EVALUATION OF EXTERNAL NOISE PRODUCED BY VEHICLES CROSSING OVER CENTERLINE RUMBLE STRIPS ON UNDIVIDED HIGHWAYS IN KANSAS

by

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Abstract

Centerline rumble strips (CLRS) are raised or indented patterns installed in the center of undivided rural two-lane highways. Their main function is to alert drivers who are encroaching or leaving the intended travel lane, by producing vibration and noise when crossed by vehicles' tires. CLRS have been demonstrated to be an effective way in reducing head on and opposite direction sideswipe on two-lane highways (cross-over accidents). However, there are some disadvantages in their utilization, such as the exterior noise created by the strips, which may disturb residents in the highway vicinity. The objective of this study was to verify if the amount of noise created by CLRS is enough to impact negatively on residences and businesses, and to discover if the mean level of noise created by CLRS is statistically different than the noise generated by vehicles driving over smooth pavement. Two types of vehicles were driven over two different patterns of milled-in CLRS (rectangular and football-shaped) and over smooth asphalt pavement, at two different speeds. Researchers collected the noise levels at three distances 50, 100, and 150 feet, measured orthogonally from the center line, in 8 different open space locations. Results indicate that vehicle type, vehicle speed, pavement type, location and distances affect the levels of noise. In addition, both football and rectangular CLRS produced significantly higher levels of noise as compared to the smooth asphalt pavement. A 15 passenger van produced higher levels of noise in comparison with a sedan. Moreover, lower the vehicle speed, noise levels were lower. At every 50 feet of distance, the noise levels dropped significantly. CLRS do increase levels of noise relative to smooth pavement at distances up to 150 feet.

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CHAPTER 1 - INTRODUCTION

1.1 Problem statement

Vehicles moving out of one travelling lane to another, unintentionally, cause nearly 20 percent of all vehicle crashes in the United States, and nearly 40 percent of the fatalities on U.S highways (Pilutti and Ulsoy, 1998). There is need for an effective means for alerting drivers from crossing out of the lane in which they are driving. Over 86 percent of fatal head–on collisions on two lane highways were not caused by a driver attempting to pass another vehicle, but rather "typically either by entering a curve at too high a speed or by drifting across the road after falling asleep or being inattentive" (Alexander et al., 1995). The National Cooperative Highway Research Program (NCHRP) published guidelines for addressing head-on collisions, and run-off-the-road collisions (Neuman et al., 2003). In all these guidelines, rumble strips are mentioned as the countermeasure for reducing these collisions. Several research projects have shown that the cross over accidents (head-on and opposite direction sideswipe) on undivided highways can be reduced by centerline rumble strips (CLRS).

However, there are trade-offs between the negative aspects and the safety of CLRS on undivided highways, such as the exterior noise produced by vehicles crossing over CLRS and its impacts on adjacent residents and businesses (Finley and Miles, 2007). Approximately 13 percent of the peak rumble strip noise levels were above the highest noise level measured for a commercial vehicle driving along the roadway and not hitting the rumble strips. Over half of the rumble strip sites tested produced an increase in exterior noise greater than 4 decibels. In general, the increase in exterior noise was greater at 70 mph than at 55 mph and lower for a commercial vehicle than for a passenger car.

External noise was the major concern of the residents near the highways installed with rumble strips. The main purpose of this research is to determine the external noise generated by vehicles crossing over the CLRS on two-lane undivided highways in Kansas. Testing regarding the noise levels produced by vehicles travelling over CLRS was done on US 40 west of

Lawrence, KS, where the residents close to the highways had raised concerns regarding the noise generated.

1.2 Organization of thesis

Chapter 2 of the thesis gives an overview of the results and different methods of recent studies regarding the noise generated by vehicles crossing over rumble strips. It begins with the effectiveness of the centerline rumble strips on two-way undivided rural highways. Further, studies conducted by the Texas Transportation Institute and University of Kansas are discussed in detail regarding the method of noise measurement and the relative noise results. Finally, the effect of the noise on human beings is discussed so as to relate the study results to the acceptable noise levels for the human ears.

Chapter 3 of the thesis discusses the methodology of the tests conducted for measuring the highway noise. It begins with the description of the eight different locations that were tested for the external noise on two-way undivided rural highways in Kansas. It continues with the description of the meters used for testing the external noise, humidity, wind speed and direction and temperature.

Chapter 4 of the thesis takes an in-depth look at the results of the tests conducted at the eight locations. Results at each location were discussed for different test conditions and also the results were compared between all conditions: Taurus at 40 mph, Taurus at 65 mph, Van at 40 mph and Van at 65 mph over smooth pavement and CLRS. The results for each location were presented graphically. Finally, a summary of all the locations' exterior noise levels were discussed.

Chapter 5 of the thesis includes the results of a resident survey sent out to the residents along the stretch of US 40 highway where the centerline rumble strips were installed in May 2005. The surveys were sent out to 22 residents and 12 of the residents responded to the survey providing valuable comments.

Chapter 6 of the thesis discusses the conclusions from the test results on the exterior noise levels produced by the vehicles traveling over CLRS on two way undivided rural highways, and future research options were also discussed.

CHAPTER 2 - LITERATURE REVIEW

Rural, two-lane roads generally lack physical measures such as wide medians or barriers to separate opposing traffic flows. As a result, a major crash problem on these roads involves vehicles crossing the centerline and either sideswiping or striking the front ends of opposing vehicles (Retting et al., 2003). Generally, the proportion of crashes involving “more than 2 fatalities per crash, a truck involved, a vehicle rollover, severe vehicle damage, a head-on collision, and ejected person” is high in rural run-off-road accidents. It is very important to keep the drivers in their driving lanes on the two-way roads as over 86 percent of fatal accidents occur on rural accidents (Retting et al., 2003). Centerline Rumble Strips (CLRS) can act as an effective countermeasure for two-lane accidents resulting from a vehicle crossing the centerline, i.e., crossover accidents. A comprehensive before-after study was undertaken to estimate the nature and magnitude of crash reductions associated due to the installation of CLRS on rural, undivided two-lane roads. Data were studied from seven states (California, Colorado, Delaware, Maryland, Minnesota, Oregon, and Washington). In total, 98 treatment sites along approximately 210 miles of road were included in the data. Statistical procedures were used to properly account for regression to the mean – a threat to the validity of simple before-after studies – while normalizing for differences in traffic volume and other factors between the before and after periods (Retting et al., 2003).

Overall, motor vehicle crashes at the treated sites analyzed were reduced 14 percent; injury crashes were reduced by an estimated 15 percent. Head-on and opposing-direction sideswipe crashes — the primary target of CLRS — were reduced by an estimated 21 percent, while head-on and opposing-direction sideswipe crashes involving injuries were reduced by an estimated 25 percent (Retting et al., 2003).

In general, there are two different classes of rumble strips, transverse and longitudinal. Transverse rumble strips (TRS) are installed across a travel lane, and subsequently are also referred to as in-lane rumble strips. Longitudinal rumble strips are installed parallel to the travel lane along the centerline, lane line, edge line or shoulder. There are several ways of installing rumble strips including milled, rolled, and raised (Finley and Miles, 2007). Milled rumble strips are installed on both new and existing concrete and asphalt roadways by a mechanical milling device. Rolled rumble strips are depressions on asphalt roadways formed by steel pipes welded onto a roller at a uniform spacing. These strips can be applied only on new or reconstructed asphalt surfaces. Metal forms are used to install formed rumble strips in new concrete during the finishing process. Raised rumble strips are rounded or rectangular markers or strips adhered to the roadway. These include traffic buttons, profile markings, preformed thermoplastic, or raised sections of asphalt pavement. Raised rumble strips can be applied to any roadway; however, typically they are restricted to warmer climates because cooler climate regions may require snowplowing that may damage the rumble strips and/or the snowplowing equipment.

There are two types of milled centerline rumble strips based on their design and shape: football centerline rumble strips and rectangular centerline rumble strips. See Figure 2.1 and Figure 2.2.

Figure 2.1 Football CLRS

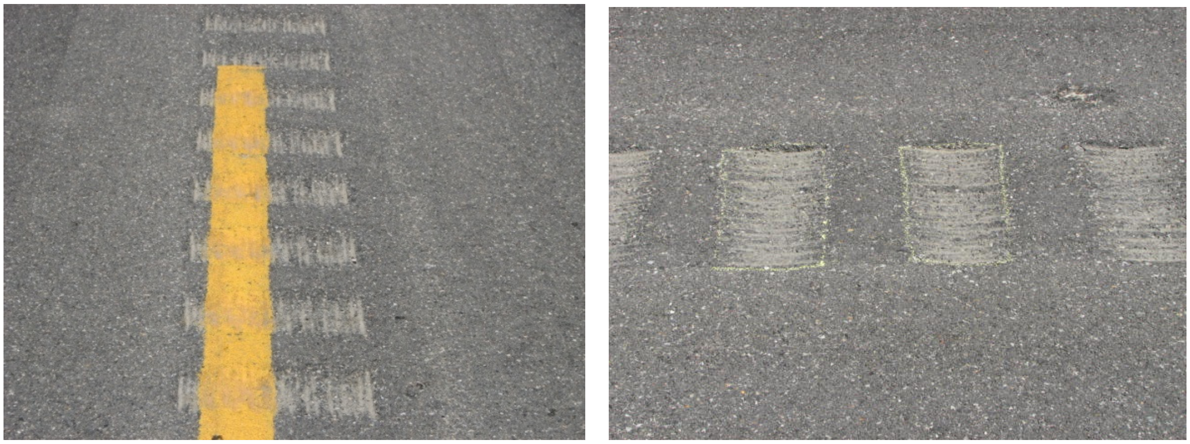

Figure 2.2 Rectangular CLRS

Rumble strip designs not only differ in type and application, but they also differ with respect to dimensions. The width of a rumble strip in this study is the dimension parallel to the direction of travel, while the length of a rumble strip is the dimension perpendicular to the direction of travel. Spacing is the distance in the direction of travel from the leading edge of one rumble strip to the leading edge of the following rumble strip. For milled and rolled rumble strips, the depth is measured from the roadway surface to the bottom of the rumble strip. For raised rumble strips, the height is measured from the roadway surface to the top of the rumble strip.

2.1 Exterior Noise Studies

In order to quantify the impact of vehicle contact with rumble strips on the surrounding environment, researchers from the Texas Transportation Institute (TTI) recorded sound measurements from the perspective of a pedestrian on the side of the road adjacent to the rumble strips (Finley and Miles, 2007). A sound level meter and data logging equipment were placed on a small, collapsible table set up 50 ft from the exterior edge of rumble strip applications. The meter had a range of 30 to 130 dB with a sensitivity of 10 millivolts per decibel. Data were collected under dry, daytime conditions. Exterior noise data were collected for the base and the rumble strip condition. The base condition was defined as the exterior noise associated with the test vehicle traveling at a specified speed (55 or 70 mph) along a designated roadway. The rumble strip condition was defined as the noise associated with the test vehicle traveling at a specified speed along a designated roadway while traveling with at least one tire contacting the rumble strips. At least two 30-second test runs were completed for each rumble strip condition, and at least one 30-second test run was completed for the base condition. During data collection, the presence of another vehicle near the test vehicle or uneven pavement surfaces not associated with the installation of rumble strips was recorded. This information was used to remove any anomalies in the data associated with such events. Table 2.1 shows rumble strip locations where the tests were carried out.

Table 2.1: Test site locations (Finley and Miles, 2007).

Roadway	Site No.	Speed Limit (mph)	Pavement Type	Rumble Strip Type	Rumble Strip Application	Rumble Strip Length (inches)	Rumble Strip Width (inches)	Rumble Strip Elevation [a] (inches)	Rumble Strip Spacing (inches)
FM 50	1	70	HMA	TRS	Raised	6	48	0.4	24
FM 969	2	55	HMA	CRS	Button	4	4	0.5	48
FM 1179	3	55	HMA	TRS	Raised	24	132	0.125	24
FM 2154	4	70	Chipseal	TRS	Raised	6	48	0.4	24
SH 6	5	70	HMA	CRS	Profile	4	6	0.25	18
SH 6	6	70	HMA	ERS	Profile	4	6	0.25	18
SH 6	7	70	HMA	SRS	Button	4	4	0.5	60
SH 21 (1)	8	70	HMA	SRS	Rolled	2	24	0.5	12
SH 21 (2)	9	70	Chipseal	CRS	Milled	7	16	0.5	24
SH 21 (2)	10	70	Chipseal	ERS	Milled	7	8	0.5	36
SH 21 (2)	11	70	Chipseal	ERS	Milled	7	6	0.5	24
SH 21 (2)	12	70	Chipseal	LRS	Milled	7	4	0.5	18
SH 21 (2)	13	70	Chipseal	LRS	Milled	7	4	0.5	36
SH 47	14	70	HMA	SRS	Milled	7	16	0.5	12

Farm to Market (FM), State Highway (SH), Hot-Mix Asphalt (HMA)
[a] For milled and rolled rumble strips this is depth. For button and profile rumble strips this is height.

The test vehicles used by the researchers were a sedan (2003 Ford Taurus), truck (2001 Ford F-150), and a commercial vehicle (1999 Kenworth half-loaded such that it weighed approximately 46,520 lb). These vehicles are shown in Figure 2.1 along with the tire specifications associated with each vehicle. The sedan and truck were driven at 55 and 70 mph along the test sections provided that the speed limit was at least 70 mph. To ensure the safety of the driver and other vehicular traffic, the commercial vehicle was only driven at 55 mph by a qualified professional.

2003 Ford Taurus	2001 Ford F-150	1999 Kenworth
Size: P215/60/R16 Width[1]: 8.5/6.5 inches Radius: 13 inches	Size: P255/70/R16 Width[1]: 10/7.5 inches Radius: 15 inches	Size: 11R24 Width[1]: 11.5/8.5 inches Radius: 21.5 inches

Figure 2.3: Test vehicles and tire specifications (Finley and Miles, 2007).

The purpose of the analysis was to: 1) quantify any change in exterior noise associated with the installation of various rumble strips and 2) investigate the effects of speed, vehicle, rumble strip application (i.e., button, profile, rolled, milled), and dimensions have on exterior noise. Over 170 test runs were completed with the two different test vehicles (127 with the sedan and 45 with the commercial vehicle). Researchers computed average noise levels and average changes in the noise level (both logarithmically).

Overall, the base exterior noise level ranged from 65 to 87 dB (Finley and Miles, 2007). The range of base exterior noise for the sedan at 55 and 70 mph was 66 to 79 dB (average of 76 dB) and 65 to 82 dB (average of 79 dB), respectively. The range of base noise for the commercial vehicle at 55 mph was 75 to 87 dB (average of 83 dB). The base exterior noise data shows that increasing the vehicle speed from 55 to 70 mph, increases the average base exterior noise level by 3 dB. Also, at 55 mph the difference in the average base exterior noise level between the sedan and commercial vehicle was 7 dB. Pavement type was also shown to affect the base exterior noise level.

The rumble strip exterior noise levels ranged from 73 to 94 dB (Finley and Miles, 2007). The range of rumble strip exterior noise for the sedan at 55 and 70 mph was 73 to 87 dB (average of 82 dB) and 77 to 94 dB (average of 87 dB), respectively. The range of rumble strip noise for the commercial vehicle at 55 mph was 81 to 93 dB (average of 88 dB). The average exterior noise created by the sedan passing over rumble strips at 55 mph is slightly less than that created by a commercial vehicle driving along the roadway not hitting rumble strips.

In general, the increase in exterior noise was greater at the higher speed and lower for the commercial vehicle. For each of the vehicle speeds, buttons showed the lowest change in the sound levels (4 to 5 dB increase generating 77 to 86 dB). For the sedan at 55 mph, profile, milled, and transverse applications performed similarly (8 to 9 dB increase generating 73 to 87 dB). The largest increase in exterior noise (12 dB change generating 83 to 94 dB) occurred for rolled and milled rumble strips when the sedan was traveling at 70 mph. Rolled rumble strips also produced the largest increase in exterior noise with the commercial vehicle (10 dB change generating 91 dB). Transverse Rumble Strips (TRS) produced a 4 to 10 dB (average of 8 dB) change in the exterior noise, raising the exterior noise level between 73 and 82 dB. Researchers theorize that the larger changes for the sedan are the result of the base commercial vehicle conditions masking the additional noise created by the rumble strips. Under base conditions, the commercial vehicle generates more exterior noise than the sedan. Auditory information is comprised of multiple sounds; thus, the sound generated by the commercial vehicle traversing over the pavement alone is competing with the additional sound created by traveling over the rumble strips. However, the increases in the exterior noise level resulting from the commercial vehicle's contact with the rumble strips results in overall higher exterior noise levels (81 to 93 dB [average of 88 dB] compared to 73 to 87 dB [average of 82 dB] for the sedan) since the base noise levels are higher (Finley and Miles, 2007).

In a study by a University of Kansas team regarding the comparison of Rumbler and Asphalt rumble strips (Meyer and Walton, 2002); data were collected at two work zones. The removable Rumbler strips were used for the most upstream set on one approach at each site. Sound and vibration measurements were taken for both smooth pavement and asphalt rumble strips at both locations. The Rumbler rumble strips were installed on the eastbound approach to a bridge maintenance project on Kansas State Route 93 at Perry Lake, just south of Ozawkie, Kansas.

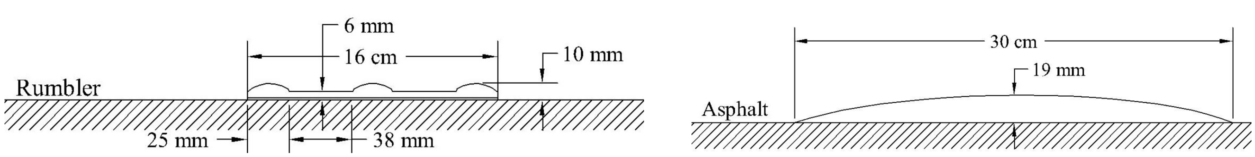

Figure 2.4: Rumbler rumble strips cross section; Asphalt rumble strips cross section (Meyer and Walton, 2002).

In order to collect the sound, vibration, and roadside noise levels, it was necessary to deploy a set of each of the types of the strips that were to be tested. These strips were then traversed repeatedly with three test vehicles at three different speeds until all of the data necessary for the comparisons had been collected. Vehicle speed data was collected in order to compare the rumble strips effect on vehicle speeds and speed reductions. Through the process of installing these model deployments, the times and costs of the installation were observed and quantified. The strips were then left in place for the duration of the respective construction projects in order to allow for the collection of speed data and to test the durability of the strips for use in long-term deployments. Sound and vibration levels were measured as Equivalent Sound Level (L_{eq}) in decibels (dB). The measurements were recorded using a Norsonic Nor-110 Sound/Vibration Analyzer. L_{eq} values were recorded using a 3 ms measurement interval. The vibration levels were measured with no frequency weighting (sometimes referred to as flat or linear), and the sound levels were measured using an A-Weighting filter. This filter is used to transform the levels collected by a microphone (sound energy scale) into levels that would be perceived by a human (perceptual loudness scale).

The in-vehicle sound data were recorded by placing the microphone on a tripod with the microphone oriented horizontally forward, centered between the driver and passenger seats, 19 cm (7.5 in) below the ceiling, and even with the joint between the seat back and seat bottom of the driver's seat. The location was intended to approximate the position of the ear of a typical driver. All measurements used in the analysis were taken with the windows rolled up and the air-conditioner and stereo turned off. Measurements were also taken to compare the sound generated by the rumble strips with the sound generated by the radio (at a moderate volume setting) and the air-conditioner (on the highest fan setting).

The Federal Highway Administration's standards were followed for the roadside noise measurements. The microphone was mounted on a tripod and placed at the roadside 15.2 m (50 ft) from the center of the lane in which the test vehicle would be driven and 1.5 m (5 ft) above the road surface. The microphone was oriented perpendicular to the road and was covered with a foam windscreen in order to reduce the effect of wind noise on the data.

Figure 2.5: Accelerometer (Left) and Microphone (Right) (Meyer and Walton, 2002).

The comparison for the sound levels were based on the maximum of the Leq values measured over 3 ms intervals while crossing the rumble strips (Meyer and Walton, 2002). When multiple observations of the same condition were made, the average was used. The measure used to compare data from different sites was the difference between the maximum L_{eq} values observed while traversing the rumble strips and the maximum L_{eq} observed while traversing smooth pavement under the same conditions.

In most cases the temporary rumble strips did not differ by an amount that was statistically significant and noticeable. There were no in-vehicle sound comparisons that yielded differences that were statistically significant but not noticeable, nor were there any comparisons that had noticeable but not statistically significant differences. The asphalt strips at one location produced significantly different sound levels in the Honda Accord than the asphalt rumble strips at the other location. While this is not much of a concern for these sets of strips, since both produce easily noticeable sound levels, it does show that the variation inherent in the cross-sections of asphalt strips can have a significant effect on the levels of sound these strips produce. The amount of roadside noise that is acceptable depends on several factors. The noise level and pitch, the frequency of occurrence, the duration of the noise, proximity of dwellings to the roadside, terrain, the propagation of the noise through walls (affects noise levels that would be experienced inside someone's home), and the time of day that the noise occurs are all factors that are used to determine if a noise level is excessive. Most of these factors are lumped into a single factor, the L_{10}, which is the noise level exceeded10 percent of the time. The L_{10} accounts for the noise level and pitch, the frequency of occurrence, and the duration of the noise. Different L_{10}

maximums are set for day, night, and type of area. Noise in work zones is considered by the public and officials to be necessary and only temporary. The L_{10} is as much a function of traffic patterns as it is ofstrip type, and is consequently very site-specific. Thus L_{10} is not an appropriate measure for this study and only roadside noise L_{eq} values were considered. The roadside noise L_{eq}s alone cannot determine whether a type of rumble strip is either acceptable or unacceptable for use, but will provide a means of comparing between strip types.

Researchers also feel that more detailed analysis should be considered before using the Rumbler rumble strip in noise sensitive areas, such as highly developed residential areas. Special care should be given to nighttime conditions because this is when residential areas are most sensitive to noise. Unlike most construction noise, the noise caused by rumble strips continues throughout the night and varies depending upon the number of vehicles traversing the strips during these hours.

Research by Danish road authorities had five different types of rumble strips milled on the both side of the center line on some two-lane rural roads (Kragh et al., 2007). Different types of rumble strips include 1) maximum 10 mm deep segments of a circle per 0.6 m, 2) maximum 7 mm deep sinusoidal shape of 0.6 m wavelength, 3) maximum 4 mm deep sinusoidal shape of 0.6 m wavelength, 4) 8 mm deep rectangular shape (per 0.33 m), and 5) 4 mm deep rectangular shape (per 0.33 m). Three different vehicles were driven on the five different types of rumble strips on both the lanes at a speed of 80 kmph (49.7 mph) and the maximum noise level is measured from a distance of 7.5 meters from the center line. Vehicle speeds are also noted done for each run with radar.

Kragh et. al (2007) stated that the rumble strips with sinusoidal shape led to only 0.5 – 1 dB increase in noise level while the rumble strip with "cylinder-segment" indentations gave an increase of 2 – 3 dB. Rectangular indentations gave rise to significantly higher noise levels (3 – 7 dB higher) than the rumble strips with a sinusoidal profile as well as significantly higher noise levels (2 – 5 dB higher) than the "cylinder segment" strip. These increments in pass-by noise level are relatively to the noise level from pass-bys on old stone mastic asphalt and they are valid at distances exceeding 25 m or so from the road.

Gupta (1993) measured the mean base noise levels for cars to be between 67 and 75 dB and for trucks between 78 and 83 dB, from a distance of 10 feet from the edge of the pavement. The noise levels when the vehicles pass over the rumble strips were measured to be between 74 and 80 dB for cars and 82 and 90 dB for trucks.

Sutton and Wray (1996) determined that the noise levels increased by 10 to 12 dB when compared with the rumble strips noise to the base noise levels immediately adjacent to the pavement. It was also determined that the noise levels increased by approximately 8 and 7 dB at a distance of 25 feet and 50 feet respectively. Based on these measurements, it was stated that at a distance of 200 feet from the edge of the pavement, the noise levels drop to the normal levels (no rumble strips).

Higgins and Barbel (1984) determined that, at 50 feet distance from the rumble strips the increase in the noise levels was 7 dB compared to the base noise levels. Higgins and Barbel also reported that exterior noise did not significantly vary with different types and configurations of rumble strips.

Chen (1994) compared the exterior noise levels between the rolled and milled rumble strips at two different speeds and found out that the average base noise levels were 72 and 75 dB for 55 and 65 mph, respectively. There was an increase of 4 dB (76 dB) at 55mph and 2.5 dB (77.5 dB) at 65 mph for the rolled shoulder rumble strips. Increase for the milled rumble strips was determined to be 11 dB (86 dB) at 65 mph. Noise levels when a van was driven over the milled rumble strips and truck driven over an asphalt surface (no rumble strips) were measured to be 60 and 69 dB respectively. They concluded that the effect of the rumble strip noise on surrounding environments can be ignored.

2.2 Effects of noise

Understanding of the effects of noise on the human body is important to analyze the results of the experiments conducted. Human response to noise varies from person to person and is subjective too. It also depends on the nature of the activity (example sleeping) or the current background noise. The majority of the people judge a noise to be doubling if the change in the noise is 10 dB and the smallest noticeable change in the noise that a human ear can sense is about 3 dB. Increases of 5 dB or more are easily noticed by human ear (Minor, 2005). Table 2.2 shows the sound levels and relative noise loudness of typical noise sources.

Table 2.2 Sound Levels and Relative Loudness of Typical Noise Sources (Minor, 2005)

Noise Source or Activity	Sound Level (dBA)	Subjective Impression	Relative Loudness (human judgment of different sound levels)
Jet aircraft takeoff from carrier (50 ft)	140	Threshold of pain	64 times as loud
50-hp siren (100 ft)	130		32 times as loud
Loud rock concert near stage, Jet takeoff (200 ft)	120	Uncomfortably loud	16 times as loud
Float plane takeoff (100 ft)	110		8 times as loud
Jet takeoff (2,000 ft)	100	Very loud	4 times as loud
Heavy truck or motorcycle (25 ft)	90		2 times as loud
Garbage disposal, food blender (2 ft), Pneumatic drill (50 ft)	80	Moderately loud	Reference loudness
Vacuum cleaner (10 ft), Passenger car at 65 mph (25 ft)	70		1/2 as loud
Large store air-conditioning unit (20 ft)	60		1/4 as loud
Light auto traffic (100 ft)	50	Quiet	1/8 as loud
Bedroom or quiet living room, Bird calls	40		1/16 as loud
Quiet library, soft whisper (15 ft)	30	Very quiet	
High quality recording studio	20		
Acoustic Test Chamber	10	Just audible	
	0	Threshold of hearing	

Noise sources associated with transportation include passenger vehicles, medium trucks, heavy trucks and buses (Minor, 2005). The noises produced by these vehicles vary greatly on the source and magnitude of the noise can vary greatly depending on vehicle type. For example, while the noise from passenger vehicles occurs mainly from the tire-roadway interface and is therefore located at ground level, noise from heavy trucks is produced by a combination of noise from tires, engine, and exhaust, resulting in a noise source that is approximately 8 feet above the ground.

In general, for all the passenger vehicles (small and regular cars, pickup trucks, small to midsize sports utility vehicles) the typical noise levels are about 72 to 74 dB at 55 mph at a distance of 50 feet. Noise is emitted primarily from tire-roadway interface, about 0 – 2 feet above roadway.

For medium vehicles (delivery vans, city transit, federal express trucks, large sports utility vehicles with knobby tires and school buses) the typical noise levels are around 80 to 82 dB at 55 mph at a distance of 50 feet. Noise is emitted from 2 to 5 feet above the roadway, with combined noise from tire-roadway interface and engine exhaust noise.

For heavy trucks (semi-trucks, large two trucks, dump trucks, cement mixers, large transit buses, the typical noise levels are around 84 to 86 dB at 55 mph at a distance of 50 feet from the roadway. Noise is emitted from 6-8 feet above the roadway, with a combined noise of the tire-roadway noise, engine noise and exhaust stack noise.

Several factors determine how the noise levels decrease over distance, which include existing structures, topography, foliage, ground cover, and atmospheric conditions such as wind, temperature, and relative humidity. A line noise (constant flowing traffic on a busy highway) decreases approximately at a rate of 3 dB each time the distance doubles, under ideal conditions (Minor, 2005). Existing structures have substantial effect on the noise levels as they can reduce the noise levels by blocking the transmission. This shielding can be almost up to 10 dB or greater. Noise levels can also be increased by the structures through reflection and the increase is almost 3 dB or lower, which is the minimum change in the noise levels a human ear can notice. Topography also plays a similar role, either by reducing or increasing the noise levels from the noise source to the receiver. Foliage, if dense enough (up to 30 feet deep of dense evergreen foliage) can reduce the noise levels by almost 5 dB. Ground cover plays an important role in noise propagation as it travels well on reflecting surfaces like water and slows down when the cover is field grass or even loose soil.

There are a number of ways to reduce traffic noise mitigation which include traffic management (change in speed limits, and limiting the highways to certain type of vehicles), roadway design and use of noise barriers between the roadway and effected receivers.

2.3 Conclusions

The studies regarding the exterior noise levels of vehicles crossing over rumble strips show that over half of the rumble strip conditions produced changes in the exterior noise greater than 4 dB (Finley and Miles, 2007). In general, the increase in exterior noise is greater at 70 mph than at 55 mph and lower for the commercial vehicle than for the sedan. Overall, rumble strips do increase the exterior noise level. Thus the impact of the increase in the noise levels on the residents and businesses near the rumble strips installations should be investigated.

CHAPTER 3 - Methodology

The study sites for measuring the exterior noise levels were selected from a list of locations where the Kansas Department of Transportation (KDOT) had already installed centerline rumble strips. Of all the installed locations in Kansas, a total of 8 locations were selected of which four were football shaped CLRS and four were rectangular shaped CLRS. These eight locations were specifically selected in order to minimize their distance from Manhattan, Kansas. All the eight locations had a posted speed limit of 65 mph. Table 3.1 shows the study sites for this research.

Table 3.1 Study sites

Location	County Name	Highway	CLRS Type	Length (Miles)
1	Chase	US-50	Football	19
2	Ellsworth	KS-156	Football	14.9
3	Doniphan	US-36	Football	6.1
4	Reno	US-50	Football	9.7
5	Jefferson	US-24	Rectangular	6.7
6	Chase	US-50	Rectangular	7.4
7	Osage	US-75	Rectangular	9.6
8	Barton	US-56	Rectangular	9.7

Data at all the locations were collected under dry, daytime conditions and at flat open space locations. To measure the noise levels three 'Ex-tech HD 600' sound level meters with data logging were used. Exterior noise produce by the vehicles is measured at three distances from the centerline on the highways. Sound level meters were place orthogonally at distances of 50 feet, 100 feet and 150 feet from the centerline on the highways. The layout of the experiments is shown in Figure 3.1.

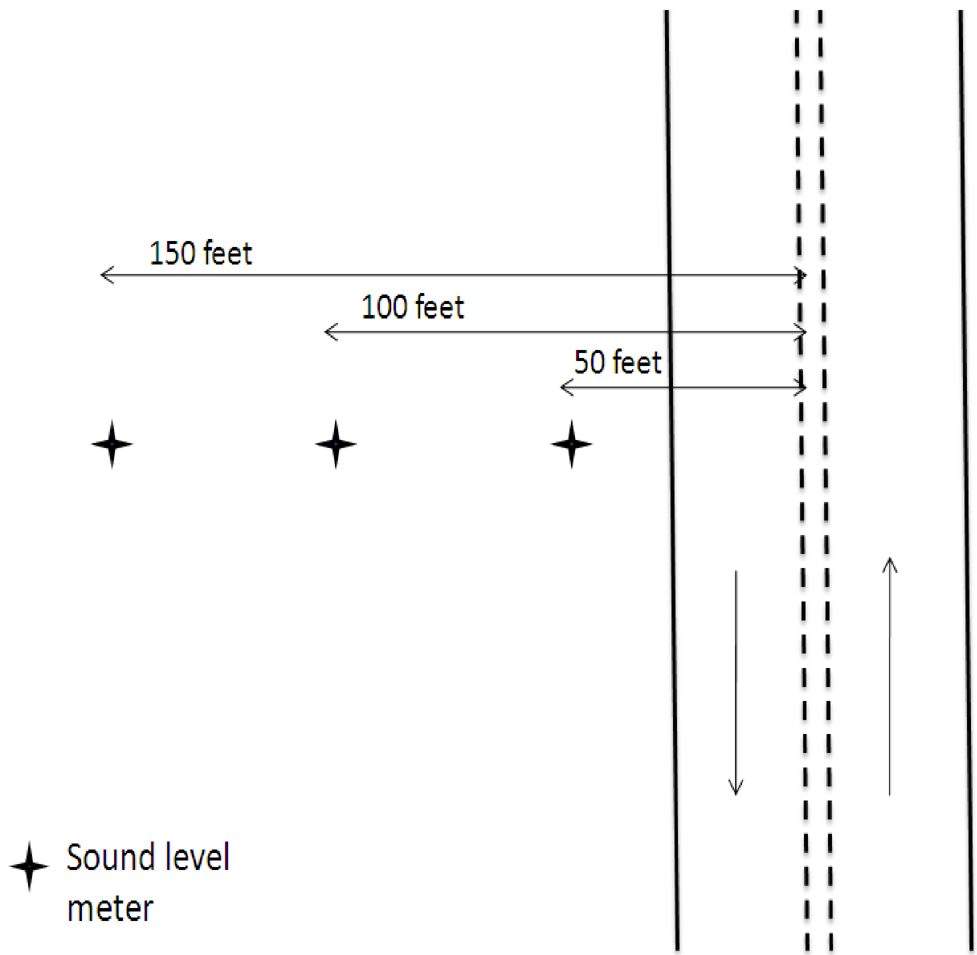

Figure 3.1 Layout of experiment

Figure 3.2 Experimental setup at the locations

The Ex-tech noise level meters used were type 2 noise levels which had a range of 30 dB to 130 dB with an accuracy of 1.4 dB. The noise level meters were calibrated before each series of measurements per location. Figure 3.3 shows the noise level meter used. The wind direction was measured using a wind vane and angle sheet conjunct before every run. A Prova AVM-07 anemometer was used to measure wind speed. Temperatures and humidity levels were measured at the beginning of the series of measurements per location and whenever perceptible changes in the weather occurred. A CE LM-81HT thermometer / anemometer / humidity meter was used to measure humidity and temperatures. The rumble strip depth dimension was measured with a Vernier's caliper.

Figure 3.3 Ex-Tech HD 600 sound level meter, PROVA Anemometer and CE LM-81HT thermometer / anemometer / humidity meter

The two test vehicles used for the experiments were 2006 Ford Taurus and a 2008 Chevrolet Express – 15 passenger van. Figure 3.4 shows the test vehicles used. Exterior noise levels from both the vehicles were measure when driven at speeds of 40 mph and 65 mph. Exterior noise data were collected per "base level run" or "rumble strip run". The base level run consisted of a test vehicle traveling over smooth asphalt pavement at two different speed levels, 40 mph and 65 mph, in a 120 meter straight segment of highway. The rumble strip run had the test vehicles traveling over CLRS at two different speed levels, 40 mph and 65 mph, in a 120 meter straight segment of highway. The segment of highway at which the noise data were collected per location was marked with two traffic cones. Runs that had another vehicle traveling within the 120 m segment of highway were not considered, in order to avoid noise contamination. Three runs of each vehicle, pavement, and speed combination were recorded to insure pure experimental error. The order of the runs and the position of the three noise meters were randomly assigned per location. The tire pressures on both the test vehicles were measured at cold tire conditions.

The data point associated with each run was the highest noise level recorded at fast response (125 ms) and using dBA scale, added to the wind contribution factor, i.e, "pure noise". The wind contribution was calculated using equation 1, given by Cho (2004).

$$\mathbf{A_{wind} = -[\ 0.88 * \log_{10} (\ L / 15\ )\ ] * U * \cos \theta} \qquad \text{Equation 1}$$

where,

A_{wind} = wind contribution

L = distance horizontal in meters, from the source of the noise to the instrument;

U = wind speed, in m/s;

θ = angle in radian, between the wind direction and the line from the vehicles to the instrument.

Figure 3.4 2008 Chevrolet van - 15 passengers

Figure 3.5 2006 Ford Taurus

CHAPTER 4 - Results

A total of eight locations where CLRS were already installed on highways in Kansas were tested for exterior noise levels produced when vehicles travel over CLRS. Locations where football CLRS and rectangular CLRS were tested are shown in Table 3.1. Data collected from all locations were analyzed per site and the results are discussed. Overall 192 test runs were conducted – 96 each over football CLRS and rectangular CLRS. Both vehicles were run over the rumble strips and the smooth pavement at speeds of 40 mph and 65 mph and each combination was run for three replications to minimize the error. Data corresponding to each location is discussed below.

4.1 Data Analysis

Location 1: Chase County – US 50

A section of 19 mile section of US 50 highway in Chase County, KS with football shaped CLRS was tested for exterior noise levels. The type of pavement chips was Overlay 3 inch, Ultrathin bonded asphalt surface. Data collected from location 1 is shown in Appendix B. Totally twenty four test runs were conducted, which included both the vehicles traveling at speeds of 40 mph and 65 mph, over the rumble strips and smooth pavement. Each run was replicated three times. An average of the three replications was taken for each condition and the results were analyzed to measure the change in the exterior noise levels for two conditions: drop in the noise levels from 50 feet to 100 feet, 100 feet to 150 feet and difference in the noise levels measured when the vehicles travel over the smooth pavement and over CLRS.

Table 4.1 Average noise levels at three distances for Chase County - US 50 on football CLRS

US 50 Chase Football			
	50 Feet	100 Feet	150 Feet
Taurus 40 RS	67.72	58.42	53.29
Taurus 40 Smooth	65.59	58.55	52.79
Difference	**2.13**	**-0.13**	**0.50**
Taurus 65 RS	76.09	73.25	64.45
Taurus 65 Smooth	71.59	62.51	53.91
Difference	**4.50**	**10.74**	**10.54**
Van 40 RS	69.62	63.52	55.95
Van 40 Smooth	66.35	61.99	55.79
Difference	**3.27**	**1.53**	**0.16**
Van 65 RS	80.72	74.55	63.52
Van 65 Smooth	74.92	67.35	58.42
Difference	**5.80**	**7.20**	**5.10**

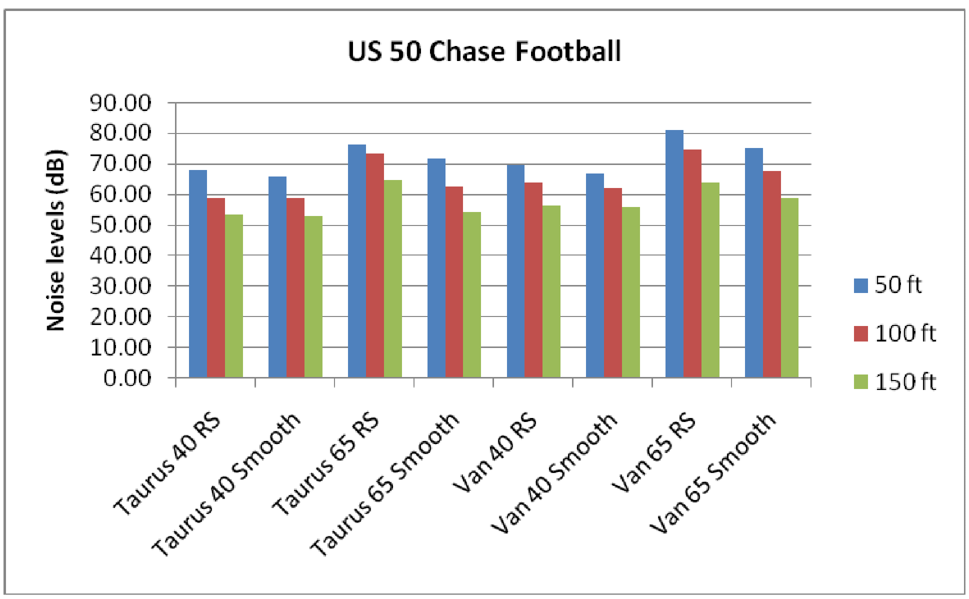

Figure 4.1 Average noise levels for Chase County - US 50 on football CLRS

Table 4.1 and Figure 4.1 shows the average noise levels for the data collected at Chase County – US 50 location. Average exterior noise levels calculated for the Taurus at speed of 40 mph over smooth pavement at distance 50 feet, 100 feet and 150 feet were recorded at 65.6 dB, 58.6 dB and 52.8 dB respectively and average noise levels at speed of 40 mph over the CLRS were recorded at 67.7 dB, 58.4 dB and 53.3 dB at distances 50, 100 and 150 feet respectively.

The difference in the average noise levels for Taurus travelling over smooth pavement and CLRS was calculated as 2.1 dB, - 0.1 dB and 0.5 dB at a speed of 40 mph at the three distances.

Average noise levels for the Taurus travelling at speed of 65 mph over smooth pavement and CLRS were calculated as 71.6 dB, 62.5 dB, 53.9 dB and 76.0 dB, 73.3 dB, 64.5 dB, at distances 50, 100 and 150 feet respectively, from the centerline. The difference in the noise levels for CLRS and smooth pavement at three distances was calculated as 4.5 dB, 10.7 dB and 10.5 dB at a speed of 65 mph.

Average exterior noise levels for Chevrolet van at a speed of 40 mph when travelling over smooth pavement and CLRS was calculated as 66.3 dB, 62.0 dB, 55.8 dB and 69.9 dB, 63.5 dB, 56.0 dB respectively at distances 50, 100 and 150 feet from the centerline. The increase in the noise levels for smooth pavement to CLRS is calculated as 3.3 dB, 1.5 dB and 0.2 dB at three distances.

Average noise levels for Chevrolet van at a speed of 65 mph travelling over smooth pavement and CLRS was calculated as 74.9, 67.3, 58.4 dB and 80.7, 74.6, 63.5 dB respectively at distances 50, 100 and 150 feet and the increase in the levels is calculated as 5.8, 7.2 and 5.1 dB at the three distances.

Location 2: Doniphan County – US 36

A 6.1 mile section on US 36 in Doniphan County, KS with football shaped CLRS was tested for exterior noise levels. The pavement type of the location was a Cold mill 0.5 inch, Overlay 1.5 inch asphalt surface. The average exterior noise levels for the location 2 are shown in Table 4.2 and Figure 4.3. Figure 4.2 shows the CLRS at the location.

Table 4.2 Average noise levels at three distances for Doniphan County - US 36 on football CLRS

HW 36 Doniphan Football			
	50 Feet	100 Feet	150 Feet
Taurus 40 RS	65.1	59.4	54.0
Taurus 40 Smooth	60.4	56.5	49.3
Difference	**4.7**	**2.9**	**4.7**
Taurus 65 RS	78.2	71.0	65.1
Taurus 65 Smooth	69.5	64.5	57.5
Difference	**8.7**	**6.5**	**7.6**
Van 40 RS	72.5	64.5	59.4
Van 40 Smooth	65.3	59.4	53.0
Difference	**7.2**	**5.1**	**6.4**
Van 65 RS	82.4	75.9	70.4
Van 65 Smooth	71.0	65.9	58.4
Difference	**11.4**	**10.0**	**12.0**

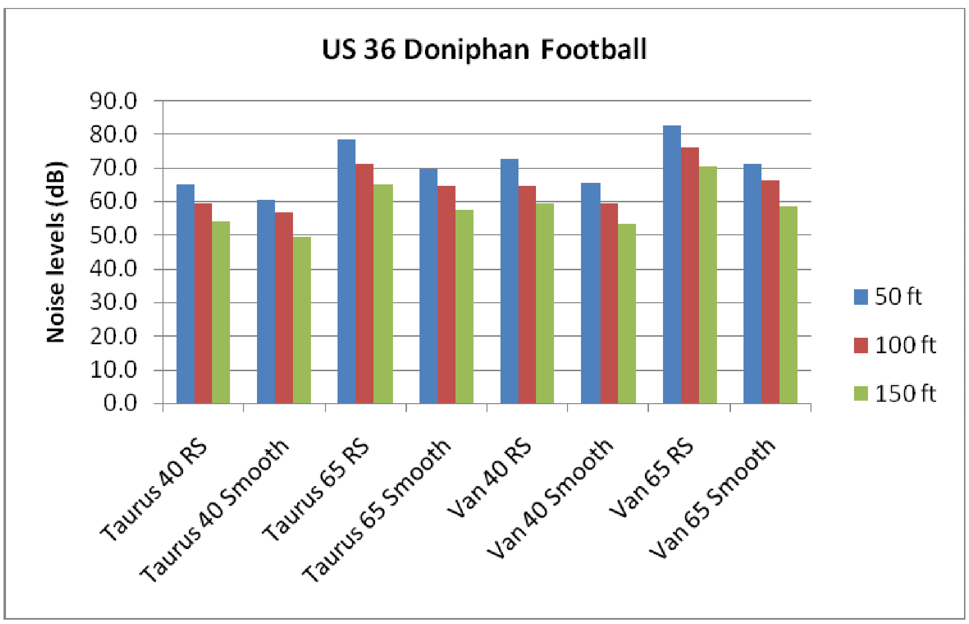

Figure 4.2 Average noise levels for Doniphan County - US 36 on football CLRS

The average noise levels for Ford Taurus travelling at a speed of 40 mph over smooth pavement and CLRS is calculated as 60.4, 56.5, 49.3 dB and 65.1, 59.4, 54.0 dB respectively at distances of 50, 100 and 150 feet from the centerline. The increase in the noise levels for smooth pavement to CLRS is calculated to be 4.7 dB, 2.7 dB and 4.7 dB for the three distances.

Average noise levels calculated when the Taurus was travelling at a speed of 65 mph over smooth pavement and CLRS were 69.5, 64.5, 57.5 dB and 78.2, 71.0, 65.1 dB respectively at distances 50, 100 and 150 feet and the increase in the exterior noise levels from smooth pavement to CLRS is calculated as 8.7, 6.5 and 7.6 dB at the three distances.

Average noise levels calculated for the Chevrolet Van travelling at a speed of 40 mph over smooth pavement and CLRS were 65.3, 59.4, 53.0 dB and 72.5, 64.5, 59.4 dB respectively at distances 50, 100 and 150 feet and the increase in the noise levels at the three distances between smooth pavement and CLRS is calculated as 7.2, 5.1 and 6.4 dB.

The average exterior noise levels calculated for the Chevrolet van travelling at 65 mph over smooth pavement and CLRS were 71.0, 65.9, 58.4 dB and 82.4, 79.5, 70.4 dB respectively at distance 50, 100 and 150 feet. The change in the noise levels at the three distances for smooth pavement and CLRS is calculated as 11.4, 10.0 and 12.0 dB.

Location 3: Ellsworth County – KS 156

A section of 14.9 mile section on KS 156 highway in the Ellsworth County, KS with football shaped centerline rumble strips. Average noise levels measurements for location 3, Ellsworth County – KS 156 are shown in Figure 4.5 and table 4.3. Figure 4.4 shows CLRS at the location.

For the Taurus travelling at a speed of 40 mph, the average noise levels at a distance of 50, 100 and 150 feet, over smooth pavement and CLRS were calculated to be 68.4, 59.3, 53.0 dB and 67.9, 61.3, 54.9 dB respectively. Change in the average noise levels for smooth pavement and CLRS is calculated to be -0.5, 1.7 and 1.9 dB for the distances 50, 100 and 150 feet from the centerline.

For the Taurus travelling at a speed of 65 mph, the average noise levels at distances 50, 100 and 150 feet, over smooth pavement and CLRS is calculated as 70.0, 2.3, 57.9 dB and 75.9, 68.2, 65.2 dB respectively. Increase in the average noise levels for smooth pavement and CLRS is calculated as 5.9, 5.9 and 7.3 dB at distances 50, 100 and 150 feet respectively.

Table 4.3 Average noise levels for Ellsworth County - KS 156 on football CLRS

KS 156 Ellsworth Football			
	50 Feet	100 Feet	150 Feet
Taurus 40 RS	67.9	61.3	54.9
Taurus 40 Smooth	68.4	59.6	53.0
Difference	**-0.5**	**1.7**	**1.9**
Taurus 65 RS	75.9	68.2	65.2
Taurus 65 Smooth	70.0	62.3	57.9
Difference	**5.9**	**5.9**	**7.3**
Van 40 RS	71.5	64.6	59.7
Van 40 Smooth	68.4	60.5	54.2
Difference	**3.1**	**4.1**	**5.5**
Van 65 RS	79.9	73.0	68.7
Van 65 Smooth	73.4	65.8	58.9
Difference	**6.5**	**7.2**	**9.8**

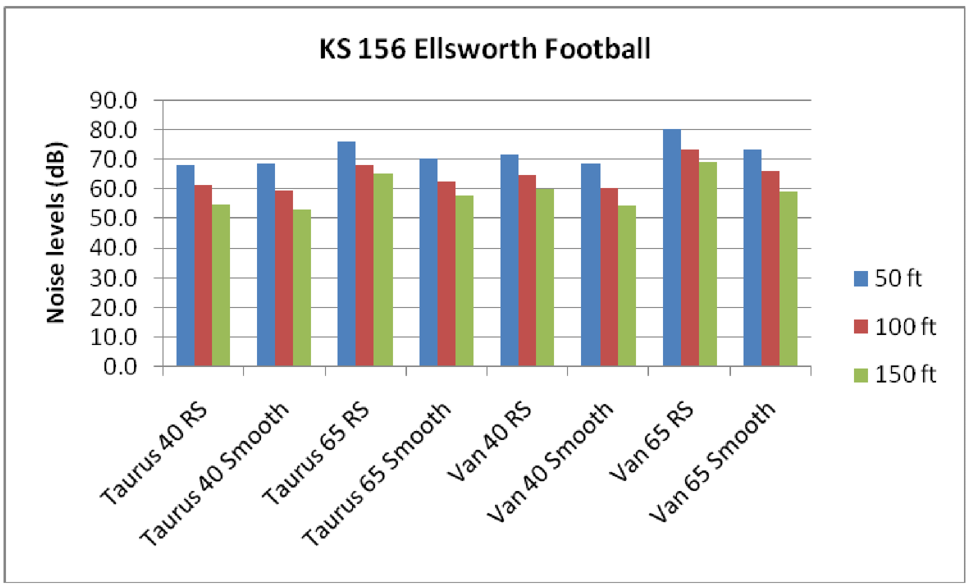

Figure 4.3 Average noise levels for Ellsworth County - KS 156 on football CLRS

For the Chevrolet van travelling at a speed of 40 mph over smooth pavement and CLRS, the average noise levels were calculated as 68.4, 60.5, 54.2 dB and 71.5, 64.6, 59.7 dB at distances 50, 100 and 150 feet respectively. The change in the average noise levels between smooth pavement and CLRS is calculated as 3.1, 4.1 and 5.5 dB at the three distances.

For the Chevrolet van travelling at a speed of 65 mph over smooth pavement and CLRS, average noise levels were calculated as 73.4, 65.8, 58.9 dB and 79.9, 73.0, 68.7 dB at distances of 50, 100 and 150 feet respectively from the centerline. The increase in the noise levels between smooth pavement and CLRS was calculated to be 6.5, 7.2 and 9.8 dB at distances 50, 100 and 150 feet respectively from the centerline.

Location 4: Reno County – US 50

A 9.7 mile section on US 50 in Reno County, KS with football shaped CLRS is tested for exterior noise levels and the averaged measurements are shown in Figure 4.6 and Table 4.4. The pavement type for this location was Cold mill 4 inch, Recy hot 6 inch, Overlay 0.75 inch asphalt surface.

Table 4.4 Average noise level measurements for Reno County - US 50 on football CLRS

US 50 Reno Football			
	50 Feet	100 Feet	150 Feet
Taurus 40 RS	67.0	60.3	56.2
Taurus 40 Smooth	64.0	54.0	50.4
Difference	**3.0**	**6.3**	**5.8**
Taurus 65 RS	74.8	68.0	65.0
Taurus 65 Smooth	68.7	61.8	55.5
Difference	**6.1**	**6.2**	**9.5**
Van 40 RS	72.2	69.6	64.5
Van 40 Smooth	66.3	60.8	56.5
Difference	**5.9**	**8.8**	**8.0**
Van 65 RS	88.6	76.7	74.9
Van 65 Smooth	69.3	60.8	56.2
Difference	**19.3**	**15.9**	**18.7**

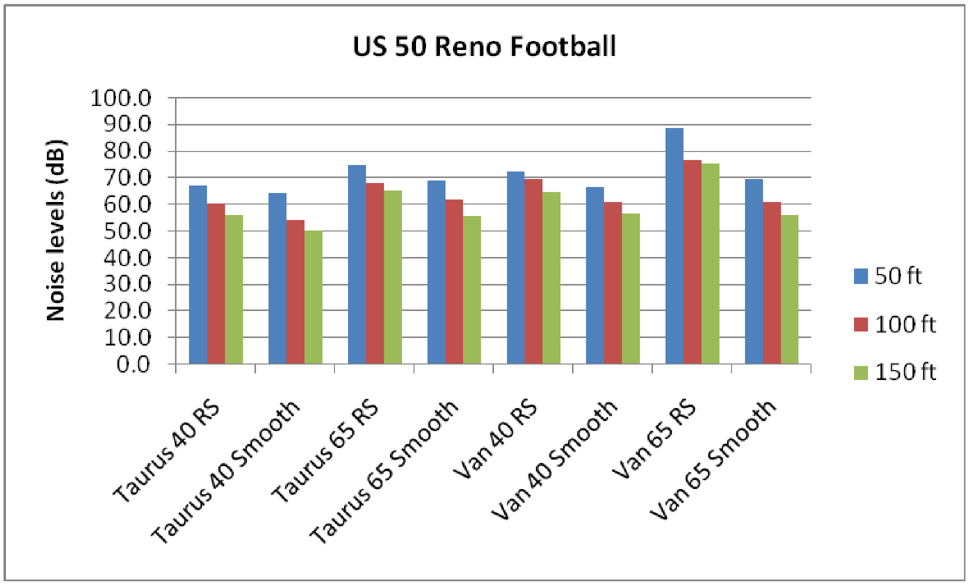

Figure 4.4 Average noise levels for Reno County - US 50 on football CLRS

The average noise levels calculated when a Taurus travelling at a speed of 40 mph over smooth pavement and CLRS were 64.0, 54.0, 50.4 dB and 67.0, 60.3, 56.2 dB at distances 50, 100 and 150 feet respectively. The change in the noise levels for smooth pavement and CLRS is calculated to be 3.0, 6.3 and 5.8 dB at the three distances.

For the Taurus travelling at a speed of 65 mph over smooth pavement and CLRS, the average noise levels were calculated to be 68.7, 61.8, 55.5 dB and 74.8, 68.0, 65.0 dB at distances 50, 100 and 150 feet respectively. The increase in the noise levels on smooth pavement and CLRS is calculated to be 6.1, 6.2 and 9.5 dB at the three distances.

The average noise levels for a Chevrolet van travelling at a speed of 40 mph over smooth pavement and CLRS is calculated to be 66.3, 60.8, 56.5 dB and 72.2, 69.6, 64.5 dB at distances 50, 100 and 150 feet respectively from the centerline. The difference in the average noise levels observed between smooth pavement and CLRS were 5.9, 8.8 and 8.0 dB at the three distances respectively.

For a van travelling at a speed of 65 mph over smooth pavement and CLRS, the average noise levels were calculated to be 69.3, 60.8, 56.2 dB and 88.6, 76.7, 74.9 dB at distances 50, 100 and 150 feet respectively. The difference in the average noise levels between smooth pavement and CLRS is calculated to be 19.3, 15.9 and 18.7 dB at distances 50, 100 and 150 feet respectively.

Location 5: Chase County – US 50

A 7.4 mile section on US 50 in Chase County was installed with rectangular shaped CLRS on which the measurements for the exterior noise were recorded for the experiment. The pavement type for this location was Surface recy 2 inch, Ultrathin bonded asphalt surface. The average noise levels of the data collected are shown in Figure 4.7 and Table 4.5.

Table 4.5 Average noise levels for US 50 Chase County for rectangular CLRS

US 50 Chase Rectangular			
	50 Feet	100 Feet	150 Feet
Taurus 40 RS	70.2	66.1	59.9
Taurus 40 Smooth	66.8	60.8	55.3
Difference	**3.4**	**5.3**	**4.6**
Taurus 65 RS	80.3	76.4	66.7
Taurus 65 Smooth	71.1	-	57.0
Difference	**9.1**	-	**9.6**
Van 40 RS	73.9	70.7	63.8
Van 40 Smooth	66.1	-	55.2
Difference	**7.8**	-	**8.6**
Van 65 RS	80.2	75.3	68.5
Van 65 Smooth	73.5	67.8	60.9
Difference	**6.67**	**7.53**	**7.55**

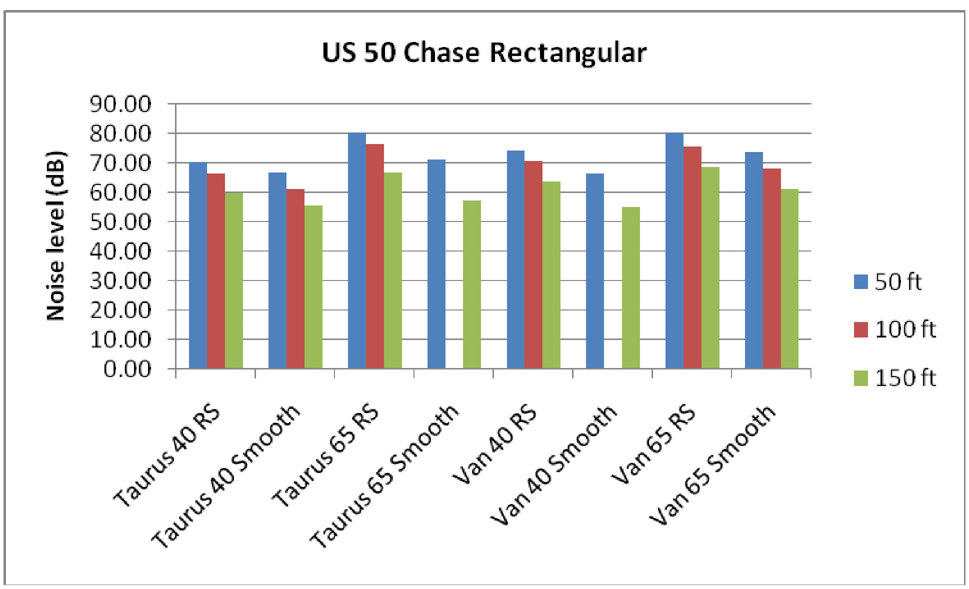

Figure 4.5 Average noise levels for US 50 Chase County for rectangular CLRS

For a Taurus travelling at a speed of 40 mph over smooth pavement and CLRS, the average noise levels were calculated as 66.8, 60.8, 55.3 dB and 70.2, 66.1, 59.9 dB at distances 50, 100 and 150 feet from the centerline. The difference between the noise levels from smooth pavement and CLRS was calculated as 3.4, 5.3 and 4.6 dB at the three distances.

The average noise levels for the Taurus travelling at a speed of 65 mph over the smooth pavement were calculated as 71.1 dB at 50 feet and 57.0 dB at 150 feet from the centerline and for CLRS the noise levels calculated were 80.3, 76.4 and 66.7 dB at distances 50, 100 and 150 feet from the centerline. An increase of 9.1 dB is calculated at 50 feet and 9.6 dB at 150 feet, from smooth pavement to CLRS.

The average noise levels for the Chevrolet van travelling at a speed of 40 mph over smooth pavement were calculated as 66.1 dB at 50 feet and 55.2 dB at 150 feet and when over CLRS the noise levels calculated were 73.9, 70.7 and 63.8 dB at distances 50, 100 and 150 feet respectively. An increase of 7.8 dB was calculated at 50 feet and 8.6 dB was calculated at a distance of 150 feet from the centerline between smooth pavement and CLRS.

For the Chevrolet van travelling at a speed of 65 mph, the average noise levels when travelling over smooth pavement were calculated as 73.5, 67.8 and 60.9 dB at distances 50, 100 and 150 feet respectively and when over CLRS the average noise levels were calculated to be 80.2, 75.3 and 68.5 dB at the three distances respectively. The difference between the average noise levels for smooth pavement and CLRS was calculated to be 6.7, 7.5 and 7.6 dB at the three distances.

Location 6: Jefferson County – US 24

A 6.7 mile section on US 24 in Jefferson County was installed with rectangular CLRS and was tested for the exterior noise levels when vehicles travel over CLRS. The pavement type for this location was Surface recy 2 inch, Overlay 1inch asphalt surface. The averages of the data collected from this location are shown in Figure 4.9 and Table 4.6. Figure 4.8 shows CLRS at the location.

Table 4.6 Average noise levels for US 24 Jefferson County for rectangular CLRS

US 24 Jefferson Rectangular			
	50 Feet	100 Feet	150 Feet
Taurus 40 RS	66.3	59.6	54.0
Taurus 40 Smooth	60.0	53.9	52.4
Difference	**6.3**	**5.7**	**1.6**
Taurus 65 RS	76.0	69.4	63.2
Taurus 65 Smooth	66.8	59.7	54.1
Difference	**9.2**	**9.7**	**9.1**
Van 40 RS	74.3	69.2	62.7
Van 40 Smooth	63.0	55.8	54.1
Difference	**11.3**	**13.4**	**8.6**
Van 65 RS	84.3	76.3	71.0
Van 65 Smooth	65.9	61.7	58.2
Difference	**18.4**	**14.6**	**12.8**

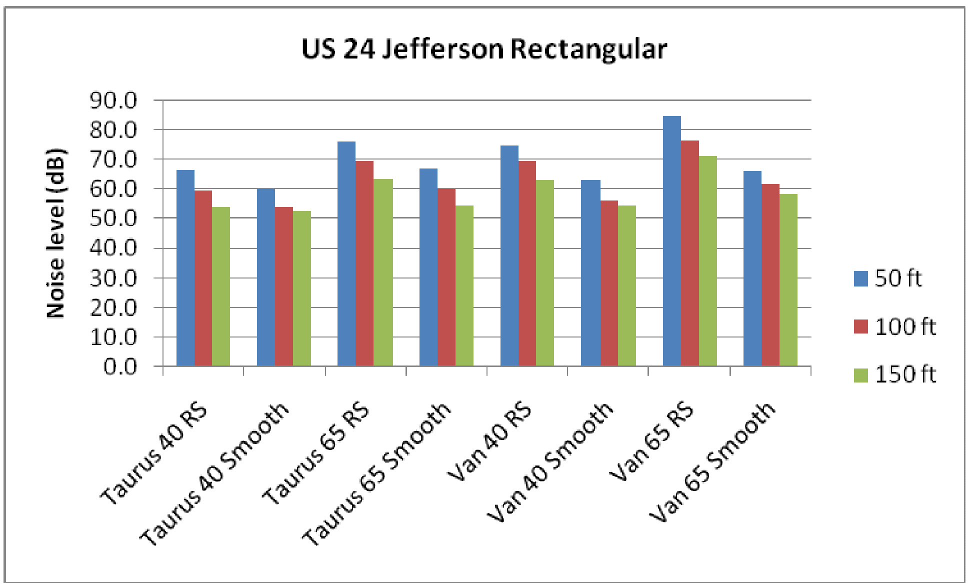

Figure 4.6 Average noise levels for US 24 Jefferson County for rectangular CLRS

The average noise levels for the Taurus travelling at a speed of 40 mph over smooth pavement and CLRS were 60.0, 53.9, 52.4 dB and 66.3, 59.6, 54.0 dB at distances of 50, 100 and 150 feet respectively from the centerline. The increase in the noise levels from smooth pavement to CLRS is calculated to be 6.3, 5.7 and 1.6 dB at the three distances.

For the Taurus travelling at a speed of 65 mph over smooth pavement and CLRS, the average noise levels were calculated to be 66.8, 59.7, 54.1 dB and 76.0, 69.4, 63.2 dB at distances 50, 100 and 150 feet, respectively, and the difference between average noise levels for smooth pavement and CLRS was calculated as 9.2, 9.7 and 9.1 dB at the three distances.

The average noise levels for the Chevrolet van travelling at a speed of 40 mph over smooth pavement and CLRS were calculated as 63.0, 55.8, 54.1 dB and 74.3, 69.2, 62.7 dB at distances 50, 100 and 150 feet respectively. The increase in the noise levels from smooth pavement to CLRS was calculated to be 11.3, 13.4 and 8.6 dB at the three distances.

For the Chevrolet van travelling at a speed of 65 mph over smooth pavement and CLRS, the average noise levels were calculated as 65.9, 61.7, 58.2 dB and 84.3, 76.3, 71.0 dB at distances 50, 100 and 150 feet and the increase in the average noise levels for smooth pavement and CLRS was calculated as 18.4, 14.6 and 12.8 dB respectively at distances 50, 100 and 150 feet.

Location 7: Barton County – US 50

A section on 9.7 mile section on US 50 in Barton County with rectangular CLRS and was tested for the exterior noise levels when vehicles travel over CLRS. The pavement type for this location was Cold mill 1inch, Overlay 1.5 inch asphalt surface. The Figure 4.10 and Table 4.7 shows the calculated average noise levels at the location.

Table 4.7 Average noise levels for US 50 Barton County with rectangular CLRS

US 50 Barton Rectangular			
	50 Feet	100 Feet	150 Feet
Taurus 40 RS	70.9	63.4	58.7
Taurus 40 Smooth	68.2	60.5	55.5
Difference	**2.7**	**2.9**	**3.2**
Taurus 65 RS	82.9	73.1	70.9
Taurus 65 Smooth	72.4	60.9	61.7
Difference	**10.5**	**12.2**	**9.2**
Van 40 RS	78.0	69.4	65.5
Van 40 Smooth	71.8	65.5	67.7
Difference	**6.2**	**3.9**	**-2.2**
Van 65 RS	84.8	75.2	69.9
Van 65 Smooth	71.6	67.7	61.9
Difference	**13.2**	**7.5**	**8.0**

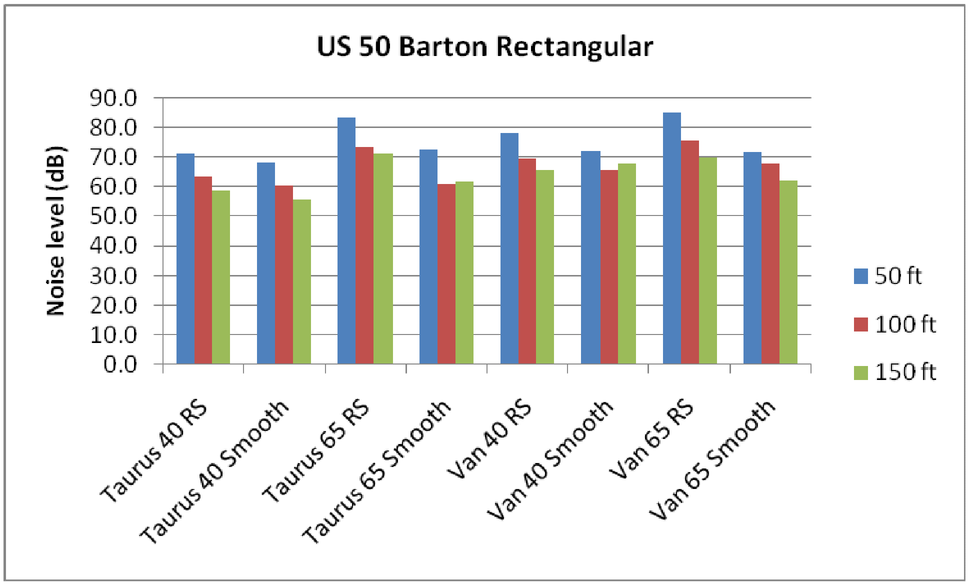

Figure 4.7 Average noise levels for US 50 Barton County with rectangular CLRS

For the Taurus travelling at a speed of 40 mph over smooth pavement and CLRS, the average noise levels were calculated to be 68.2, 60.5, 55.5 dB and 70.9, 63.4, 58.7 dB respectively at distances 50, 100 and 150 feet from the centerline. The difference in the average noise levels for smooth pavement and CLRS was calculated as 2.7, 2.9 and 3.2 dB at the three distances.

The average noise levels for the Taurus travelling at a speed of 65 mph over smooth pavement and CLRS were calculated as 72.4, 60.9, 61.7 dB and 82.9, 73.1, 70.9 dB respectively at distances 50, 100 and 150 feet from the centerline. The increase in the noise levels for smooth pavement and CLRS was calculated as 10.5, 12.2 and 9.2 dB at the three distances.

The average noise levels for the Chevrolet van travelling at a speed of 40 mph over smooth pavement and CLRS were calculated to be 71.8, 65.5, 67.7 dB and 78.0, 69.4, 61.7 dB respectively at distances 50, 100 and 150 feet from the centerline. The changes in the average noise levels were calculated to be 6.2, 3.9 and -2.2 dB at the three distances.

For the Chevrolet van travelling at a speed of 65 mph over smooth pavement and CLRS, the average noise levels were calculated to be 71.6, 67.7, 61.9 dB and 84.8, 75.2, 69.9 dB respectively at distances 50, 100 and 150 feet. The changes in the noise levels were calculated to be 13.2, 7.5 and 8.0 dB at the three distances.

Location 8: Harvey County – US 50

A 17.5 mile section in US 50 in Harvey County region was installed with rectangular CLRS which was tested for the exterior noise levels at 50, 100 and 150 feet from the centerline when vehicles travel over CLRS. The pavement type for this location was Overlay 1 inch asphalt surface. The Figure 4.11 and Table 4.8 show the averaged data for the location.

Table 4.8 Average noise levels for US 50 in Harvey County with rectangular CLRS

US 50 Harvey Rectangular			
	50 Feet	100 Feet	150 Feet
Taurus 40 RS	59.6	54.7	49.7
Taurus 40 Smooth	56.3	51.5	47.3
Difference	**3.3**	**3.2**	**2.4**
Taurus 65 RS	71.3	66.8	61.8
Taurus 65 Smooth	64.0	58.6	52.1
Difference	**7.3**	**8.2**	**9.7**
Van 40 RS	65.7	61.5	55.8
Van 40 Smooth	60.3	53.7	48.4
Difference	**5.4**	**7.8**	**7.4**
Van 65 RS	74.5	69.6	62.1
Van 65 Smooth	66.2	61.0	55.3
Difference	**8.3**	**8.6**	**6.8**

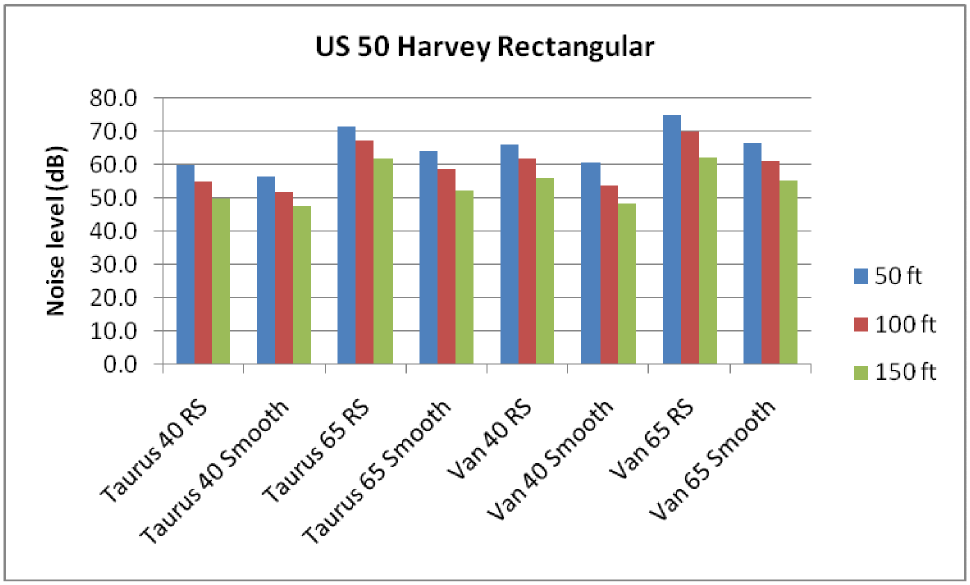

Figure 4.8 Average noise levels for US 50 in Harvey County with rectangular CLRS

For the Taurus travelling at a speed of 40 mph over smooth pavement and CLRS, the average noise levels were calculated as 56.3, 51.5, 47.3 dB and 59.6, 54.7, 49.7 dB respectively at distances 50, 100 and 150 feet from the centerline. The change in the noise levels for smooth pavement and CLRS was calculated as 3.3, 3.2, and 2.4 dB at the three distances.

The average noise levels recorded for the Taurus travelling at a speed of 65 mph over smooth pavement and CLRS were calculated to be 64.0, 58.6, 52.1 dB and 71.3, 66.8, 61.8 dB respectively at distances 50, 100 and 150 feet from the centerline. The difference in the noise levels for smooth pavement and CLRS was calculated to be 7.3, 8.2 and 9.7 dB at the three distances.

The average noise levels for the Chevrolet van travelling at a speed of 40 mph over smooth pavement and CLRS were calculated as 60.3, 53.7, 48.4 dB and 65.7, 61.5, 55.8 dB at distances 50, 100 and 150 feet respectively. The increase in the noise levels from smooth pavement to CLRS was calculated to be 5.4, 7.8 and 7.4 dB at the three distances.

For the Chevrolet van travelling at a speed of 65 mph over smooth pavement and CLRS, the average noise levels were calculated as 66.2, 61.0, 55.3 dB and 74.5, 69.6, 62.1 dB at distances 50, 100 and 150 feet and the increase in the average noise levels for smooth pavement and CLRS was calculated as 8.3, 8.6 and 6.8 dB respectively at distances 50, 100 and 150 feet.

Overall noise level summary

The Taurus; Football CLRS locations

The average noise levels for the Taurus over the smooth pavement at three distances (50, 100, 150 feet) from the centerline are 64.6, 57.2, 51.4 dB at 40 mph and 69.9, 62.8, 56.2 dB at 65 mph for the Football rumble strips locations. Average rumble strip noise at speeds of 40 mph and 65 mph at the three distances are 66.9, 59.9, 54.6 dB and 76.2, 70.1, 64.9 dB respectively. The increase in the noise levels was calculated as 2.3, 2.7 and 3.2 dB for Taurus at 40 mph and 6.3, 7.3 and 8.7 dB for Taurus at 65 mph at the three distances for the locations with football rumble strips.

The Chevrolet van; Football CLRS locations

The average noise levels for the Chevrolet van over smooth pavement are 66.6, 60.7 and 54.6 dB at 40 mph and 72.2, 65.0 and 58.0 dB at 65 mph at the three distances respectively for the Football rumble strips locations. The average rumble strip noise at speeds of 40 mph and 65 mph at the three distances are 71.5, 65.6, 59.9 dB and 82.9, 75.0, 69.4 dB respectively. The increase in the noise levels was calculated as 4.9, 4.9, 5.0 dB at 40 mph and 10.7, 10.0, 11.0 dB at 65 mph at the three distances for Van at the locations with football rumble strips.

The Taurus; Rectangular CLRS locations

Average smooth pavement noise for the Taurus at the Rectangular rumble strips locations at the three distances (50, 100, 150 feet) are 62.8, 57.0, 52.6 dB at 40 mph and 68.6, 59.7, 56.2 dB at 65 mph and the increase in the noise levels when traversed over the rumble strips is noticed as 3.9, 4.0 and 3.0 dB (66.7, 61.0 and 55.6 dB) at 40 mph and 9.0, 11.7 and 9.5 dB (77.6, 71.4 and 65.7 dB) at 65 mph.

The Chevrolet van; Rectangular CLRS locations

Average noise levels for the smooth pavement at the locations with rectangular rumble strips for the Chevrolet van at the distances 50, 100 and 150 feet are observed to be at 65.3, 58.3 and 56.3 dB at 40 mph and 69.3, 66.6 and 59.1 dB at 65 mph respectively. The increase in the noise levels when the Chevrolet van is traversed over the rectangular rumble strips is observed to be 7.7, 9.7 and 5.7 dB (73.0, 68.0 and 62.0 dB) at 40 mph and 11.7, 7.5 and 8.8 dB (81.0, 74.1 and 67.9 dB) at 65 mph.

The increase in the rumble strip noise for the Taurus and Chevrolet van at both the speeds and for both football and rectangular rumble strips is shown in Table 4.9 and Figure 4.12

Table 4.9 Overall average noise levels

	Football			Rectangular		
	50 Feet	100 Feet	150 Feet	50 Feet	100 Feet	150 Feet
Taurus 40 RS	66.9	59.9	54.6	66.7	61.0	55.6
Taurus 40 Smooth	64.6	57.2	51.4	62.8	57.0	52.6
Difference	**2.3**	**2.7**	**3.2**	**3.9**	**4.0**	**3.0**
Taurus 65 RS	76.2	70.1	64.9	77.6	71.4	65.7
Taurus 65 Smooth	69.9	62.8	56.2	68.6	59.7	56.2
Difference	**6.3**	**7.3**	**8.7**	**9.0**	**11.7**	**9.5**
Van 40 RS	71.5	65.6	59.9	73.0	68.0	62.0
Van 40 Smooth	66.6	60.7	54.9	65.3	58.3	56.3
Difference	**4.9**	**4.9**	**5.0**	**7.7**	**9.7**	**5.7**
Van 65 RS	82.9	75.0	69.4	81.0	74.1	67.9
Van 65 Smooth	72.2	65.0	58.0	69.3	66.6	59.1
Difference	**10.7**	**10.0**	**11.4**	**11.7**	**7.5**	**8.8**

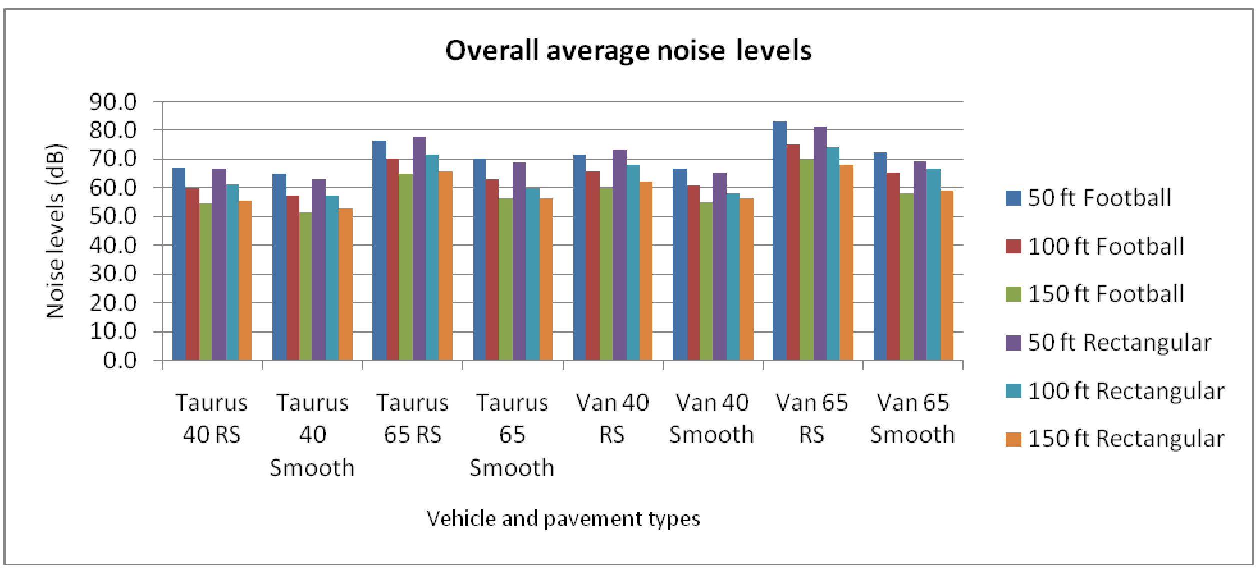

Figure 4.9 Overall average noise levels

Based on the analysis of the results it can be stated that the difference between noise levels generated by the test vehicles driving over CLRS is at least 5 dB more than the test vehicles driven on the smooth surface. According to Minor's study in 2005, a difference of 5 dB or higher is enough for a human ear to notice the change and therefore, installing CLRS would affect the noise levels for residents at 50, 100, and 150 feet.

Tables 4.10 and 4.11 show the difference in the noise levels at speeds 40 mph and 65 mph at distances 50, 100 and 150 feet for both football and rectangular CLRS compared to the smooth pavement.

Table 4.10 Comparison between CLRS noise levels for 40 mph and 65 mph

	Football			Rectangular		
	50 Feet	100 Feet	150 Feet	50 Feet	100 Feet	150 Feet
Taurus 40 RS	66.9	59.9	54.6	66.7	61.0	55.6
Taurus 65 RS	76.2	70.1	64.9	77.6	71.4	65.7
Difference	9.3	10.2	10.3	10.9	10.4	10.1
Van 40 RS	71.5	65.6	59.9	73.0	68.0	62.0
Van 65 RS	82.9	75.0	69.4	81.0	74.1	67.9
Difference	11.4	9.4	9.5	8.0	6.1	5.9

Table 4.4.11 Comparison between smooth pavement noise levels for 40 mph and 65 mph

	Football			Rectangular		
	50 Feet	100 Feet	150 Feet	50 Feet	100 Feet	150 Feet
Taurus 40 Smooth	64.6	57.2	51.4	62.8	57.0	52.6
Taurus 65 Smooth	69.9	62.8	56.2	68.6	59.7	56.2
Difference	5.3	5.6	4.8	5.8	2.7	3.6
Van 40 Smooth	66.6	60.7	54.9	65.3	58.3	56.3
Van 65 Smooth	72.2	65.0	58.0	69.3	66.6	59.1
Difference	5.6	4.3	3.1	4.0	8.3	2.8

When the differences in the noise levels for the cases with speeds 40 mph and 65 mph, for CLRS (both football and rectangular) and the smooth pavement were compared, the rumble strip noise was twice as loud as the smooth pavement. A two-tailed t-test on the calculated difference between smooth pavement noise and CLRS noise for test vehicles at 40 mph and 65 mph proves that it is significantly different. The t-test is shown in Appendix B. The same trend was observed at 50 feet, 100 feet and 150 feet for both rectangular and football CLRS except at 100 feet distance for van traveling over rectangular CLRS.

4.2 Additional results

Apart from the tests run using the Taurus and the 15- passenger Chevrolet van, measurements were collected for Semi-trucks when traveling at operational speeds with a sample size of 12 on US 75, Brown County with football CLRS. The results compared to the noise levels for the Taurus and the 15- passenger Chevrolet van at distances 50, 100 and 150 feet and the noise levels for a Semi-truck are shown in Table 4.12.

Table 4.12 Comparison with the noise levels of semi-trucks

Mean Corrected Noise (dB)			
Distance	Taurus - RS	Chevrolet van - RS	Semi-Trucks Smooth
50 feet	78.0	81.9	83.9
100 feet	72.0	74.3	76.4
150 feet	67.0	68.8	73.1

The noise levels when the Taurus and the 15- passenger Chevrolet van traveling at a speed of 65 mph over CLRS were less than the noise levels generated by Semi-trucks traveling at operational speeds on smooth pavement.

4.3 Prediction Model

A prediction model was created to measure the noise at other distances from the CLRS based on the data collected for the distances 50, 100 and 150 feet. A regression model was created based on the average noise levels for the vehicles passing over the CLRS (average of both football and rectangular CLRS noise levels) at a speed of 65 mph. The regression model for the Taurus and the 15- passenger Chevrolet van is shown below.

$$\mathbf{Noise_{Td} = 83.33 - (0.11)*(d)}$$

Where

$Noise_{Td}$ = Noise for the Taurus at distance d

d = distance where the noise is to be calculated from CLRS

The average noise at a distance of 200 feet for the Taurus travelling at a speed of 65 mph over CLRS was calculated to be 61.3 dB.

The regression model for the Chevrolet van travelling at a speed of 65 mph over CLRS is shown below.

$Noise_{Vd} = 88.10 – (0.13)*(d)$

Where

$Noise_{Vd}$ = Noise for the Chevrolet van at distance d

d = distance where the noise is to be calculated from CLRS

The average noise at a distance of 200 feet for the Chevrolet van travelling at a speed of 65 mph over CLRS was calculated to be 62.1 dB.

4.4 Discussion

The change in noise levels between smooth pavement and rumble strips for the Taurus travelling at a speed of 40 mph at a distance of 150 feet from the centerline was measured as 3.2 dB for football CLRS and 3.0 dB on rectangular CLRS. For Taurus at 65 mph the change in noise levels between smooth pavement and CLRS at a distance 150 feet was measured to be 8.7 dB for football CLRS and 9.5 dB for rectangular CLRS. For the Chevrolet van at 40 mph, the change in the noise levels was calculated to be 5.0 dB and 5.7 dB respectively for football and rectangular CLRS at distance of 150 feet. For the Chevrolet van travelling at a speed of 65 mph, the change in the noise levels at a distance of 150 feet was calculated to be 11.4 dB and 8.8 dB, respectively, for football and rectangular CLRS. Based on the literature review in chapter 2, a change of over 5 dB is enough for a normal human ear to notice the change and being disturbed (Minor 2005). Recent studies regarding the rumble strip noise when vehicles cross over them show that over half of the rumble strip conditions produced changes in the exterior noise levels greater than 4 dB (Finley and Miles, 2007). Chen (1994) observed the exterior noise levels for rolled and milled rumble strips and concluded that there was an increase of 4 dB and 11 dB respectively for rolled rumble strips and milled rumble strips. Higgins and Barbel (1984) determined that, at 50 feet distance from the rumble strips the increase in the noise levels was 7 dB when compared to the base noise levels.

The increase in the noise levels for both the test vehicles used for the experiment was calculated to be more than 5 dB at a speed of 65 mph and at a distance of 150 feet from the CLRS, which is in agreement with the previous researches.

CHAPTER 5 - Resident Survey

In October 2009, surveys were sent out to the residents along the section of the US 40 highway where the football CLRS were installed in May 2005. The main idea behind the survey was to compare the results of a similar survey given out to the residents along the same section in January 2006. The survey consisted of eight questions which gives the residents' likes, dislikes or concerns related to the noise produced from vehicles traveling over CLRS. A copy of the survey can be found in the Appendix C. The surveys were mailed back to the K-State rumble research team at the Department of Industrial and Manufacturing Systems Engineering and the data was analyzed to determine the residents' response to the external noise generated by vehicles traveling over CLRS, after 53 months since installation.

5.1 Data Analysis

A total of 22 surveys were sent out through the mail to the residents along the stretch of the US 40 Highway where football CLRS were installed in May 2005. The results of each question in the survey are discussed below along with any comments from the residents. A total of 12 surveys were received back form the residents which constitutes a 55% return rate.

Question 1: How many years have you been at the current address?

The residents were asked to notify the number of years they have been living at the current address. The results were allotted into three categories: less than 3 years, 3-10 years and more than 10 years. The resident response distribution for the question 1 is represented in Figure 5.1.

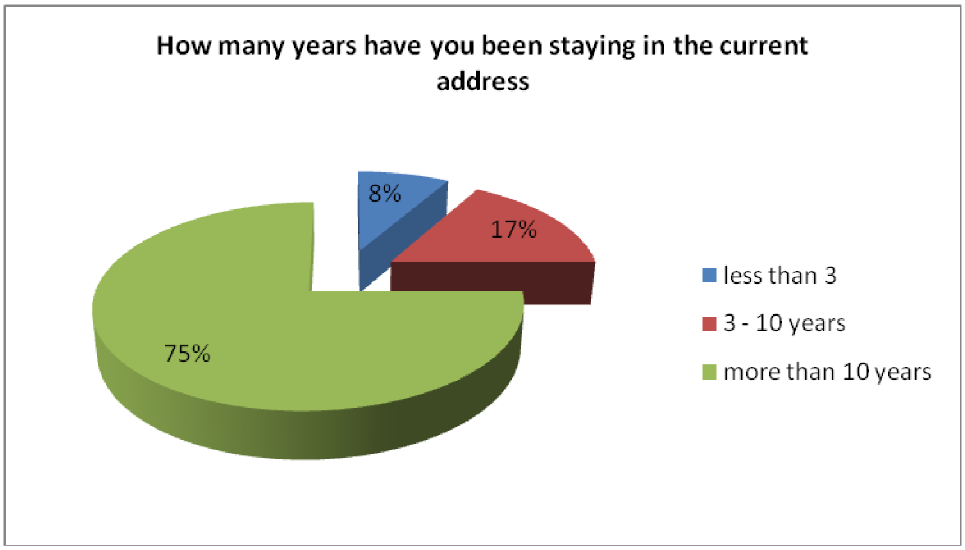

Figure 5.1 Resident response distribution for question 1, resident survey

It can be seen from the response distribution that 75% (n=9) of the residents were living at the current address for more than 10 years. Also, 17% (n=2) of the residents were living between 3-10 years and 8% (n=1) of the residents were living for less than 3 years at the current address. This is a positive response as the residents were living at the current address well before the installation of CLRS and can compare the change in the noise levels for before and after installation.

Question 2: Can you hear any noise of Traffic on US 40 from your residence?

The residents were asked to answer yes or no for the question 2. The response distribution was plotted below.

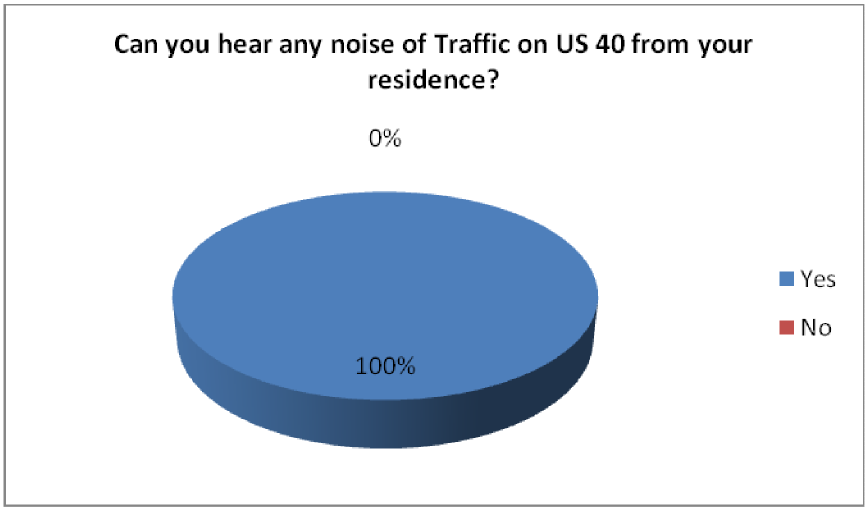

Figure 5.2 Resident response distribution for question 2, resident survey

It can be seen from the figure that 100% of the residents (n = 12) hear noise from the traffic on US 40 highway.

Question 3: Can you hear from your residence when a driver crosses over (comes in contact with) the centerline rumble strips?

The residents were asked to answer yes or no to the question 3. If the answer was yes, they must proceed to question 4 or else proceed to question 6. The response distribution was plotted in the Figure 5.3.

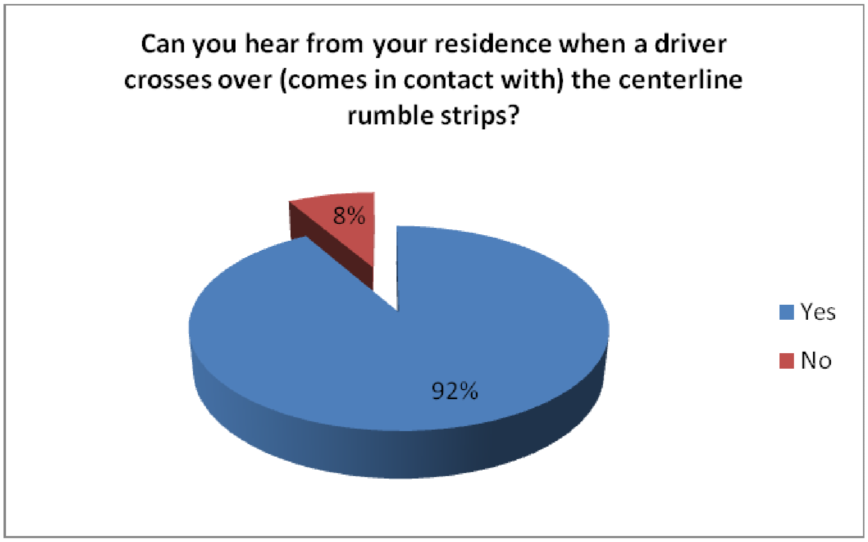

Figure 5.3 Resident response distribution for question 3, resident survey

It can be seen from the distribution that 92 % of the residents (n = 11) hear noise from the vehicles when they cross over CLRS and 8 % (n = 1) said they do not hear noise when vehicles cross over CLRS.

Question 4:

The residents were asked to choose one from the four following options: the noise is unnoticeable and not a concern, noise is noticeable and not a concern, the noise is only inconvenient and annoying and the noise is produced is loud enough to cause a concern or a distraction. The response distribution of the residents is shown in Figure 5.4.

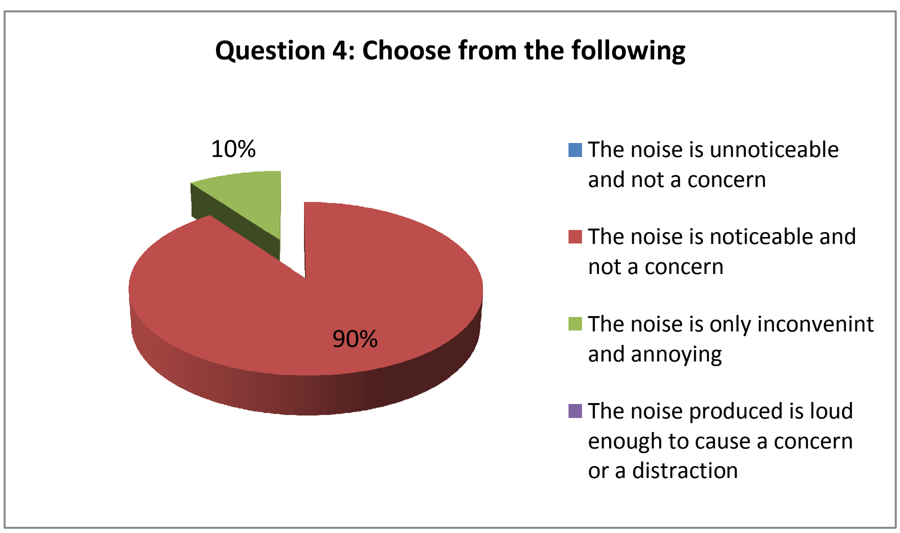

Figure 5.4 Response distribution for question 4, resident survey

From the response distribution of the resident survey for question 4, it can be noticed that 90% (n=9) of the residents agree that the noise is noticeable and it is not a concern. This is a positive response as it indicates that these residents most likely have gotten used to the noise generated from the vehicles traveling over CLRS.

The results to the survey conducted in January 2006 indicated that 16 % of residents said the noise was loud enough to cause a problem or a distraction and 32 % of residents said the noise is inconvenient or annoying. Even though the number responding to the follow-up survey is less, it is speculated that those not responding have no major concerns with the noise generated; otherwise, it is likely they would have taken this opportunity to express concerns regarding noise.

Question 5: If you answered yes to question3, how often can you hear the noise produced from a driver crossing the centerline rumble strips?

The residents on US 40 highway were asked to mention the number of times they hear the noise produced by vehicles traveling over CLRS in a day, for which they had to pick from the available four options: Less than once a day, 1-5 times a day, 5-10 times a day and more than 10 times a day. The response distribution of the residents is shown in Figure 5.5.

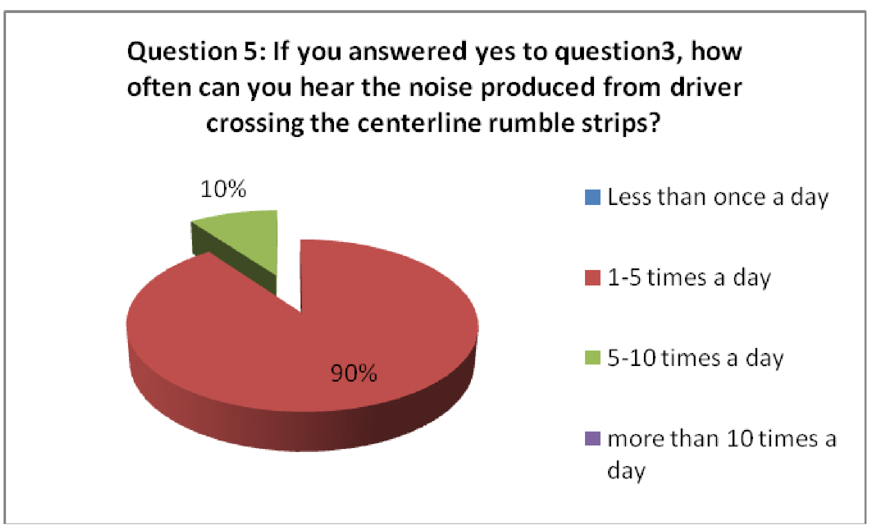

Figure 5.5 Resident response distribution for question 5, resident survey

From the response distribution graph, it can be noticed that 90 % of the residents hear the noise from vehicles crossing from CLRS is not more than 5 time a day. It can be also seen that none of the residents responding hear the noise more than 10 times a day whereas the results from the survey in January 2006 said that 36 % of the residents said they hear the noise from the US 40 traffic when crossing centerline rumble strips.

Question 6: What is the approximate distance from your house to US 40?

The residents were asked to give the approximate distance from their house to US 40, so that the intensity of noise reaching their house from the US 40 traffic can be roughly assessed based on the results from field studies.

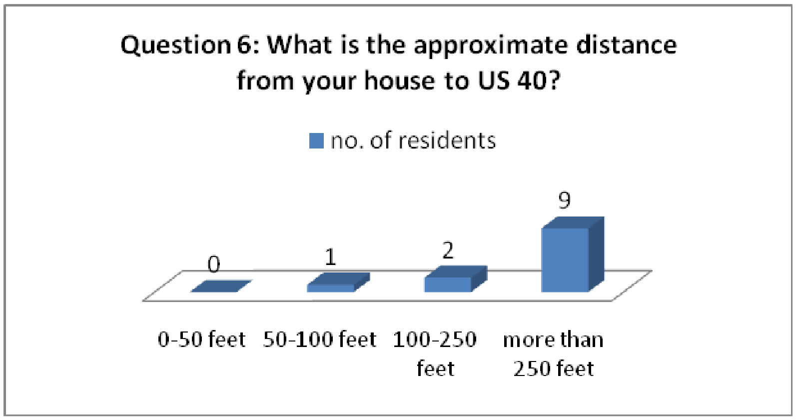

Figure 5.6: Resident response distribution for question 6, resident survey

Question 7: Do you believe Centerline rumble strips on US 40 contribute to your driving safety?

Residents were asked to answer Yes, No or No Opinion for question 7 of the survey. The resident response distribution is shown in Figure 5.7 below.

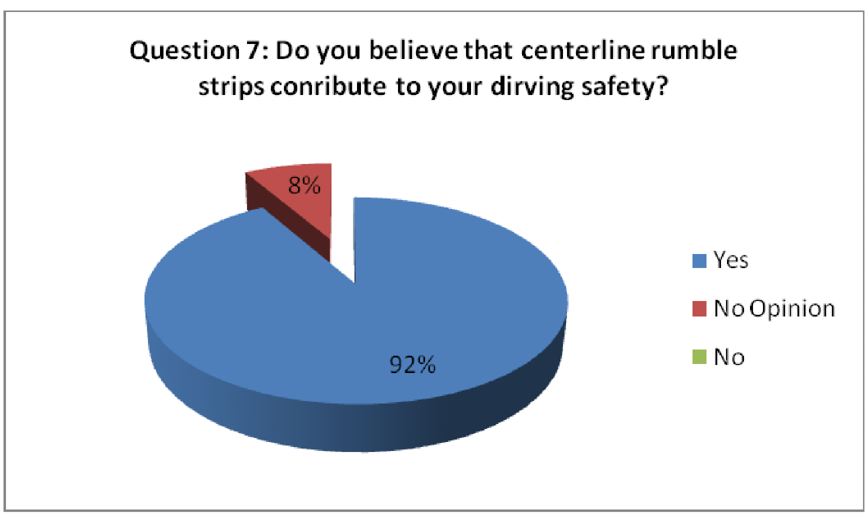

Figure 5.7: Resident response distribution for question 7, resident survey

The resident response distribution shows that 92% (n=11) of residents think that the centerline rumble strips contribute to their driving safety and 8% (n=1) of the residents say they have no opinion. This is a positive response as all of the residents believe that CLRS will contribute to their driving safety. From the results of the survey sent out in January 2006 to the residents of US 40 highway, 16 % of the residents responded said that centerline rumble strips do not contribute to drivers safety.

Question 8: Do you believe the potential safety effect is worth some level of annoying noise?

The residents were asked to answer yes, no or no opinion for the question 8 of the survey. The response distribution of the residents is shown in Figure 5.8.

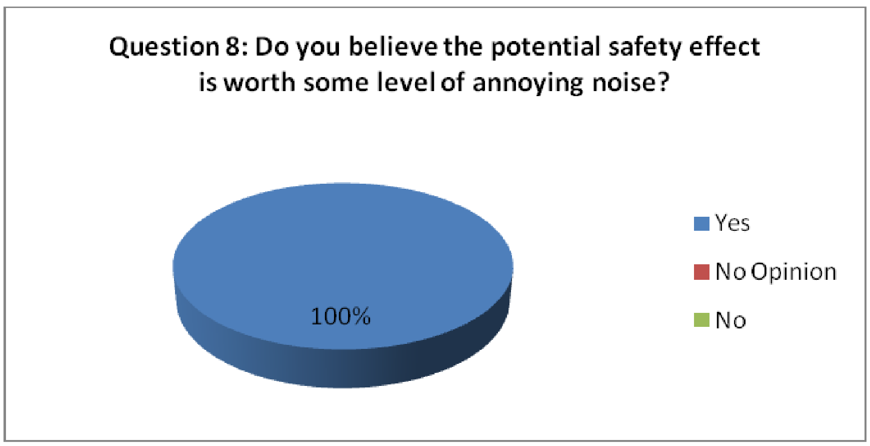

Figure 5.8: Resident response distribution for question 8, resident survey

From the resident response distribution graph for question 8, it can be seen that 100% (n=12) of the residents believed that potential safety is worth some level of annoying noise. This is a positive response as it helps in future research regarding the CLRS on undivided highways.

5.2 Additional Comments

Respondents were also asked to write any additional comments about the centerline rumble strips and the noise produced from driving over them. The following are the additional comments.

- ✓ *"I believe that rumble strips are a helpful safety factor. I would like to see them on many 2 lane highways."*

- ✓ *“I think the rumble strips are a good thing to have.”*
- ✓ *“One of the best things that ever happened. It is a safety factor, it helps.”*
- ✓ *“We appreciate the rumble strips. It definitely makes you aware you are driving a little carelessly when you venture onto it.”*
- ✓ *“Those strips have already saved my life more than once and I have only lived here two months.”*
- ✓ *“Rumble strips really help staying in the same lane on two way highways.”*

5.3 Discussion

According to the resident survey results, 90 % (n = 11) of the respondents think that the noise generated from the vehicles crossing over centerline rumble strips was noticeable but not a concern to them. Also, it was evident that none of the respondents to the resident survey responded that they heard the noise from vehicles crossing CLRS more than 10 times a day. Also, 100% of the respondents (n = 12) said that CLRS contribute to drivers safety and also that they believe the potential safety effect is worth some level of annoying noise. Therefore, it can be concluded that majority of the residents on US 40 highway believed that installation of centerline rumble strips was a positive step taken to ensure the drivers’ safety. When compared to a similar survey results conducted by a Kansas State University CLRS research team during January 2006, the percentage of residents who believed that installation is a good safety measure increased substantially over the past three and a half years and that the residents are getting used to CLRS, and the number of residents paying attention to or concerned over noise produced by the CLRS has decreased over the past three and a half years.

CHAPTER 6 - Conclusions and Future Work

6.1 Conclusions

Based on the literature review and the overall results in chapter 4, it can be concluded that the change in the noise levels produced by vehicles traveling over CLRS compared to that of noise levels produced when vehicles travel on the smooth pavement, for both football CLRS and rectangular CLRS is enough to cause a noticeable increase to a normal human at a distance of up to 150 feet from the centerline of the pavement.

From the results in chapter 4, the change in noise levels for the Taurus travelling at a speed of 40 mph at a distance of 150 feet from the centerline was measured as 3.2 dB and 3.0 dB respectively for football CLRS and rectangular CLRS. For the rest of the scenarios; the Taurus at 65 mph, the Chevrolet van at 40 mph and 65 mph, the change in the noise levels at a distance of 150 feet was measured to be greater than 7 dB for both football and rectangular CLRS. Based on the literature review in chapter 2, a change of over 5 dB is enough for a normal human ear to notice the change and being disturbed.

The maximum noise levels for the Chevrolet van travelling at a speed of 65 mph over CLRS ranges from 88 dB to 80 dB at 50 feet, 77 to 73 dB at 100 feet and 75 to 69 dB at 150 feet for the football CLRS and for the rectangular CLRS, the maximum noise levels for Chevrolet van at 65 mph range between 85 to 78 dB at 50 feet, 77 to 70 dB at 100 feet and 71 to 64 dB at 150 feet distance.

The maximum noise levels for the Taurus travelling at 65 mph over CLRS ranges between 78 to 75 dB at 50 feet, 71 dB to 68 dB at 100 feet and 67 to 65 dB at 150 feet for football CLRS and for the Taurus traveling at a speed of 65 mph over rectangular CLRS, the maximum noise levels range between 83 to 76 dB at 50 feet, 76 to 70 dB at 100 feet and 71 to 63 dB at 150 feet distance from the center of the pavement.

It is observed that both football CLRS and rectangular CLRS increase the noise levels generated by vehicles when passing over CLRS. The lower the speed of the vehicles travelling over CLRS, the lower the noise generated. It was also observed that the noise levels decrease as the distance is increased from the CLRS. Based on the two test vehicles chosen, it is believed that heavier vehicles have a tendency to produce higher noise levels compared to smaller vehicles. It was also observed that noise levels generated by semi-trucks travelling at a speed of 65 mph over smooth pavement are higher than the noise levels generated by the test vehicles at a speed of 65 mph over CLRS.

6.2 Future Research

For future work, there are several areas which could be researched. The noise measurement at distances over 150 feet can be determined to find a point where the noise from CLRS is same as the noise from the smooth pavement. Research can be done taking into account the natural and artificial noise barriers along the highways with CLRS. Also, measurements can be taken on different pavement types. More detailed research could be conducted on measuring and analyzing external noise produced by semi-trucks travelling over CLRS. Research can be done on predicting a minimum distance away from the highway for constructing a house, based on the noise measured from semi-trucks.

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APPENDIX A

Figure A1: Experimental setup; Ex-Tech sound level meter and Sony camcorder

Figure A2: Position of sound level meter with respect to the highway.

APPENDIX B

Loc	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Avergae	Dist (feet)
1	US-50	Chase	Taurus	40	FRS	63.5	64.56		50
1	US-50	Chase	Taurus	40	FRS	69.8	70.86	67.72	50
1	US-50	Chase	Taurus	40	FRS	66.7	67.76		50
1	US-50	Chase	Taurus	40	Smooth	64.9	65.65		50
1	US-50	Chase	Taurus	40	Smooth	64	65.06	65.59	50
1	US-50	Chase	Taurus	40	Smooth	65	66.06		50
1	US-50	Chase	Taurus	65	FRS	77.7	78.45		50
1	US-50	Chase	Taurus	65	FRS	77.5	78.25	76.09	50
1	US-50	Chase	Taurus	65	FRS	70.8	71.55		50
1	US-50	Chase	Taurus	65	Smooth	71.8	72.55		50
1	US-50	Chase	Taurus	65	Smooth	68.1	69.16	71.59	50
1	US-50	Chase	Taurus	65	Smooth	72	73.06		50
1	US-50	Chase	Van	40	FRS	66.3	67.05		50
1	US-50	Chase	Van	40	FRS	69.8	70.86	69.62	50
1	US-50	Chase	Van	40	FRS	69.9	70.96		50
1	US-50	Chase	Van	40	Smooth	65.9	66.65		50
1	US-50	Chase	Van	40	Smooth	68.3	69.36	66.35	50
1	US-50	Chase	Van	40	Smooth	62	63.06		50
1	US-50	Chase	Van	65	FRS	84.9	85.65		50
1	US-50	Chase	Van	65	FRS	77.6	78.66	80.72	50
1	US-50	Chase	Van	65	FRS	76.8	77.86		50
1	US-50	Chase	Van	65	Smooth	74.9	75.65		50
1	US-50	Chase	Van	65	Smooth	73.7	74.45	74.92	50
1	US-50	Chase	Van	65	Smooth	73.9	74.65		50

Table B1 Data sheet for football CLRS, US 50 chase county at 50 feet distance

Loc	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Avergae	Dist (feet)
1	US-50	Chase	Taurus	40	FRS	58.2	59.26		100
1	US-50	Chase	Taurus	40	FRS	55.5	56.56	58.42	100
1	US-50	Chase	Taurus	40	FRS	58.4	59.46		100
1	US-50	Chase	Taurus	40	Smooth	57.5	58.25		100
1	US-50	Chase	Taurus	40	Smooth	58	59.06	58.55	100
1	US-50	Chase	Taurus	40	Smooth	57.3	58.36		100
1	US-50	Chase	Taurus	65	FRS	73	73.75		100
1	US-50	Chase	Taurus	65	FRS			73.25	100
1	US-50	Chase	Taurus	65	FRS	72	72.75		100
1	US-50	Chase	Taurus	65	Smooth				100
1	US-50	Chase	Taurus	65	Smooth	61	62.06	62.51	100
1	US-50	Chase	Taurus	65	Smooth	61.9	62.96		100
1	US-50	Chase	Van	40	FRS	61.5	62.25		100
1	US-50	Chase	Van	40	FRS	62.8	63.86	63.52	100
1	US-50	Chase	Van	40	FRS	63.4	64.46		100
1	US-50	Chase	Van	40	Smooth	58.1	58.85		100
1	US-50	Chase	Van	40	Smooth	63	64.06	61.99	100
1	US-50	Chase	Van	40	Smooth	62	63.06		100
1	US-50	Chase	Van	65	FRS	74	74.75		100
1	US-50	Chase	Van	65	FRS	73.2	74.26	74.55	100
1	US-50	Chase	Van	65	FRS	73.6	74.66		100
1	US-50	Chase	Van	65	Smooth				100
1	US-50	Chase	Van	65	Smooth	66.1	66.85	67.35	100
1	US-50	Chase	Van	65	Smooth	67.1	67.85		100

Table B2 Data sheet for football CLRS, US 50 chase county at 100 feet distance

Loc	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Avergae	Dist (feet)
1	US-50	Chase	Taurus	40	FRS	51.8	52.86		150
1	US-50	Chase	Taurus	40	FRS	54.4	55.46	53.29	150
1	US-50	Chase	Taurus	40	FRS	50.5	51.56		150
1	US-50	Chase	Taurus	40	Smooth	55.4	56.15		150
1	US-50	Chase	Taurus	40	Smooth	48.1	49.16	52.79	150
1	US-50	Chase	Taurus	40	Smooth	52	53.06		150
1	US-50	Chase	Taurus	65	FRS	67.4	68.15		150
1	US-50	Chase	Taurus	65	FRS	63.9	64.65	64.45	150
1	US-50	Chase	Taurus	65	FRS	59.8	60.55		150
1	US-50	Chase	Taurus	65	Smooth				150
1	US-50	Chase	Taurus	65	Smooth	54.2	55.26	53.91	150
1	US-50	Chase	Taurus	65	Smooth	51.5	52.56		150
1	US-50	Chase	Van	40	FRS	55.3	56.05		150
1	US-50	Chase	Van	40	FRS	56	57.06	55.95	150
1	US-50	Chase	Van	40	FRS	53.7	54.76		150
1	US-50	Chase	Van	40	Smooth	60.6	61.35		150
1	US-50	Chase	Van	40	Smooth	51.7	52.76	55.79	150
1	US-50	Chase	Van	40	Smooth	52.2	53.26		150
1	US-50	Chase	Van	65	FRS	70.4	71.15		150
1	US-50	Chase	Van	65	FRS	61.6	62.66	63.52	150
1	US-50	Chase	Van	65	FRS	55.7	56.76		150
1	US-50	Chase	Van	65	Smooth	59.6	60.35		150
1	US-50	Chase	Van	65	Smooth	57.4	58.15	58.42	150
1	US-50	Chase	Van	65	Smooth	56	56.75		150

Table B3 Data sheet for football CLRS, US 50 Chase County at 150 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
7	KS 156	Ellsworth	Taurus	40	RS	68.1	67.6		50
7	KS 156	Ellsworth	Taurus	40	RS	68.5	68.0	67.9	50
7	KS 156	Ellsworth	Taurus	40	RS	68.6	68.1		50
7	KS 156	Ellsworth	Taurus	40	Smooth	65	64.5		50
7	KS 156	Ellsworth	Taurus	40	Smooth	70.2	69.7	68.4	50
7	KS 156	Ellsworth	Taurus	40	Smooth	71.5	70.9		50
7	KS 156	Ellsworth	Taurus	65	RS	76.7	76.2		50
7	KS 156	Ellsworth	Taurus	65	RS	76.8	76.3	75.9	50
7	KS 156	Ellsworth	Taurus	65	RS	75.7	75.2		50
7	KS 156	Ellsworth	Taurus	65	Smooth	71.6	71.1		50
7	KS 156	Ellsworth	Taurus	65	Smooth	71.2	70.7	70.0	50
7	KS 156	Ellsworth	Taurus	65	Smooth	68.7	68.2		50
7	KS 156	Ellsworth	Van	40	RS	71.6	71.1		50
7	KS 156	Ellsworth	Van	40	RS	71.4	70.9	71.5	50
7	KS 156	Ellsworth	Van	40	RS	73	72.5		50
7	KS 156	Ellsworth	Van	40	Smooth	72.5	72.0		50
7	KS 156	Ellsworth	Van	40	Smooth	69.8	69.3	68.4	50
7	KS 156	Ellsworth	Van	40	Smooth	64.3	63.8		50
7	KS 156	Ellsworth	Van	65	RS	79.3	78.8		50
7	KS 156	Ellsworth	Van	65	RS	82	81.5	79.9	50
7	KS 156	Ellsworth	Van	65	RS	79.8	79.3		50
7	KS 156	Ellsworth	Van	65	Smooth	67.9	67.4		50
7	KS 156	Ellsworth	Van	65	Smooth	75.9	75.6	73.4	50
7	KS 156	Ellsworth	Van	65	Smooth	77.8	77.3		50

Table B4 Data sheet for football CLRS, KS 156 Ellsworth county at 50 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
7	KS 156	Ellsworth	Taurus	40	RS	60.5	**60.0**		100
7	KS 156	Ellsworth	Taurus	40	RS	62.2	**61.7**	**61.3**	100
7	KS 156	Ellsworth	Taurus	40	RS	62.6	**62.1**		100
7	KS 156	Ellsworth	Taurus	40	Smooth	57.5	**57.0**		100
7	KS 156	Ellsworth	Taurus	40	Smooth	59.1	**58.6**	**59.6**	100
7	KS 156	Ellsworth	Taurus	40	Smooth	63.7	**63.1**		100
7	KS 156	Ellsworth	Taurus	65	RS	67.1	**66.6**		100
7	KS 156	Ellsworth	Taurus	65	RS	70.6	**70.1**	**68.2**	100
7	KS 156	Ellsworth	Taurus	65	RS	68.2	**67.7**		100
7	KS 156	Ellsworth	Taurus	65	Smooth	64.9	**64.4**		100
7	KS 156	Ellsworth	Taurus	65	Smooth	62.7	**62.2**	**62.3**	100
7	KS 156	Ellsworth	Taurus	65	Smooth	60.8	**60.3**		100
7	KS 156	Ellsworth	Van	40	RS	64.8	**64.3**		100
7	KS 156	Ellsworth	Van	40	RS	65.5	**65.0**	**64.6**	100
7	KS 156	Ellsworth	Van	40	RS	64.8	**64.3**		100
7	KS 156	Ellsworth	Van	40	Smooth	61.2	**60.7**		100
7	KS 156	Ellsworth	Van	40	Smooth	62.8	**62.3**	**60.5**	100
7	KS 156	Ellsworth	Van	40	Smooth	59.1	**58.6**		100
7	KS 156	Ellsworth	Van	65	RS	71.8	**71.3**		100
7	KS 156	Ellsworth	Van	65	RS	73.6	**73.1**	**73.0**	100
7	KS 156	Ellsworth	Van	65	RS	74.9	**74.4**		100
7	KS 156	Ellsworth	Van	65	Smooth	61.6	**61.1**		100
7	KS 156	Ellsworth	Van	65	Smooth	66.8	**66.5**	**65.8**	100
7	KS 156	Ellsworth	Van	65	Smooth	70.4	**69.9**		100

Table B5 Data sheet for football CLRS, KS 156 Ellsworth county at 100 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
7	KS 156	Ellsworth	Taurus	40	RS	56.6	**56.1**		150
7	KS 156	Ellsworth	Taurus	40	RS	53.4	**52.9**	**54.9**	150
7	KS 156	Ellsworth	Taurus	40	RS	56.1	**55.6**		150
7	KS 156	Ellsworth	Taurus	40	Smooth	52.1	**51.6**		150
7	KS 156	Ellsworth	Taurus	40	Smooth	54.6	**54.1**	**53.0**	150
7	KS 156	Ellsworth	Taurus	40	Smooth	54	**53.4**		150
7	KS 156	Ellsworth	Taurus	65	RS	64.4	**63.9**		150
7	KS 156	Ellsworth	Taurus	65	RS	66.9	**66.4**	**65.2**	150
7	KS 156	Ellsworth	Taurus	65	RS	65.7	**65.2**		150
7	KS 156	Ellsworth	Taurus	65	Smooth	59.1	**58.6**		150
7	KS 156	Ellsworth	Taurus	65	Smooth	57.6	**57.1**	**57.9**	150
7	KS 156	Ellsworth	Taurus	65	Smooth	58.5	**58.0**		150
7	KS 156	Ellsworth	Van	40	RS	60.6	**60.1**		150
7	KS 156	Ellsworth	Van	40	RS	59.6	**59.1**	**59.7**	150
7	KS 156	Ellsworth	Van	40	RS	60.2	**59.7**		150
7	KS 156	Ellsworth	Van	40	Smooth	56.8	**56.3**		150
7	KS 156	Ellsworth	Van	40	Smooth	54.8	**54.3**	**54.2**	150
7	KS 156	Ellsworth	Van	40	Smooth	52.4	**51.9**		150
7	KS 156	Ellsworth	Van	65	RS	68.1	**67.6**		150
7	KS 156	Ellsworth	Van	65	RS	69.1	**68.6**	**68.7**	150
7	KS 156	Ellsworth	Van	65	RS	70.2	**69.7**		150
7	KS 156	Ellsworth	Van	65	Smooth	57.8	**57.3**		150
7	KS 156	Ellsworth	Van	65	Smooth	59.3	**59.0**	**58.9**	150
7	KS 156	Ellsworth	Van	65	Smooth	61	**60.5**		150

Table B6 Data sheet for football CLRS, KS 156 Ellsworth county at 150 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
4	HW-36	Doniphan	Taurus	40	RS	63.5	63.9		50
4	HW-36	Doniphan	Taurus	40	RS	66.5	66.7	65.1	50
4	HW-36	Doniphan	Taurus	40	RS	64.2	64.6		50
4	HW-36	Doniphan	Taurus	40	S	54.7	54.7		50
4	HW-36	Doniphan	Taurus	40	S	63.9	64.2	60.4	50
4	HW-36	Doniphan	Taurus	40	S	62	62.4		50
4	HW-36	Doniphan	Taurus	65	RS	78.5	78.8		50
4	HW-36	Doniphan	Taurus	65	RS	77.5	77.7	78.2	50
4	HW-36	Doniphan	Taurus	65	RS	77.8	78.2		50
4	HW-36	Doniphan	Taurus	65	S				50
4	HW-36	Doniphan	Taurus	65	S	69	69.2	69.5	50
4	HW-36	Doniphan	Taurus	65	S	69.4	69.8		50
4	HW-36	Doniphan	Van	40	RS	75.3	75.6		50
4	HW-36	Doniphan	Van	40	RS	71.3	71.7	72.5	50
4	HW-36	Doniphan	Van	40	RS	70.1	70.3		50
4	HW-36	Doniphan	Van	40	S	65.2	65.6		50
4	HW-36	Doniphan	Van	40	S	66.7	67.0	65.3	50
4	HW-36	Doniphan	Van	40	S	63.3	63.4		50
4	HW-36	Doniphan	Van	65	RS	82.9	82.9		50
4	HW-36	Doniphan	Van	65	RS	82.6	82.8	82.4	50
4	HW-36	Doniphan	Van	65	RS	84	84.5		50
4	HW-36	Doniphan	Van	65	S	71.3	71.7		50
4	HW-36	Doniphan	Van	65	S	72.1	72.5	71.0	50
4	HW-36	Doniphan	Van	65	S	68.5	68.9		50

Table B7 Data sheet for football CLRS, KS 36 Doniphan county at 50 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
4	HW-36	Doniphan	Taurus	40	RS	58.8	59.2		100
4	HW-36	Doniphan	Taurus	40	RS	60.3	60.5	59.4	100
4	HW-36	Doniphan	Taurus	40	RS	58.1	58.5		100
4	HW-36	Doniphan	Taurus	40	S	54.7	54.7		100
4	HW-36	Doniphan	Taurus	40	S	58.1	58.4	56.5	100
4	HW-36	Doniphan	Taurus	40	S	56	56.4		100
4	HW-36	Doniphan	Taurus	65	RS	69.8	70.1		100
4	HW-36	Doniphan	Taurus	65	RS	71.4	71.6	71.0	100
4	HW-36	Doniphan	Taurus	65	RS	71	71.4		100
4	HW-36	Doniphan	Taurus	65	S	64.3	64.7		100
4	HW-36	Doniphan	Taurus	65	S	64.5	64.7	64.5	100
4	HW-36	Doniphan	Taurus	65	S	63.6	64.0		100
4	HW-36	Doniphan	Van	40	RS	65	65.3		100
4	HW-36	Doniphan	Van	40	RS	64.9	65.3	64.5	100
4	HW-36	Doniphan	Van	40	RS	62.8	63.0		100
4	HW-36	Doniphan	Van	40	S	60.2	60.6		100
4	HW-36	Doniphan	Van	40	S	58.7	59.0	59.4	100
4	HW-36	Doniphan	Van	40	S	58.7	58.8		100
4	HW-36	Doniphan	Van	65	RS	76.8	76.8		100
4	HW-36	Doniphan	Van	65	RS	74.7	74.9	75.9	100
4	HW-36	Doniphan	Van	65	RS	75.3	75.8		100
4	HW-36	Doniphan	Van	65	S	66.7	67.1		100
4	HW-36	Doniphan	Van	65	S	64.6	65.0	65.9	100
4	HW-36	Doniphan	Van	65	S	65.2	65.6		100

Table B8 Data sheet for football CLRS, KS 36 Doniphan county at 100 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
4	HW-36	Doniphan	Taurus	40	RS	53	**53.4**		150
4	HW-36	Doniphan	Taurus	40	RS	54.8	**55.0**	**54.0**	150
4	HW-36	Doniphan	Taurus	40	RS	53.2	**53.6**		150
4	HW-36	Doniphan	Taurus	40	S	47.8	**47.8**		150
4	HW-36	Doniphan	Taurus	40	S	50.5	**50.8**	**49.3**	150
4	HW-36	Doniphan	Taurus	40	S	48.8	**49.2**		150
4	HW-36	Doniphan	Taurus	65	RS	64.2	**64.5**		150
4	HW-36	Doniphan	Taurus	65	RS	64.9	**65.1**	**65.1**	150
4	HW-36	Doniphan	Taurus	65	RS	65.2	**65.6**		150
4	HW-36	Doniphan	Taurus	65	S	57.4	**57.8**		150
4	HW-36	Doniphan	Taurus	65	S	58.3	**58.5**	**57.5**	150
4	HW-36	Doniphan	Taurus	65	S	55.7	**56.1**		150
4	HW-36	Doniphan	Van	40	RS	59.5	**59.8**		150
4	HW-36	Doniphan	Van	40	RS	59.1	**59.5**	**59.4**	150
4	HW-36	Doniphan	Van	40	RS	58.9	**59.1**		150
4	HW-36	Doniphan	Van	40	S	52.8	**53.2**		150
4	HW-36	Doniphan	Van	40	S	52.8	**53.1**	**53.0**	150
4	HW-36	Doniphan	Van	40	S	52.6	**52.7**		150
4	HW-36	Doniphan	Van	65	RS	71	**71.0**		150
4	HW-36	Doniphan	Van	65	RS	70.7	**70.9**	**70.4**	150
4	HW-36	Doniphan	Van	65	RS	68.8	**69.3**		150
4	HW-36	Doniphan	Van	65	S	60.8	**61.2**		150
4	HW-36	Doniphan	Van	65	S	56.8	**57.2**	**58.4**	150
4	HW-36	Doniphan	Van	65	S	56.4	**56.8**		150

Table B9 Data sheet for football CLRS, KS 36 Doniphan county at 150 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
9	US-50	Reno	Van	40	RS	66.4	**66.1**		50
9	US-50	Reno	Van	40	RS	73.3	**73.0**	**72.2**	50
9	US-50	Reno	Van	40	RS	77.8	**77.5**		50
9	US-50	Reno	Van	40	Smooth	68.1	**67.8**		50
9	US-50	Reno	Van	40	Smooth	62.8	**62.5**	**66.3**	50
9	US-50	Reno	Van	40	Smooth	68.5	**68.5**		50
9	US-50	Reno	Van	65	RS	89.8	**89.8**		50
9	US-50	Reno	Van	65	RS	85.4	**85.4**	**88.6**	50
9	US-50	Reno	Van	65	RS	91.1	**90.7**		50
9	US-50	Reno	Van	65	Smooth	69.6	**69.6**		50
9	US-50	Reno	Van	65	Smooth	70.2	**70.2**	**69.3**	50
9	US-50	Reno	Van	65	Smooth	68.5	**68.1**		50
9	US-50	Reno	Taurus	40	RS	69.1	**69.1**		50
9	US-50	Reno	Taurus	40	RS	66.7	**66.7**	**67.0**	50
9	US-50	Reno	Taurus	40	RS	65.4	**65.1**		50
9	US-50	Reno	Taurus	40	Smooth	64.5	**64.5**		50
9	US-50	Reno	Taurus	40	Smooth	63.2	**63.2**	**64.0**	50
9	US-50	Reno	Taurus	40	Smooth	64.5	**64.2**		50
9	US-50	Reno	Taurus	65	RS	76.5	**76.1**		50
9	US-50	Reno	Taurus	65	RS	79.4	**79.4**	**74.8**	50
9	US-50	Reno	Taurus	65	RS	68.9	**68.9**		50
9	US-50	Reno	Taurus	65	Smooth	68.7	**68.3**		50
9	US-50	Reno	Taurus	65	Smooth	70.2	**70.2**	**68.7**	50
9	US-50	Reno	Taurus	65	Smooth	67.9	**67.6**		50

Table B10 Data sheet for football CLRS, US 50 Reno county at 50 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
9	US-50	Reno	Van	40	RS	72.2	**71.9**		100
9	US-50	Reno	Van	40	RS	68.4	**68.1**	**69.6**	100
9	US-50	Reno	Van	40	RS	69	**68.7**		100
9	US-50	Reno	Van	40	Smooth	61.9	**61.6**		100
9	US-50	Reno	Van	40	Smooth	59.1	**58.8**	**60.8**	100
9	US-50	Reno	Van	40	Smooth	61.9	**61.9**		100
9	US-50	Reno	Van	65	RS	78.1	**78.1**		100
9	US-50	Reno	Van	65	RS	76.2	**76.2**	**76.7**	100
9	US-50	Reno	Van	65	RS	76.3	**75.9**		100
9	US-50	Reno	Van	65	Smooth	61.2	**61.2**		100
9	US-50	Reno	Van	65	Smooth	62.8	**62.8**	**60.8**	100
9	US-50	Reno	Van	65	Smooth	58.9	**58.5**		100
9	US-50	Reno	Taurus	40	RS	61	**61.0**		100
9	US-50	Reno	Taurus	40	RS	61.4	**61.4**	**60.3**	100
9	US-50	Reno	Taurus	40	RS	58.7	**58.4**		100
9	US-50	Reno	Taurus	40	Smooth	56.6	**56.6**		100
9	US-50	Reno	Taurus	40	Smooth	53	**53.0**	**54.0**	100
9	US-50	Reno	Taurus	40	Smooth	52.8	**52.5**		100
9	US-50	Reno	Taurus	65	RS	67.7	**67.3**		100
9	US-50	Reno	Taurus	65	RS	69.2	**69.2**	**68.0**	100
9	US-50	Reno	Taurus	65	RS	67.5	**67.5**		100
9	US-50	Reno	Taurus	65	Smooth	60.9	**60.5**		100
9	US-50	Reno	Taurus	65	Smooth	62.4	**62.4**	**61.8**	100
9	US-50	Reno	Taurus	65	Smooth	62.9	**62.6**		100

Table B11 Data sheet for football CLRS, US 50 Reno county at 100 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
9	US-50	Reno	Van	40	RS	68.3	**68.0**		150
9	US-50	Reno	Van	40	RS	60.9	**60.6**	**64.5**	150
9	US-50	Reno	Van	40	RS	65.2	**64.9**		150
9	US-50	Reno	Van	40	Smooth	55.6	**55.3**		150
9	US-50	Reno	Van	40	Smooth	52.2	**51.9**	**56.5**	150
9	US-50	Reno	Van	40	Smooth	62.1	**62.1**		150
9	US-50	Reno	Van	65	RS	72	**72.0**		150
9	US-50	Reno	Van	65	RS	73.6	**73.6**	**74.9**	150
9	US-50	Reno	Van	65	RS	79.6	**79.2**		150
9	US-50	Reno	Van	65	Smooth	56.6	**56.6**		150
9	US-50	Reno	Van	65	Smooth	58	**58.0**	**56.2**	150
9	US-50	Reno	Van	65	Smooth	54.3	**53.9**		150
9	US-50	Reno	Taurus	40	RS	59.4	**59.4**		150
9	US-50	Reno	Taurus	40	RS	53.4	**53.4**	**56.2**	150
9	US-50	Reno	Taurus	40	RS	56.2	**55.9**		150
9	US-50	Reno	Taurus	40	Smooth	51.3	**51.3**		150
9	US-50	Reno	Taurus	40	Smooth	51.1	**51.1**	**50.4**	150
9	US-50	Reno	Taurus	40	Smooth	49.1	**48.8**		150
9	US-50	Reno	Taurus	65	RS	66.3	**65.9**		150
9	US-50	Reno	Taurus	65	RS	65	**65.0**	**65.0**	150
9	US-50	Reno	Taurus	65	RS	64	**64.0**		150
9	US-50	Reno	Taurus	65	Smooth	53	**52.6**		150
9	US-50	Reno	Taurus	65	Smooth	56.2	**56.2**	**55.5**	150
9	US-50	Reno	Taurus	65	Smooth	57.9	**57.6**		150

Table B12 Data sheet for football CLRS, US 50 Reno county at 150 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
2	US-50	Chase	Taurus	40	RRS	72.4	**71.01**		50
2	US-50	Chase	Taurus	40	RRS	72.2	**70.81**	**70.18**	50
2	US-50	Chase	Taurus	40	RRS	70.1	**68.71**		50
2	US-50	Chase	Taurus	40	Smooth	68.6	**67.21**		50
2	US-50	Chase	Taurus	40	Smooth	66.4	**65.01**	**66.81**	50
2	US-50	Chase	Taurus	40	Smooth	69.6	**68.21**		50
2	US-50	Chase	Taurus	65	RRS	84.7	**83.37**		50
2	US-50	Chase	Taurus	65	RRS	88.6	**87.21**	**80.26**	50
2	US-50	Chase	Taurus	65	RRS	71.6	**70.21**		50
2	US-50	Chase	Taurus	65	Smooth	72.8	**71.47**		50
2	US-50	Chase	Taurus	65	Smooth	73.1	**71.71**	**71.13**	50
2	US-50	Chase	Taurus	65	Smooth	71.6	**70.21**		50
2	US-50	Chase	Van	40	RRS	80.8	**79.41**		50
2	US-50	Chase	Van	40	RRS	72.9	**71.51**	**73.91**	50
2	US-50	Chase	Van	40	RRS	72.2	**70.81**		50
2	US-50	Chase	Van	40	Smooth	69.5	**68.11**		50
2	US-50	Chase	Van	40	Smooth	65.9	**64.51**	**66.11**	50
2	US-50	Chase	Van	40	Smooth	67.1	**65.71**		50
2	US-50	Chase	Van	65	RRS	77.7	**76.31**		50
2	US-50	Chase	Van	65	RRS	82.1	**80.71**	**80.18**	50
2	US-50	Chase	Van	65	RRS	84.9	**83.51**		50
2	US-50	Chase	Van	65	Smooth	74.9	**73.51**		50
2	US-50	Chase	Van	65	Smooth	75.7	**74.31**	**73.51**	50
2	US-50	Chase	Van	65	Smooth	74.1	**72.71**		50

Table B13 Data sheet for rectangular CLRS, US 50 Chase county at 50 feet distance

Loc	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Avergae	Dist (feet)
2	US-50	Chase	Taurus	40	RRS	67.9	**66.51**		100
2	US-50	Chase	Taurus	40	RRS	65.7	**64.31**	**66.11**	100
2	US-50	Chase	Taurus	40	RRS	68.9	**67.51**		100
2	US-50	Chase	Taurus	40	Smooth				100
2	US-50	Chase	Taurus	40	Smooth	62.2	**60.81**	**60.81**	100
2	US-50	Chase	Taurus	40	Smooth				100
2	US-50	Chase	Taurus	65	RRS	75.1	**73.71**		100
2	US-50	Chase	Taurus	65	RRS	80.4	**79.01**	**76.36**	100
2	US-50	Chase	Taurus	65	RRS				100
2	US-50	Chase	Taurus	65	Smooth				100
2	US-50	Chase	Taurus	65	Smooth				100
2	US-50	Chase	Taurus	65	Smooth				100
2	US-50	Chase	Van	40	RRS	77.6	**76.21**		100
2	US-50	Chase	Van	40	RRS	69.9	**68.51**	**70.65**	100
2	US-50	Chase	Van	40	RRS	68.6	**67.21**		100
2	US-50	Chase	Van	40	Smooth				100
2	US-50	Chase	Van	40	Smooth				100
2	US-50	Chase	Van	40	Smooth				100
2	US-50	Chase	Van	65	RRS	75.5	**74.11**		100
2	US-50	Chase	Van	65	RRS	77.9	**76.57**	**75.34**	100
2	US-50	Chase	Van	65	RRS				100
2	US-50	Chase	Van	65	Smooth	69.2	**67.81**		100
2	US-50	Chase	Van	65	Smooth			**67.81**	100
2	US-50	Chase	Van	65	Smooth				100

Table B14 Data sheet for rectangular CLRS, US 50 Chase County at 100 feet distance

Loc	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Avergae	Dist (feet)
2	US-50	Chase	Taurus	40	RRS	59.6	**58.21**		150
2	US-50	Chase	Taurus	40	RRS	60.7	**59.31**	**59.91**	150
2	US-50	Chase	Taurus	40	RRS	63.6	**62.21**		150
2	US-50	Chase	Taurus	40	Smooth	57	**55.61**		150
2	US-50	Chase	Taurus	40	Smooth	57.1	**55.71**	**55.31**	150
2	US-50	Chase	Taurus	40	Smooth	56	**54.61**		150
2	US-50	Chase	Taurus	65	RRS	67.9	**66.57**		150
2	US-50	Chase	Taurus	65	RRS	76.4	**75.01**	**66.66**	150
2	US-50	Chase	Taurus	65	RRS	59.8	**58.41**		150
2	US-50	Chase	Taurus	65	Smooth	59.3	**57.97**		150
2	US-50	Chase	Taurus	65	Smooth	59.1	**57.71**	**57.03**	150
2	US-50	Chase	Taurus	65	Smooth	56.8	**55.41**		150
2	US-50	Chase	Van	40	RRS	72.8	**71.47**		150
2	US-50	Chase	Van	40	RRS	60.9	**59.57**	**63.75**	150
2	US-50	Chase	Van	40	RRS	61.6	**60.21**		150
2	US-50	Chase	Van	40	Smooth	58.5	**57.17**		150
2	US-50	Chase	Van	40	Smooth	56.1	**54.71**	**55.16**	150
2	US-50	Chase	Van	40	Smooth	55	**53.61**		150
2	US-50	Chase	Van	65	RRS	68	**66.67**		150
2	US-50	Chase	Van	65	RRS	72.5	**71.11**	**68.46**	150
2	US-50	Chase	Van	65	RRS	69	**67.61**		150
2	US-50	Chase	Van	65	Smooth	61.6	**60.27**		150
2	US-50	Chase	Van	65	Smooth	62	**60.67**	**60.91**	150
2	US-50	Chase	Van	65	Smooth	63.2	**61.81**		150

Table B15 Data sheet for rectangular CLRS, US 50 Chase County at 150 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
3	US-24	Jeffereson	Van	40	RS	71.7	**71.70**		50
3	US-24	Jeffereson	Van	40	RS	74.3	**74.80**	**74.3**	50
3	US-24	Jeffereson	Van	40	RS	75.9	**76.40**		50
3	US-24	Jeffereson	Van	40	Smooth	63.5	**64.00**		50
3	US-24	Jeffereson	Van	40	Smooth	61.3	**61.80**	**63.0**	50
3	US-24	Jeffereson	Van	40	Smooth	63	**63.30**		50
3	US-24	Jeffereson	Van	65	RS	83.3	**83.80**		50
3	US-24	Jeffereson	Van	65	RS	84.2	**84.70**	**84.3**	50
3	US-24	Jeffereson	Van	65	RS	84.2	**84.50**		50
3	US-24	Jeffereson	Van	65	Smooth	66.6	**66.89**		50
3	US-24	Jeffereson	Van	65	Smooth	64.8	**65.09**	**65.9**	50
3	US-24	Jeffereson	Van	65	Smooth	65.2	**65.70**		50
3	US-24	Jeffereson	Taurus	40	RS	66.7	**66.99**		50
3	US-24	Jeffereson	Taurus	40	RS	65.9	**66.35**	**66.3**	50
3	US-24	Jeffereson	Taurus	40	RS	65	**65.45**		50
3	US-24	Jeffereson	Taurus	40	Smooth	58.1	**58.55**		50
3	US-24	Jeffereson	Taurus	40	Smooth	59.3	**59.75**	**60.0**	50
3	US-24	Jeffereson	Taurus	40	Smooth	61.4	**61.85**		50
3	US-24	Jeffereson	Taurus	65	RS	77.1	**77.39**		50
3	US-24	Jeffereson	Taurus	65	RS	76.3	**76.59**	**76.0**	50
3	US-24	Jeffereson	Taurus	65	RS	73.7	**74.15**		50
3	US-24	Jeffereson	Taurus	65	Smooth	65.2	**65.49**		50
3	US-24	Jeffereson	Taurus	65	Smooth	67.3	**67.59**	**66.8**	50
3	US-24	Jeffereson	Taurus	65	Smooth	67.1	**67.39**		50

Table B16 Data sheet for rectangular CLRS, US 24 Jefferson County at 50 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
3	US-24	Jefferson	Van	40	RS	66.8	**66.80**	**69.2**	100
3	US-24	Jefferson	Van	40	RS	70.8	**71.30**		100
3	US-24	Jefferson	Van	40	RS	69.1	**69.60**		100
3	US-24	Jefferson	Van	40	Smooth	56.5	**57.00**	**55.8**	100
3	US-24	Jefferson	Van	40	Smooth	53.3	**53.80**		100
3	US-24	Jefferson	Van	40	Smooth	56.2	**56.50**		100
3	US-24	Jefferson	Van	65	RS	74.8	**75.30**	**76.3**	100
3	US-24	Jefferson	Van	65	RS	76.4	**76.90**		100
3	US-24	Jefferson	Van	65	RS	76.5	**76.80**		100
3	US-24	Jefferson	Van	65	Smooth	64	**64.29**	**61.7**	100
3	US-24	Jefferson	Van	65	Smooth	61.4	**61.69**		100
3	US-24	Jefferson	Van	65	Smooth	58.5	**59.00**		100
3	US-24	Jefferson	Taurus	40	RS	60.2	**60.49**	**59.6**	100
3	US-24	Jefferson	Taurus	40	RS	60.2	**60.65**		100
3	US-24	Jefferson	Taurus	40	RS	57.3	**57.75**		100
3	US-24	Jefferson	Taurus	40	Smooth	54	**54.45**	**53.9**	100
3	US-24	Jefferson	Taurus	40	Smooth	51.5	**51.95**		100
3	US-24	Jefferson	Taurus	40	Smooth	55	**55.45**		100
3	US-24	Jefferson	Taurus	65	RS	69.4	**69.69**	**69.4**	100
3	US-24	Jefferson	Taurus	65	RS	68.1	**68.39**		100
3	US-24	Jefferson	Taurus	65	RS	69.8	**70.25**		100
3	US-24	Jefferson	Taurus	65	Smooth	58	**58.29**	**59.7**	100
3	US-24	Jefferson	Taurus	65	Smooth	60.9	**61.19**		100
3	US-24	Jefferson	Taurus	65	Smooth	59.2	**59.49**		100

Table B17 Data sheet for rectangular CLRS, US 24 Jefferson County at 100 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
3	US-24	Jefferson	Van	40	RS	60.9	**60.90**	**62.7**	150
3	US-24	Jefferson	Van	40	RS	64	**64.50**		150
3	US-24	Jefferson	Van	40	RS	62.3	**62.80**		150
3	US-24	Jefferson	Van	40	Smooth	55.4	**55.90**	**54.1**	150
3	US-24	Jefferson	Van	40	Smooth	50.9	**51.40**		150
3	US-24	Jefferson	Van	40	Smooth	54.8	**55.10**		150
3	US-24	Jefferson	Van	65	RS	69.5	**70.00**	**71.0**	150
3	US-24	Jefferson	Van	65	RS	71.5	**72.00**		150
3	US-24	Jefferson	Van	65	RS	70.8	**71.10**		150
3	US-24	Jefferson	Van	65	Smooth	59.3	**59.59**	**58.2**	150
3	US-24	Jefferson	Van	65	Smooth	59.5	**59.79**		150
3	US-24	Jefferson	Van	65	Smooth	54.6	**55.10**		150
3	US-24	Jefferson	Taurus	40	RS	54	**54.29**	**54.0**	150
3	US-24	Jefferson	Taurus	40	RS	54.1	**54.55**		150
3	US-24	Jefferson	Taurus	40	RS	52.7	**53.15**		150
3	US-24	Jefferson	Taurus	40	Smooth	52.8	**53.25**	**52.4**	150
3	US-24	Jefferson	Taurus	40	Smooth	50.5	**50.95**		150
3	US-24	Jefferson	Taurus	40	Smooth	52.5	**52.95**		150
3	US-24	Jefferson	Taurus	65	RS	64.3	**64.59**	**63.2**	150
3	US-24	Jefferson	Taurus	65	RS	61.2	**61.49**		150
3	US-24	Jefferson	Taurus	65	RS	63.1	**63.55**		150
3	US-24	Jefferson	Taurus	65	Smooth	52.7	**52.99**	**54.1**	150
3	US-24	Jefferson	Taurus	65	Smooth	54.4	**54.69**		150
3	US-24	Jefferson	Taurus	65	Smooth	54.3	**54.59**		150

Table B18 Data sheet for rectangular CLRS, US 24 Jefferson County at 150 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
5	US 75	Brown	Taurus	40	RS	65.7	**66.0**		50
5	US 75	Brown	Taurus	40	RS	64.8	**65.1**	**63.8**	50
5	US 75	Brown	Taurus	40	RS	60.1	**60.4**		50
5	US 75	Brown	Taurus	40	Smooth	56	**56.4**		50
5	US 75	Brown	Taurus	40	Smooth	58.1	**58.3**	**57.8**	50
5	US 75	Brown	Taurus	40	Smooth	58.5	**58.7**		50
5	US 75	Brown	Taurus	65	RS	79.8	**80.1**		50
5	US 75	Brown	Taurus	65	RS	81.8	**82.0**	**81.1**	50
5	US 75	Brown	Taurus	65	RS	81.2	**81.3**		50
5	US 75	Brown	Taurus	65	Smooth	66.4	**66.8**		50
5	US 75	Brown	Taurus	65	Smooth	66.9	**67.1**	**66.5**	50
5	US 75	Brown	Taurus	65	Smooth	65.2	**65.4**		50
5	US 75	Brown	Van	40	RS	77.8	**78.1**		50
5	US 75	Brown	Van	40	RS	71.8	**71.9**	**75.2**	50
5	US 75	Brown	Van	40	RS	75.5	**75.7**		50
5	US 75	Brown	Van	40	Smooth	59	**59.1**		50
5	US 75	Brown	Van	40	Smooth	63.6	**64.1**	**62.4**	50
5	US 75	Brown	Van	40	Smooth	63.9	**64.1**		50
5	US 75	Brown	Van	65	RS	81.9	**82.1**		50
5	US 75	Brown	Van	65	RS	83.7	**83.9**	**83.6**	50
5	US 75	Brown	Van	65	RS	84.7	**84.7**		50
5	US 75	Brown	Van	65	Smooth	71.2	**71.4**		50
5	US 75	Brown	Van	65	Smooth	71.7	**72.2**	**70.2**	50
5	US 75	Brown	Van	65	Smooth	67.1	**67.1**		50

Table B19 Data sheet for rectangular CLRS, US 75 Brown County at 50 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
5	US 75	Brown	Taurus	40	RS	57.3	**57.6**		100
5	US 75	Brown	Taurus	40	RS	56.1	**56.4**	**57.4**	100
5	US 75	Brown	Taurus	40	RS	58	**58.3**		100
5	US 75	Brown	Taurus	40	Smooth	55.4	**55.8**		100
5	US 75	Brown	Taurus	40	Smooth	51.1	**51.3**	**52.8**	100
5	US 75	Brown	Taurus	40	Smooth	51	**51.2**		100
5	US 75	Brown	Taurus	65	RS	70.2	**70.5**		100
5	US 75	Brown	Taurus	65	RS	73	**73.2**	**72.3**	100
5	US 75	Brown	Taurus	65	RS	73	**73.1**		100
5	US 75	Brown	Taurus	65	Smooth	59.6	**60.0**		100
5	US 75	Brown	Taurus	65	Smooth	58.5	**58.7**	**58.6**	100
5	US 75	Brown	Taurus	65	Smooth	56.8	**57.0**		100
5	US 75	Brown	Van	40	RS	70.4	**70.7**		100
5	US 75	Brown	Van	40	RS	65.7	**65.8**	**68.1**	100
5	US 75	Brown	Van	40	RS	67.6	**67.8**		100
5	US 75	Brown	Van	40	Smooth	52.1	**52.2**		100
5	US 75	Brown	Van	40	Smooth	57.7	**58.2**	**55.8**	100
5	US 75	Brown	Van	40	Smooth	56.9	**57.1**		100
5	US 75	Brown	Van	65	RS	74	**74.2**		100
5	US 75	Brown	Van	65	RS	76.9	**77.1**	**75.4**	100
5	US 75	Brown	Van	65	RS	74.9	**74.9**		100
5	US 75	Brown	Van	65	Smooth	64.5	**64.7**		100
5	US 75	Brown	Van	65	Smooth	64.6	**65.1**	**64.1**	100
5	US 75	Brown	Van	65	Smooth	62.6	**62.6**		100

Table B20 Data sheet for rectangular CLRS, US 75 Brown County at 100 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
5	US 75	Brown	Taurus	40	RS	71.2	**71.5**	**69.7**	150
5	US 75	Brown	Taurus	40	RS	70.2	**70.5**		150
5	US 75	Brown	Taurus	40	RS	66.8	**67.1**		150
5	US 75	Brown	Taurus	40	Smooth	70.6	**71.0**	**66.0**	150
5	US 75	Brown	Taurus	40	Smooth	63.6	**63.8**		150
5	US 75	Brown	Taurus	40	Smooth	63	**63.2**		150
5	US 75	Brown	Taurus	65	RS	77.8	**78.1**	**78.9**	150
5	US 75	Brown	Taurus	65	RS	79.2	**79.4**		150
5	US 75	Brown	Taurus	65	RS	79.2	**79.3**		150
5	US 75	Brown	Taurus	65	Smooth	71.6	**72.0**	**66.2**	150
5	US 75	Brown	Taurus	65	Smooth	62.9	**63.1**		150
5	US 75	Brown	Taurus	65	Smooth	63.1	**63.3**		150
5	US 75	Brown	Van	40	RS	70	**70.3**	**74.0**	150
5	US 75	Brown	Van	40	RS	75.6	**75.7**		150
5	US 75	Brown	Van	40	RS	75.9	**76.1**		150
5	US 75	Brown	Van	40	Smooth	59.9	**60.0**	**62.5**	150
5	US 75	Brown	Van	40	Smooth	60.9	**61.4**		150
5	US 75	Brown	Van	40	Smooth	65.8	**66.0**		150
5	US 75	Brown	Van	65	RS	81.2	**81.4**	**81.6**	150
5	US 75	Brown	Van	65	RS	82	**82.2**		150
5	US 75	Brown	Van	65	RS	81.1	**81.1**		150
5	US 75	Brown	Van	65	Smooth	66.3	**66.5**	**65.8**	150
5	US 75	Brown	Van	65	Smooth	67.1	**67.6**		150
5	US 75	Brown	Van	65	Smooth	63.2	**63.2**		150

Table B21 Data sheet for rectangular CLRS, US 75 Brown County at 150 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
8	US-50	Harvey	Taurus	40	RS	59.1	**59.1**	**59.6**	50
8	US-50	Harvey	Taurus	40	RS	61.3	**60.9**		50
8	US-50	Harvey	Taurus	40	RS	58.9	**58.7**		50
8	US-50	Harvey	Taurus	40	Smooth	55	**54.7**	**56.3**	50
8	US-50	Harvey	Taurus	40	Smooth	58.2	**57.9**		50
8	US-50	Harvey	Taurus	40	Smooth	56.7	**56.3**		50
8	US-50	Harvey	Taurus	65	RS	70.2	**70.2**	**71.3**	50
8	US-50	Harvey	Taurus	65	RS	73.1	**73.1**		50
8	US-50	Harvey	Taurus	65	RS	70.6	**70.6**		50
8	US-50	Harvey	Taurus	65	Smooth	64	**64.0**	**64.0**	50
8	US-50	Harvey	Taurus	65	Smooth	63.8	**63.5**		50
8	US-50	Harvey	Taurus	65	Smooth	64.6	**64.4**		50
8	US-50	Harvey	Van	40	RS	66.2	**66.0**	**65.7**	50
8	US-50	Harvey	Van	40	RS	66.2	**66.0**		50
8	US-50	Harvey	Van	40	RS	65.5	**65.3**		50
8	US-50	Harvey	Van	40	Smooth	61	**60.8**	**60.3**	50
8	US-50	Harvey	Van	40	Smooth	62.3	**62.1**		50
8	US-50	Harvey	Van	40	Smooth	58.3	**58.1**		50
8	US-50	Harvey	Van	65	RS	80.8	**80.6**	**74.5**	50
8	US-50	Harvey	Van	65	RS	67.5	**67.3**		50
8	US-50	Harvey	Van	65	RS	75.9	**75.7**		50
8	US-50	Harvey	Van	65	Smooth	65	**64.8**	**66.2**	50
8	US-50	Harvey	Van	65	Smooth	65.1	**64.9**		50
8	US-50	Harvey	Van	65	Smooth	69.1	**68.9**		50

Table B22 Data sheet for rectangular CLRS, US 50 Harvey County at 50 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
8	US-50	Harvey	Taurus	40	RS	54.9	54.9	54.7	100
8	US-50	Harvey	Taurus	40	RS	55.3	54.9		100
8	US-50	Harvey	Taurus	40	RS	54.6	54.4		100
8	US-50	Harvey	Taurus	40	Smooth	51.5	51.2	51.5	100
8	US-50	Harvey	Taurus	40	Smooth	52.2	51.9		100
8	US-50	Harvey	Taurus	40	Smooth	51.8	51.4		100
8	US-50	Harvey	Taurus	65	RS	66.7	66.7	66.8	100
8	US-50	Harvey	Taurus	65	RS	67.6	67.6		100
8	US-50	Harvey	Taurus	65	RS	66.2	66.2		100
8	US-50	Harvey	Taurus	65	Smooth	60.9	60.9	58.6	100
8	US-50	Harvey	Taurus	65	Smooth	57.7	57.4		100
8	US-50	Harvey	Taurus	65	Smooth	57.7	57.5		100
8	US-50	Harvey	Van	40	RS	62.8	62.6	61.5	100
8	US-50	Harvey	Van	40	RS	62.1	61.9		100
8	US-50	Harvey	Van	40	RS	60.3	60.1		100
8	US-50	Harvey	Van	40	Smooth	53	52.8	53.7	100
8	US-50	Harvey	Van	40	Smooth	55.4	55.2		100
8	US-50	Harvey	Van	40	Smooth	53.5	53.3		100
8	US-50	Harvey	Van	65	RS	73.4	73.2	69.6	100
8	US-50	Harvey	Van	65	RS	65.9	65.7		100
8	US-50	Harvey	Van	65	RS	70.2	70.0		100
8	US-50	Harvey	Van	65	Smooth	60.5	60.3	61.0	100
8	US-50	Harvey	Van	65	Smooth	58.6	58.4		100
8	US-50	Harvey	Van	65	Smooth	64.6	64.4		100

Table B23 Data sheet for rectangular CLRS, US 50 Harvey County at 100 feet distance

Location	Highway	County	Vehicle	Speed	Pavement	Max Noise Level (dBA fast response)	Corrected Noise	Average	Distance (feet)
8	US-50	Harvey	Taurus	40	RS	51.9	51.9	49.7	150
8	US-50	Harvey	Taurus	40	RS	48.9	48.5		150
8	US-50	Harvey	Taurus	40	RS	49	48.8		150
8	US-50	Harvey	Taurus	40	Smooth	53.8	53.5	47.3	150
8	US-50	Harvey	Taurus	40	Smooth	44.8	44.5		150
8	US-50	Harvey	Taurus	40	Smooth	44.3	43.9		150
8	US-50	Harvey	Taurus	65	RS	60.7	60.7	61.8	150
8	US-50	Harvey	Taurus	65	RS	63	63.0		150
8	US-50	Harvey	Taurus	65	RS	61.7	61.7		150
8	US-50	Harvey	Taurus	65	Smooth	54	54.0	52.1	150
8	US-50	Harvey	Taurus	65	Smooth	51	50.7		150
8	US-50	Harvey	Taurus	65	Smooth	51.7	51.5		150
8	US-50	Harvey	Van	40	RS	56.6	56.4	55.8	150
8	US-50	Harvey	Van	40	RS	55.9	55.7		150
8	US-50	Harvey	Van	40	RS	55.6	55.4		150
8	US-50	Harvey	Van	40	Smooth	47	46.8	48.4	150
8	US-50	Harvey	Van	40	Smooth	50.4	50.2		150
8	US-50	Harvey	Van	40	Smooth	48.5	48.3		150
8	US-50	Harvey	Van	65	RS	64.2	64.0	62.1	150
8	US-50	Harvey	Van	65	RS	59.7	59.5		150
8	US-50	Harvey	Van	65	RS	63.2	63.0		150
8	US-50	Harvey	Van	65	Smooth	54.8	54.6	55.3	150
8	US-50	Harvey	Van	65	Smooth	54.3	54.1		150
8	US-50	Harvey	Van	65	Smooth	57.4	57.2		150

Table B24 Data sheet for rectangular CLRS, US 50 Harvey County at 150 feet distance

Table B25 Two sample t-test for the Taurus noise levels difference

	CLRS	*Smooth*
Mean	10.2	4.633333333
Variance	0.272	1.514666667
Observations	6	6
Pooled Variance	0.893333333	
Hypothesized Mean Difference	0	
df	10	
t Stat	10.2011486	
P(T<=t) one-tail	6.61974E-07	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	1.32395E-06	
t Critical two-tail	2.228138852	

Table B26 Two sample t-test for the Chevrolet van noise levels difference

	CLRS	*Smooth*
Mean	8.383333333	3.85
Variance	4.581666667	1.051
Observations	6	6
Pooled Variance	2.816333333	
Hypothesized Mean Difference	0	
df	10	
t Stat	4.678819091	
P(T<=t) one-tail	0.000434537	
t Critical one-tail	1.812461123	
P(T<=t) two-tail	0.000869073	
t Critical two-tail	2.228138852	

APPENDIX C

Kansas State University Centerline Rumble Strip Research US 40 Survey:

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1. How many years have you been at the current address? ________________
2. Can you hear any noise of traffic on US 40 from your residence?
   ☐ Yes ☐ No
3. Can you hear from your residence when a driver crosses over (comes in contact with) the centerline rumble strips?
   ☐ Yes (continue to question 4) ☐ No (continue to question 6)
4. Choose one of the following and please comment below:
   The noise is unnoticeable and not a concern. ☐
   The noise is noticeable but not a concern. ☐
   The noise is only inconvenient and annoying. ☐
   The noise produced is loud enough to cause a concern or a distraction. ☐
5. If you answered yes to question 3, how often can you hear the noise produced from a driver crossing the centerline rumble strips?
   ☐ less than once a day ☐ 1-5 times a day ☐ 5-10 times a day ☐ more than 10 times a day
6. What is the approximate distance from your house to US 40?____________________
7. Do you believe the centerline rumble strips on US 40 contribute to your driving safety?
   ☐ Yes ☐No opinion ☐ No
8. Do you believe the potential safety effect is worth some level of annoying noise?
   ☐ Yes ☐No opinion ☐ No

Comments: ____
____
____