment*

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APPENDIX OF TABLES

Table A.1 ND-1806
Crash Rates per 100 Million VMT, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0.0	2.7	2.7	0.0	7.9	7.9	0.0	5.1	5.1
Other Injuries	2.7	282.7	285.4	5.3	326.1	331.4	2.5	43.4	45.9
Crash Severity									
Fatal Crashes	0.0	2.7	2.7	0.0	2.6	2.6	0.0	-0.1	-0.1
Injury Crashes	2.7	8.2	11.0	2.6	26.3	28.9	-0.1	18.1	18.0
Property-Damage Only	0.0	274.5	274.5	2.6	305.1	307.7	2.6	30.6	33.2
Crashes Involving Large Trucks									
Total	0.0	2.7	2.7	0.0	0.0	0.0	0.0	-2.7	-2.7
Single-Vehicle	0.0	2.7	2.7	0.0	0.0	0.0	0.0	-2.7	-2.7
Multi-vehicle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crashes Not Involving Large Trucks									
Total	2.7	282.7	285.4	5.3	334.0	339.3	2.5	51.3	53.8
Single-Vehicle	2.7	266.2	269.0	5.3	323.5	328.7	2.5	57.2	59.8
Multi-vehicle	0.0	16.5	16.5	0.0	10.5	10.5	0.0	-5.9	-5.9
Relationship to Roadway									
Run off road	0.0	24.7	24.7	0.0	31.6	31.6	0.0	6.9	6.9
On Roadway	2.7	260.7	263.5	5.3	302.4	307.7	2.5	41.7	44.2
Rollover									
Rollover	0.0	8.2	8.2	5.3	21.0	26.3	5.3	12.8	18.1
Lane Departures									
Head On	0.0	0.0	0.0	0.0	2.6	2.6	0.0	2.6	2.6
Sideswipe Same D.	0.0	5.5	5.5	0.0	0.0	0.0	0.0	-5.5	-5.5
Sideswipe Opposite D.	0.0	2.7	2.7	0.0	0.0	0.0	0.0	-2.7	-2.7
Road Geometry									
Curve	0.0	5.5	5.5	0.0	15.8	15.8	0.0	10.3	10.3
Hill	0.0	11.0	11.0	2.6	21.0	23.7	2.6	10.1	12.7
Driver Condition									
Drowsy	0.0	2.7	2.7	0.0	0.0	0.0	0.0	-2.7	-2.7
Contributing Factors									
Distracted	2.7	2.7	5.5	0.0	2.6	2.6	-2.7	-0.1	-2.9
Speed	0.0	16.5	16.5	0.0	13.1	13.1	0.0	-3.3	-3.3
Improper Overtaking	0.0	0.0	0.0	0.0	2.6	2.6	0.0	2.6	2.6
Light									
Daylight	0.0	38.4	38.4	0.0	55.2	55.2	0.0	16.8	16.8
Dawn, Dusk, or Dark	2.7	247.0	249.8	5.3	278.8	284.0	2.5	31.7	34.3
Weather									
Clear or Cloudy	2.7	274.5	277.2	2.6	318.2	320.8	-0.1	43.8	43.6
Other	0.0	11.0	11.0	2.6	15.8	18.4	2.6	4.8	7.4
Visual Obstruction									
Yes	2.7	5.5	8.2	2.6	5.3	7.9	-0.1	-0.2	-0.3
No	0.0	280.0	280.0	2.6	328.7	331.4	2.6	48.8	51.4

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement
** Center and shoulder rumble strips/rumble stripes were installed.*

Table A.2 ND-1806
Number of Crashes, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0	1	1	0	3	3	0	2	2
Other Injuries	1	103	104	2	124	126	1	21	22
Crash Severity									
Fatal Crashes	0	1	1	0	1	1	0	0	0
Injury Crashes	1	3	4	1	10	11	0	7	7
Property-Damage	0	100	100	1	116	117	1	16	17
Crashes Involving Large Trucks									
Total	0	1	1	0	0	0	0	-1	-1
Single-Vehicle	0	1	1	0	0	0	0	-1	-1
Multi-vehicle	0	0	0	0	0	0	0	0	0
Crashes Not Involving Large Trucks									
Total	1	103	104	2	127	129	1	24	25
Single-Vehicle	1	97	98	2	123	125	1	26	27
Multi-vehicle	0	6	6	0	4	4	0	-2	-2
Relationship to Roadway									
Run off road	0	9	9	0	12	12	0	3	3
On Roadway	1	95	96	2	115	117	1	20	21
Rollover									
Rollover	0	3	3	2	8	10	2	5	7
Lane Departures									
Head On	0	0	0	0	1	1	0	1	1
Sideswipe Same D.	0	2	2	0	0	0	0	-2	-2
Sideswipe Opposite	0	1	1	0	0	0	0	-1	-1
Road Geometry									
Curve	0	2	2	0	6	6	0	4	4
Hill	0	4	4	1	8	9	1	4	5
Driver Condition									
Drowsy	0	1	1	0	0	0	0	-1	-1
Contributing Factors									
Distracted	1	1	2	0	1	1	-1	0	-1
Speed	0	6	6	0	5	5	0	-1	-1
Improper Overtaking	0	0	0	0	1	1	0	1	1
Light									
Daylight	0	14	14	0	21	21	0	7	7
Dawn, Dusk, or Dark	1	90	91	2	106	108	1	16	17
Weather									
Clear or Cloudy	1	100	101	1	121	122	0	21	21
Other	0	4	4	1	6	7	1	2	3
Visual Obstruction									
Yes	1	2	3	1	2	3	0	0	0
No	0	102	102	1	125	126	1	23	24

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement
** Center and shoulder rumble strips/rumble stripes were installed.*

Table A.3 ND-15

Crash Rates per 100 Million VMT, Before and After Rumble Strips

	Before			After			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Injuries	5.8	119.9	125.7	5.8	148.0	153.8	0.0	28.1	28.1
Crash Severity									
Fatal Crashes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Injury Crashes	2.9	11.7	14.6	0.0	23.2	23.2	-2.9	11.5	8.6
Property-Damage Only	2.9	108.2	111.1	5.8	124.8	130.6	2.9	16.6	19.5
Crashes Involving Large Trucks									
Total	0.0	5.8	5.8	0.0	0.0	0.0	0.0	-5.8	-5.8
Single-Vehicle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Multi-vehicle	0.0	5.8	5.8	0.0	0.0	0.0	0.0	-5.8	-5.8
Crashes Not Involving Large Trucks									
Total	5.8	114.0	119.9	5.8	148.0	153.8	0.0	34.0	33.9
Single-Vehicle	0.0	93.6	93.6	0.0	127.7	127.7	0.0	34.1	34.1
Multi-vehicle	5.8	20.5	26.3	5.8	20.3	26.1	0.0	-0.2	-0.2
Relationship to Roadway									
Run off road	0.0	23.4	23.4	0.0	17.4	17.4	0.0	-6.0	-6.0
On Roadway	5.8	96.5	102.3	5.8	130.6	136.4	0.0	34.1	34.1
Rollover									
Rollover	0.0	17.5	17.5	0.0	14.5	14.5	0.0	-3.0	-3.0
Lane Departures									
Head On	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sideswipe Same D.	0.0	8.8	8.8	0.0	2.9	2.9	0.0	-5.9	-5.9
Sideswipe Opposite D.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Road Geometry									
Curve	0.0	2.9	2.9	0.0	8.7	8.7	0.0	5.8	5.8
Hill	0.0	2.9	2.9	2.9	5.8	8.7	2.9	2.9	5.8
Driver Condition									
Drowsy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Contributing Factors									
Distracted	0.0	8.8	8.8	0.0	11.6	11.6	0.0	2.8	2.8
Speed	0.0	17.5	17.5	0.0	23.2	23.2	0.0	5.7	5.7
Improper Overtaking	0.0	0.0	0.0	0.0	2.9	2.9	0.0	2.9	2.9
Light									
Daylight	0.0	52.6	52.6	5.8	43.5	49.3	5.8	-9.1	-3.3
Dawn, Dusk, or Dark	5.8	67.2	73.1	0.0	104.5	104.5	-5.8	37.2	31.4
Weather									
Clear or Cloudy	5.8	102.3	108.2	2.9	148.0	150.9	-2.9	45.7	42.7
Other	0.0	17.5	17.5	2.9	0.0	2.9	2.9	-17.5	-14.6
Visual Obstruction									
Yes	0.0	2.9	2.9	0.0	0.0	0.0	0.0	-2.9	-2.9
No	5.8	117.0	122.8	5.8	148.0	153.8	0.0	31.1	31.0

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement

Table A.4 ND-15
Number of Crashes, Before and After Rumble Strips

	Before			After			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0	0	0	0	0	0	0	0	0
Other Injuries	2	41	43	2	51	53	0	10	10
Crash Severity									
Fatal Crashes	0	0	0	0	0	0	0	0	0
Injury Crashes	1	4	5	0	8	8	-1	4	3
Property-Damage	1	37	38	2	43	45	1	6	7
Crashes Involving Large Trucks									
Total	0	2	2	0	0	0	0	-2	-2
Single-Vehicle	0	0	0	0	0	0	0	0	0
Multi-vehicle	0	2	2	0	0	0	0	-2	-2
Crashes Not Involving Large Trucks									
Total	2	39	41	2	51	53	0	12	12
Single-Vehicle	0	32	32	0	44	44	0	12	12
Multi-vehicle	2	7	9	2	7	9	0	0	0
Relationship to Roadway									
Run off road	0	8	8	0	6	6	0	-2	-2
On Roadway	2	33	35	2	45	47	0	12	12
Rollover									
Rollover	0	6	6	0	5	5	0	-1	-1
Lane Departures									
Head On	0	0	0	0	0	0	0	0	0
Sideswipe Same D.	0	3	3	0	1	1	0	-2	-2
Sideswipe Opposite	0	0	0	0	0	0	0	0	0
Road Geometry									
Curve	0	1	1	0	3	3	0	2	2
Hill	0	1	1	1	2	3	1	1	2
Driver Condition									
Drowsy	0	0	0	0	0	0	0	0	0
Contributing Factors									
Distracted	0	3	3	0	4	4	0	1	1
Speed	0	6	6	0	8	8	0	2	2
Improper Overtaking	0	0	0	0	1	1	0	1	1
Light									
Daylight	0	18	18	2	15	17	2	-3	-1
Dawn, Dusk, or Dark	2	23	25	0	36	36	-2	13	11
Weather									
Clear or Cloudy	2	35	37	1	51	52	-1	16	15
Other	0	6	6	1	0	1	1	-6	-5
Visual Obstruction									
Yes	0	1	1	0	0	0	0	-1	-1
No	2	40	42	2	51	53	0	11	11

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement

Table A.5 ND-49

Crash Rates per 100 Million VMT, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Injuries	0.0	209.2	209.2	5.1	149.3	154.5	5.1	-59.9	-54.7
Crash Severity									
Fatal Crashes	0.0	6.0	6.0	0.0	0.0	0.0	0.0	-6.0	-6.0
Injury Crashes	0.0	41.8	41.8	5.1	20.6	25.7	5.1	-21.2	-16.1
Property-Damage	0.0	161.4	161.4	0.0	128.7	128.7	0.0	-32.7	-32.7
Crashes Involving Large Trucks									
Total	0.0	0.0	0.0	0.0	15.4	15.4	0.0	15.4	15.4
Single-Vehicle	0.0	0.0	0.0	0.0	5.1	5.1	0.0	5.1	5.1
Multi-vehicle	0.0	0.0	0.0	0.0	10.3	10.3	0.0	10.3	10.3
Crashes Not Involving Large Trucks									
Total	0.0	209.2	209.2	5.1	133.9	139.0	5.1	-75.3	-70.2
Single-Vehicle	0.0	197.2	197.2	5.1	108.1	113.3	5.1	-89.1	-84.0
Multi-vehicle	0.0	12.0	12.0	0.0	25.7	25.7	0.0	13.8	13.8
Relationship to Roadway									
Run off road	0.0	65.7	65.7	0.0	20.6	20.6	0.0	-45.2	-45.2
On Roadway	0.0	143.4	143.4	5.1	128.7	133.9	5.1	-14.7	-9.6
Rollover									
Rollover	0.0	12.0	12.0	0.0	10.3	10.3	0.0	-1.7	-1.7
Lane Departures									
Head On	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sideswipe Same D.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sideswipe Opposite	0.0	0.0	0.0	0.0	5.1	5.1	0.0	5.1	5.1
Road Geometry									
Curve	0.0	12.0	12.0	0.0	10.3	10.3	0.0	-1.7	-1.7
Hill	0.0	17.9	17.9	5.1	25.7	30.9	5.1	7.8	13.0
Driver Condition									
Drowsy	0.0	6.0	6.0	0.0	0.0	0.0	0.0	-6.0	-6.0
Contributing Factors									
Distracted	0.0	12.0	12.0	0.0	0.0	0.0	0.0	-12.0	-12.0
Speed	0.0	35.9	35.9	0.0	20.6	20.6	0.0	-15.3	-15.3
Improper	0.0	6.0	6.0	0.0	5.1	5.1	0.0	-0.8	-0.8
Light									
Daylight	0.0	53.8	53.8	0.0	56.6	56.6	0.0	2.8	2.8
Dawn, Dusk, or Dark	0.0	155.4	155.4	5.1	92.7	97.8	5.1	-62.7	-57.6
Weather									
Clear or Cloudy	0.0	179.3	179.3	5.1	128.7	133.9	5.1	-50.6	-45.5
Other	0.0	29.9	29.9	0.0	20.6	20.6	0.0	-9.3	-9.3
Visual Obstruction									
Yes	0.0	6.0	6.0	0.0	0.0	0.0	0.0	-6.0	-6.0
No	0.0	203.2	203.2	5.1	149.3	154.5	5.1	-53.9	-48.8

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement

** Center and shoulder rumble strips/rumble stripes were installed.*

.

Table A.6 ND-49
Number of Crashes, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0	0	0	0	0	0	0	0	0
Other Injuries	0	35	35	1	29	30	1	-6	-5
Crash Severity									
Fatal Crashes	0	1	1	0	0	0	0	-1	-1
Injury Crashes	0	7	7	1	4	5	1	-3	-2
Property-Damage	0	27	27	0	25	25	0	-2	-2
Crashes Involving Large Trucks									
Total	0	0	0	0	3	3	0	3	3
Single-Vehicle	0	0	0	0	1	1	0	1	1
Multi-vehicle	0	0	0	0	2	2	0	2	2
Crashes Not Involving Large Trucks									
Total	0	35	35	1	26	27	1	-9	-8
Single-Vehicle	0	33	33	1	21	22	1	-12	-11
Multi-vehicle	0	2	2	0	5	5	0	3	3
Relationship to Roadway									
Run off road	0	11	11	0	4	4	0	-7	-7
On Roadway	0	24	24	1	25	26	1	1	2
Rollover									
Rollover	0	2	2	0	2	2	0	0	0
Lane Departures									
Head On	0	0	0	0	0	0	0	0	0
Sideswipe Same D.	0	0	0	0	0	0	0	0	0
Sideswipe Opposite	0	0	0	0	1	1	0	1	1
Road Geometry									
Curve	0	2	2	0	2	2	0	0	0
Hill	0	3	3	1	5	6	1	2	3
Driver Condition									
Drowsy	0	1	1	0	0	0	0	-1	-1
Contributing Factors									
Distracted	0	2	2	0	0	0	0	-2	-2
Speed	0	6	6	0	4	4	0	-2	-2
Improper Overtaking	0	1	1	0	1	1	0	0	0
Light									
Daylight	0	9	9	0	11	11	0	2	2
Dawn, Dusk, or Dark	0	26	26	1	18	19	1	-8	-7
Weather									
Clear or Cloudy	0	30	30	1	25	26	1	-5	-4
Other	0	5	5	0	4	4	0	-1	-1
Visual Obstruction									
Yes	0	1	1	0	0	0	0	-1	-1
No	0	34	34	1	29	30	1	-5	-4

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement
** Center and shoulder rumble strips/rumble stripes were installed.*

Table A.7 ND-23

Crash Rates per 100 Million VMT, Before and After Rumble Strips

	Before			After			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0.0	10.8	10.8	4.1	0.0	4.1	4.1	-10.8	-6.7
Other Injuries	10.8	108.4	119.2	4.1	99.0	103.1	-6.7	-9.4	-16.1
Crash Severity									
Fatal Crashes	0.0	0.0	0.0	0.0	16.5	16.5	0.0	16.5	16.5
Injury Crashes	5.4	10.8	16.3	0.0	28.9	28.9	-5.4	18.0	12.6
Property-Damage	5.4	108.4	113.8	8.3	53.6	61.9	2.8	-54.7	-51.9
Crashes Involving Large Trucks									
Total	0.0	5.4	5.4	0.0	16.5	16.5	0.0	11.1	11.1
Single-Vehicle	0.0	0.0	0.0	0.0	8.3	8.3	0.0	8.3	8.3
Multi-vehicle	0.0	5.4	5.4	0.0	8.3	8.3	0.0	2.8	2.8
Crashes Not Involving Large Trucks									
Total	10.8	113.8	124.6	8.3	82.5	90.8	-2.6	-31.3	-33.9
Single-Vehicle	5.4	108.4	113.8	4.1	66.0	70.1	-1.3	-42.4	-43.7
Multi-vehicle	5.4	5.4	10.8	4.1	16.5	20.6	-1.3	11.1	9.8
Relationship to Roadway									
Run off road	10.8	37.9	48.8	4.1	28.9	33.0	-6.7	-9.1	-15.8
On Roadway	0.0	81.3	81.3	4.1	70.1	74.3	4.1	-11.2	-7.0
Rollover									
Rollover	0.0	37.9	37.9	4.1	28.9	33.0	4.1	-9.1	-4.9
Lane Departures									
Head On	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sideswipe Same D.	0.0	0.0	0.0	0.0	4.1	4.1	0.0	4.1	4.1
Sideswipe Opposite	0.0	5.4	5.4	0.0	0.0	0.0	0.0	-5.4	-5.4
Road Geometry									
Curve	0.0	27.1	27.1	0.0	12.4	12.4	0.0	-14.7	-14.7
Hill	0.0	21.7	21.7	0.0	20.6	20.6	0.0	-1.0	-1.0
Driver Condition									
Drowsy	0.0	5.4	5.4	0.0	4.1	4.1	0.0	-1.3	-1.3
Contributing Factors									
Distracted	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Speed	0.0	27.1	27.1	4.1	33.0	37.1	4.1	5.9	10.0
Improper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Light									
Daylight	5.4	48.8	54.2	0.0	66.0	66.0	-5.4	17.2	11.8
Dawn, Dusk, or Dark	5.4	70.4	75.9	8.3	33.0	41.3	2.8	-37.4	-34.6
Weather									
Clear or Cloudy	5.4	103.0	108.4	4.1	70.1	74.3	-1.3	-32.8	-34.1
Other	5.4	16.3	21.7	4.1	28.9	33.0	-1.3	12.6	11.3
Visual Obstruction									
Yes	0.0	0.0	0.0	0.0	8.3	8.3	0.0	8.3	8.3
No	10.8	119.2	130.1	8.3	90.8	99.0	-2.6	-28.5	-31.0

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement

Table A.8 ND-23
Number of Crashes, Before and After Rumble Strips

	Before			After			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0	2	2	1	0	1	1	-2	-1
Other Injuries	2	20	22	1	24	25	-1	4	3
Crash Severity									
Fatal Crashes	0	0	0	0	4	4	0	4	4
Injury Crashes	1	2	3	0	7	7	-1	5	4
Property-Damage	1	20	21	2	13	15	1	-7	-6
Crashes Involving Large Trucks									
Total	0	1	1	0	4	4	0	3	3
Single-Vehicle	0	0	0	0	2	2	0	2	2
Multi-vehicle	0	1	1	0	2	2	0	1	1
Crashes Not Involving Large Trucks									
Total	2	21	23	2	20	22	0	-1	-1
Single-Vehicle	1	20	21	1	16	17	0	-4	-4
Multi-vehicle	1	1	2	1	4	5	0	3	3
Relationship to Roadway									
Run off road	2	7	9	1	7	8	-1	0	-1
On Roadway	0	15	15	1	17	18	1	2	3
Rollover									
Rollover	0	7	7	1	7	8	1	0	1
Lane Departures									
Head On	0	0	0	0	0	0	0	0	0
Sideswipe Same D.	0	0	0	0	1	1	0	1	1
Sideswipe Opposite	0	1	1	0	0	0	0	-1	-1
Road Geometry									
Curve	0	5	5	0	3	3	0	-2	-2
Hill	0	4	4	0	5	5	0	1	1
Driver Condition									
Drowsy	0	1	1	0	1	1	0	0	0
Contributing Factors									
Distracted	0	0	0	0	0	0	0	0	0
Speed	0	5	5	1	8	9	1	3	4
Improper Overtaking	0	0	0	0	0	0	0	0	0
Light									
Daylight	1	9	10	0	16	16	-1	7	6
Dawn, Dusk, or Dark	1	13	14	2	8	10	1	-5	-4
Weather									
Clear or Cloudy	1	19	20	1	17	18	0	-2	-2
Other	1	3	4	1	7	8	0	4	4
Visual Obstruction									
Yes	0	0	0	0	2	2	0	2	2
No	2	22	24	2	22	24	0	0	0

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement

Table A.9 ND-8

Crash Rates per 100 Million VMT, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0.0	3.0	3.0	6.4	8.5	14.9	6.4	5.5	12.0
Other Injuries	9.0	119.9	128.9	10.7	98.2	108.9	1.7	-21.7	-20.0
Crash Severity									
Fatal Crashes	0.0	3.0	3.0	2.1	0.0	2.1	2.1	-3.0	-0.9
Injury Crashes	3.0	30.0	33.0	10.7	23.5	34.2	7.7	-6.5	1.2
Property-Damage	6.0	89.9	95.9	4.3	83.3	87.5	-1.7	-6.6	-8.4
Crashes Involving Large Trucks									
Total	0.0	21.0	21.0	2.1	34.2	36.3	2.1	13.2	15.3
Single-Vehicle	0.0	12.0	12.0	0.0	8.5	8.5	0.0	-3.4	-3.4
Multi-vehicle	0.0	9.0	9.0	2.1	25.6	27.8	2.1	16.6	18.8
Crashes Not Involving Large Trucks									
Total	9.0	101.9	110.9	14.9	72.6	87.5	6.0	-29.3	-23.4
Single-Vehicle	9.0	83.9	92.9	10.7	42.7	53.4	1.7	-41.2	-39.5
Multi-vehicle	0.0	18.0	18.0	4.3	29.9	34.2	4.3	11.9	16.2
Relationship to Roadway									
Run off road	9.0	39.0	48.0	10.7	21.4	32.0	1.7	-17.6	-15.9
On Roadway	0.0	83.9	83.9	6.4	85.4	91.8	6.4	1.5	7.9
Rollover									
Rollover	3.0	21.0	24.0	6.4	21.4	27.8	3.4	0.4	3.8
Lane Departures									
Head On	0.0	3.0	3.0	0.0	0.0	0.0	0.0	-3.0	-3.0
Sideswipe Same D.	0.0	0.0	0.0	0.0	6.4	6.4	0.0	6.4	6.4
Sideswipe Opposite	0.0	3.0	3.0	0.0	10.7	10.7	0.0	7.7	7.7
Road Geometry									
Curve	3.0	12.0	15.0	4.3	4.3	8.5	1.3	-7.7	-6.4
Hill	6.0	42.0	48.0	12.8	25.6	38.4	6.8	-16.3	-9.5
Driver Condition									
Drowsy	0.0	0.0	0.0	0.0	2.1	2.1	0.0	2.1	2.1
Contributing Factors									
Distracted	3.0	3.0	6.0	0.0	10.7	10.7	-3.0	7.7	4.7
Speed	3.0	15.0	18.0	8.5	19.2	27.8	5.5	4.2	9.8
Improper	0.0	3.0	3.0	0.0	2.1	2.1	0.0	-0.9	-0.9
Light									
Daylight	0.0	59.9	59.9	0.0	49.1	49.1	0.0	-10.8	-10.8
Dawn, Dusk, or Dark	9.0	62.9	71.9	17.1	57.7	74.7	8.1	-5.3	2.8
Weather									
Clear or Cloudy	6.0	92.9	98.9	10.7	64.1	74.7	4.7	-28.9	-24.2
Other	3.0	30.0	33.0	6.4	42.7	49.1	3.4	12.7	16.1
Visual Obstruction									
Yes	0.0	9.0	9.0	0.0	4.3	4.3	0.0	-4.7	-4.7
No	9.0	113.9	122.9	17.1	102.5	119.6	8.1	-11.4	-3.3

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement

** Center and shoulder rumble strips/rumble stripes were installed.*

Table A.10 ND-8
Number of Crashes, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0	1	1	3	4	7	3	3	6
Other Injuries	3	40	43	5	46	51	2	6	8
Crash Severity									
Fatal Crashes	0	1	1	1	0	1	1	-1	0
Injury Crashes	1	10	11	5	11	16	4	1	5
Property-Damage	2	30	32	2	39	41	0	9	9
Crashes Involving Large Trucks									
Total	0	7	7	1	16	17	1	9	10
Single-Vehicle	0	4	4	0	4	4	0	0	0
Multi-vehicle	0	3	3	1	12	13	1	9	10
Crashes Not Involving Large Trucks									
Total	3	34	37	7	34	41	4	0	4
Single-Vehicle	3	28	31	5	20	25	2	-8	-6
Multi-vehicle	0	6	6	2	14	16	2	8	10
Relationship to Roadway									
Run off road	3	13	16	5	10	15	2	-3	-1
On Roadway	0	28	28	3	40	43	3	12	15
Rollover									
Rollover	1	7	8	3	10	13	2	3	5
Lane Departures									
Head On	0	1	1	0	0	0	0	-1	-1
Sideswipe Same D.	0	0	0	0	3	3	0	3	3
Sideswipe Opposite	0	1	1	0	5	5	0	4	4
Road Geometry									
Curve	1	4	5	2	2	4	1	-2	-1
Hill	2	14	16	6	12	18	4	-2	2
Driver Condition									
Drowsy	0	0	0	0	1	1	0	1	1
Contributing Factors									
Distracted	1	1	2	0	5	5	-1	4	3
Speed	1	5	6	4	9	13	3	4	7
Improper Overtaking	0	1	1	0	1	1	0	0	0
Light									
Daylight	0	20	20	0	23	23	0	3	3
Dawn, Dusk, or Dark	3	21	24	8	27	35	5	6	11
Weather									
Clear or Cloudy	2	31	33	5	30	35	3	-1	2
Other	1	10	11	3	20	23	2	10	12
Visual Obstruction									
Yes	0	3	3	0	2	2	0	-1	-1
No	3	38	41	8	48	56	5	10	15

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement
** Center and shoulder rumble strips/rumble stripes were installed.*

Table A.11 ND-2 Ray
Crash Rates per 100 Million VMT, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	5.5	5.5	11.0	0.0	4.7	4.7	-5.5	-0.8	-6.2
Other Injuries	5.5	98.7	104.2	0.0	89.7	89.7	-5.5	-9.0	-14.5
Crash Severity									
Fatal Crashes	5.5	0.0	5.5	0.0	0.0	0.0	-5.5	0.0	-5.5
Injury Crashes	0.0	5.5	5.5	0.0	23.6	23.6	0.0	18.1	18.1
Property-Damage	5.5	98.7	104.2	0.0	70.9	70.9	-5.5	-27.9	-33.4
Crashes Involving Large Trucks									
Total	5.5	5.5	11.0	0.0	9.4	9.4	-5.5	4.0	-1.5
Single-Vehicle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Multi-vehicle	5.5	5.5	11.0	0.0	9.4	9.4	-5.5	4.0	-1.5
Crashes Not Involving Large Trucks									
Total	5.5	98.7	104.2	0.0	85.0	85.0	-5.5	-13.7	-19.2
Single-Vehicle	5.5	93.2	98.7	0.0	80.3	80.3	-5.5	-12.9	-18.4
Multi-vehicle	0.0	5.5	5.5	0.0	4.7	4.7	0.0	-0.8	-0.8
Relationship to Roadway									
Run off road	5.5	16.5	21.9	0.0	23.6	23.6	-5.5	7.2	1.7
On Roadway	5.5	87.8	93.2	0.0	70.9	70.9	-5.5	-16.9	-22.4
Rollover									
Rollover	5.5	5.5	11.0	0.0	9.4	9.4	-5.5	4.0	-1.5
Lane Departures									
Head On	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sideswipe Same D.	0.0	5.5	5.5	0.0	4.7	4.7	0.0	-0.8	-0.8
Sideswipe Opposite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Road Geometry									
Curve	5.5	0.0	5.5	0.0	0.0	0.0	-5.5	0.0	-5.5
Hill	11.0	21.9	32.9	0.0	18.9	18.9	-	-3.0	-14.0
Driver Condition									
Drowsy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Contributing Factors									
Distracted	0.0	5.5	5.5	0.0	0.0	0.0	0.0	-5.5	-5.5
Speed	0.0	21.9	21.9	0.0	18.9	18.9	0.0	-3.0	-3.0
Improper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Light									
Daylight	0.0	27.4	27.4	0.0	37.8	37.8	0.0	10.4	10.4
Dawn, Dusk, or Dark	11.0	76.8	87.8	0.0	56.7	56.7	-	-20.1	-31.1
Weather									
Clear or Cloudy	11.0	87.8	98.7	0.0	61.4	61.4	-	-26.4	-37.3
Other	0.0	16.5	16.5	0.0	33.1	33.1	0.0	16.6	16.6
Visual Obstruction									
Yes	0.0	5.5	5.5	0.0	9.4	9.4	0.0	4.0	4.0
No	11.0	98.7	109.7	0.0	85.0	85.0	-	-13.7	-24.7

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement
** Shoulder rumble strips/rumble stripes were installed.*

Table A.12 ND-2 Ray
Number of Crashes, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	1	1	2	0	1	1	-1	0	-1
Other Injuries	1	18	19	0	19	19	-1	1	0
Crash Severity									
Fatal Crashes	1	0	1	0	0	0	-1	0	-1
Injury Crashes	0	1	1	0	5	5	0	4	4
Property-Damage	1	18	19	0	15	15	-1	-3	-4
Crashes Involving Large Trucks									
Total	1	1	2	0	2	2	-1	1	0
Single-Vehicle	0	0	0	0	0	0	0	0	0
Multi-vehicle	1	1	2	0	2	2	-1	1	0
Crashes Not Involving Large Trucks									
Total	1	18	19	0	18	18	-1	0	-1
Single-Vehicle	1	17	18	0	17	17	-1	0	-1
Multi-vehicle	0	1	1	0	1	1	0	0	0
Relationship to Roadway									
Run off road	1	3	4	0	5	5	-1	2	1
On Roadway	1	16	17	0	15	15	-1	-1	-2
Rollover									
Rollover	1	1	2	0	2	2	-1	1	0
Lane Departures									
Head On	0	0	0	0	0	0	0	0	0
Sideswipe Same D.	0	1	1	0	1	1	0	0	0
Sideswipe Opposite	0	0	0	0	0	0	0	0	0
Road Geometry									
Curve	1	0	1	0	0	0	-1	0	-1
Hill	2	4	6	0	4	4	-2	0	-2
Driver Condition									
Drowsy	0	0	0	0	0	0	0	0	0
Contributing Factors									
Distracted	0	1	1	0	0	0	0	-1	-1
Speed	0	4	4	0	4	4	0	0	0
Improper Overtaking	0	0	0	0	0	0	0	0	0
Light									
Daylight	0	5	5	0	8	8	0	3	3
Dawn, Dusk, or Dark	2	14	16	0	12	12	-2	-2	-4
Weather									
Clear or Cloudy	2	16	18	0	13	13	-2	-3	-5
Other	0	3	3	0	7	7	0	4	4
Visual Obstruction									
Yes	0	1	1	0	2	2	0	1	1
No	2	18	20	0	18	18	-2	0	-2

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement
** Shoulder rumble strips/rumble stripes were installed.*

Table A.13 ND-2 Stanley
Crash Rates per 100 Million VMT, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Injuries	0.0	90.4	90.4	0.0	80.0	80.0	0.0	-10.3	-10.3
Crash Severity									
Fatal Crashes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Injury Crashes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Property-Damage	0.0	90.4	90.4	0.0	80.0	80.0	0.0	-10.3	-10.3
Crashes Involving Large Trucks									
Total	0.0	0.0	0.0	0.0	4.2	4.2	0.0	4.2	4.2
Single-Vehicle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Multi-vehicle	0.0	0.0	0.0	0.0	4.2	4.2	0.0	4.2	4.2
Crashes Not Involving Large Trucks									
Total	0.0	90.4	90.4	0.0	75.8	75.8	0.0	-14.6	-14.6
Single-Vehicle	0.0	85.6	85.6	0.0	71.6	71.6	0.0	-14.0	-14.0
Multi-vehicle	0.0	4.8	4.8	0.0	4.2	4.2	0.0	-0.5	-0.5
Relationship to Roadway									
Run off road	0.0	0.0	0.0	0.0	16.9	16.9	0.0	16.9	16.9
On Roadway	0.0	90.4	90.4	0.0	63.2	63.2	0.0	-27.2	-27.2
Rollover									
Rollover	0.0	0.0	0.0	0.0	8.4	8.4	0.0	8.4	8.4
Lane Departures									
Head On	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sideswipe Same D.	0.0	4.8	4.8	0.0	4.2	4.2	0.0	-0.5	-0.5
Sideswipe Opposite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Road Geometry									
Curve	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hill	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Driver Condition									
Drowsy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Contributing Factors									
Distracted	0.0	0.0	0.0	0.0	4.2	4.2	0.0	4.2	4.2
Speed	0.0	0.0	0.0	0.0	16.9	16.9	0.0	16.9	16.9
Improper Overtaking	0.0	4.8	4.8	0.0	0.0	0.0	0.0	-4.8	-4.8
Light									
Daylight	0.0	23.8	23.8	0.0	16.9	16.9	0.0	-6.9	-6.9
Dawn, Dusk, or Dark	0.0	66.6	66.6	0.0	63.2	63.2	0.0	-3.4	-3.4
Weather									
Clear or Cloudy	0.0	90.4	90.4	0.0	80.0	80.0	0.0	-10.3	-10.3
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Visual Obstruction									
Yes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
No	0.0	90.4	90.4	0.0	80.0	80.0	0.0	-10.3	-10.3

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement
** Shoulder rumble strips/rumble stripes were installed.*

Table A.14 ND-2 Stanley

Number of Crashes, Before and After Rumble Strips

	Before			After*			Change		
	ADI	Normal	Total	ADI	Normal	Total	ADI	Normal	Total
Injury Class									
Serious Injuries	0	0	0	0	0	0	0	0	0
Other Injuries	0	19	19	0	19	19	0	0	0
Crash Severity									
Fatal Crashes	0	0	0	0	0	0	0	0	0
Injury Crashes	0	0	0	0	0	0	0	0	0
Property-Damage	0	19	19	0	19	19	0	0	0
Crashes Involving Large Trucks									
Total	0	0	0	0	1	1	0	1	1
Single-Vehicle	0	0	0	0	0	0	0	0	0
Multi-vehicle	0	0	0	0	1	1	0	1	1
Crashes Not Involving Large Trucks									
Total	0	19	19	0	18	18	0	-1	-1
Single-Vehicle	0	18	18	0	17	17	0	-1	-1
Multi-vehicle	0	1	1	0	1	1	0	0	0
Relationship to Roadway									
Run off road	0	0	0	0	4	4	0	4	4
On Roadway	0	19	19	0	15	15	0	-4	-4
Rollover									
Rollover	0	0	0	0	2	2	0	2	2
Lane Departures									
Head On	0	0	0	0	0	0	0	0	0
Sideswipe Same D.	0	1	1	0	1	1	0	0	0
Sideswipe Opposite	0	0	0	0	0	0	0	0	0
Road Geometry									
Curve	0	0	0	0	0	0	0	0	0
Hill	0	0	0	0	0	0	0	0	0
Driver Condition									
Drowsy	0	0	0	0	0	0	0	0	0
Contributing Factors									
Distracted	0	0	0	0	1	1	0	1	1
Speed	0	0	0	0	4	4	0	4	4
Improper Overtaking	0	1	1	0	0	0	0	-1	-1
Light									
Daylight	0	5	5	0	4	4	0	-1	-1
Dawn, Dusk, or Dark	0	14	14	0	15	15	0	1	1
Weather									
Clear or Cloudy	0	19	19	0	19	19	0	0	0
Other	0	0	0	0	0	0	0	0	0
Visual Obstruction									
Yes	0	0	0	0	0	0	0	0	0
No	0	19	19	0	19	19	0	0	0

ADI: alcohol/other drug involvement; Normal: no alcohol/other drug involvement

** Shoulder rumble strips/rumble stripes were installed.*