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COMPARISON OF FOOTBALL SHAPED RUMBLE STRIPS VERSUS RECTANGULAR RUMBLE STRIPS

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16 Abstract

Shoulder and centerline rumble strips have become a predominantly used safety measure along American highways in almost all states and in Canadian provinces. Milled shoulder rumble strips are indentations along the shoulder of a highway to warn drivers who may start drifting off the road through an audible and tactile alert. Centerline rumble strips are similar, but are placed between lanes, usually two lane, two way highways, to warn drivers who may start drifting into oncoming traffic. Researchers at Kansas State University (KSU) have conducted research on a new design for highway rumble strips. A new football shaped rumble strip was created by an independent firm in Kansas. Test strips were installed along a Kansas highway, and the KSU Rumble Strip Research Team conducted several tests to evaluate the new football shaped rumble strip versus the rectangular rumble strip. The comparison consisted of water and debris collection, interior sound and vibration production, the opinions of bicyclists, and the opinions of residents in areas where rumble strips are installed. Based on the literature review, the limited tests performed (Water and Debris Removal, Noise, and Vibration), the surveys conducted (Bicyclists on K-96 and residents along US 40), and similarity in cost of the football shaped rumble strips to the rectangular rumble strips, it can be concluded that no significant difference was found between the two types. The KSU Rumble Strip Research Team concludes that the football shaped rumble strips can be considered an effective alternative to the rectangular rumble strips.

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Final Report

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

Shoulder and centerline rumble strips have become a predominantly used safety measure along American highways in almost all states and in Canadian provinces. Milled shoulder rumble strips are indentations along the shoulder of a highway to warn drivers who may start drifting off the road through an audible and tactile alert. Centerline rumble strips are similar, but are placed between lanes, usually two lane, two way highways, to warn drivers who may start drifting into oncoming traffic. Researchers at Kansas State University (KSU) have conducted research on a new design for highway rumble strips. A new football shaped rumble strip was created by an independent firm in Kansas. Test strips were installed along a Kansas highway, and the KSU Rumble Strip Research Team conducted several tests to evaluate the new football shaped rumble strip versus the rectangular rumble strip. The comparison consisted of water and debris collection, interior sound and vibration production, the opinions of bicyclists, and the opinions of residents in areas where rumble strips are installed. Based on the literature review, the limited tests performed (Water and Debris Removal, Noise, and Vibration), the surveys conducted (Bicyclists on K-96 and residents along US 40), and similarity in cost of the football shaped rumble strips to the rectangular rumble strips, it can be concluded that no significant difference was found between the two types. The KSU Rumble Strip Research Team concludes that the football shaped rumble strips can be considered an effective alternative to the rectangular rumble strips.

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Chapter 1: Introduction

Since August 1999, researchers at Kansas State University have been conducting research on rumble strips and their use on highways in the United States (U.S.). The result of this research is a better understanding of other U.S. States use of rumble strips and the benefits derived from their use. Through the research, it was learned that many states use different patterns and sizes of rumble strips. A literature review of current designs, effects, and issues are included in the next section of this report.

Many states use an intermittent skip pattern for rumble strips along the shoulder and in the centerline of some highways. The Kansas State University (KSU) research team conducted a minor experiment to determine the size of a gap which a car with a small wheelbase could cross the intermittent pattern and not touch a rumble strip. The results of that experiment are presented in the third section of this report.

Dustrol, Inc. of Towanda, KS has designed a new type of rumble strip to be used for shoulder and centerline rumble strips. The design is oval in shape resembling the print a football. The company claims that the uniquely rounded design allows wind and rain to clean the self-draining indentations while maintaining the audible and tactile warning signals. Also, the company claims that the gradual increase in depth of the indentation is more bicycle and motorcycle friendly (Dustrol, 2003). The overall objective of this project is to test the effectiveness and safety of the new football shaped rumble strip as compared to the conventional rectangular rumble strip. A secondary objective is to test Dustrol's claims regarding self-cleaning due to wind and rain. A last objective is to compare the football shape rumble strip with the rectangular rumble strip

through bicyclist opinions. Research was also conducted concerning public opinion of the external noise output of the football shaped rumble strips.

Chapter 2: Literature Review

2.1 Shoulder Rumble Strips

Shoulder rumble strips (SRS) have been widely researched and used by many states. Different patterns and shapes have been designed, before and after studies have been conducted, and non-vehicular issues have been considered. This is a review of these topics dealing with SRS and their effect on run-off-the-road (ROR) accidents.

2.1.1 Shoulder Rumble Strip Designs by State

According to the Federal Highway Administration (FHWA) (2001), there are four basic rumble strip designs or types: milled-in, rolled, formed (corrugated), and raised. Milled strips have been proven to be effective and are the most widely used (Brin, 2001; Chen 2001; Morena, 2003). The milled-in strips are cut into the pavement surface using a grinding head. The most common dimensions for milled SRS are 1/2 inch deep, 7 inches wide parallel to the travel lane, and 16 inches long perpendicular to the travel lane (FHWA, 2001). These dimensions are a basis for many states to use when designing milled-in rumble strips for highway shoulder use. The Virginia DOT used these dimensions when conducting research on the effects of continuous SRS on highway safety (Chen et al., 2003). Connecticut, Iowa, and Maryland also use the FHWA dimensions for milled-in SRS cut continuously 12 inches center-to-center offset 12 inches from the edge-of-travel-line (Annino, 2003; Iowa, 2004; Maryland, 2004).

Some states have made variations to the FHWA dimensions based on research and bicyclist issues discussed later in the report. A recent study report produced for the Missouri DOT (MoDOT) suggests a 7/16 inch deep, 5 inches wide parallel to the travel

line and 12 inches perpendicular to the travel line milled-in SRS as optimal for all non-interstate highways with shoulder widths of 5-6 feet (Spring, 2003). The SRS on non-interstate highways with shoulder widths of 5-6 feet are cut intermittently with a 60-foot cut/12 foot gap pattern offset 0 inches from the edge-of-travel-line. The study also suggests that the FHWA design (FHWA, 2001) still be used for all interstate highway SRS applications and for all non-interstate highways with shoulders exceeding 6 feet. Interstate highway rumble strips in Missouri are cut continuously 12 inches center-to-center with an offset of 6 inches from the edge-of-travel-line. All non-interstate highways with shoulders exceeding 6 feet use the intermittent 60-foot cut/12 foot gap pattern and are offset 6 inches from the edge-of-travel-line. The MoDOT proposal coincides with the study completed at the Midwest Research Institute in Kansas City, MO (Torbic, et al., 2003). This study found that using the 7/16 inch by 5 inches by 12 inches design is more “bicycle-friendly”. This will be discussed later in the report.

The North Dakota DOT has similar guidelines to that of the MoDOT report. Sixteen inch SRS are used on interstates and are cut continuously at 12 inches center-to-center and offset 12 inches from the edge-of-travel-line. The 12 inch SRS are used on all multilane divided highways, multilane undivided highways and two-lane highways with shoulders between 4 and 6 feet (Birst, 2002). The SRS on multilane divided highways are cut continuously 12 inches center-to-center offset 12 in from the edge-of-travel-line on the left side of the road. The right side of multilane divided highways uses an intermittent pattern of 40 foot cut/10 foot gap offset 12 inches from the edge-of-travel-line. Multilane undivided highways use the intermittent pattern on both sides of

the highway. Two lane highways use the continuous pattern cut 12 inches center-to-center offset 12 inches from the edge-of-travel-line.

The Canadian Province of British Columbia also uses a design 5 inches wide parallel to the travel line and 12 inches long perpendicular to the travel line. However, the SRS are only cut to a maximum depth of 3/8 inch For shoulders greater than or equal to 5 feet, the strips are cut continuously 12 inches center-to-center with an offset of 4 inches from the edge-of-travel line. For shoulders between 2.5 and 5 feet, SRS are cut continuously 12 inches center-to-center with an offset of 0 inches from the edge-of-travel line (Coulter, 2003).

Michigan uses three types of SRS: milled-in, rolled-in, and corrugated (Morena, 2003). No dimensions for design were given, but the Michigan DOT installs SRS continuously with either a 12 or 24 inches offset from the edge of travel line. Table 2.1 provides a summary of all the reviewed States' designs.

Table 2.1: Summary of States' Designs for SRS

State/Province	Width	Length	Depth	Pattern	Shoulder Width	Offset from Travel Lane
Virginia	7 in.	16 in.	½ in.	Continuous, 12 in. Center to Center	N/A	12 in.
Connecticut	7 in.	16 in.	½ in.	Continuous, 12 in. Center to Center	N/A	12 in.
Iowa	7 in.	16 in.	½ in.	Continuous, 12 in. Center to Center	N/A	12 in.
Maryland	7 in.	16 in.	½ in.	Continuous, 12 in. Center to Center	N/A	12 in.
Missouri (1)	5 in.	12 in.	7/16 in.	Intermittent 60 ft. cut/12 ft. gap	5-6 ft.	0 in.
Missouri (2)	5 in.	12 in.	7/16 in.	Intermittent 60 ft. cut/12 ft. gap	≥ 6 ft.	6 in.
North Dakota	5 in.	12 in.	7/16 in.	Continuous, 12 in. Center to Center	4-6 ft.	12 in.
British Columbia (1)	5 in.	12 in.	3/8 in.	Continuous, 12 in. Center to Center	≥ 5 ft.	4 in.
British Columbia (2)	5 in.	12 in.	3/8 in.	Continuous, 12 in. Center to Center	2.5-5 ft.	0 in.
Michigan	N/A	N/A	N/A	Continuous, 12 in. Center to Center	N/A	12-24 in.

There are no regulations or guidelines showing the pattern and placement from the edge-of-travel line. Therefore states are allowed to determine an optimal pattern to be used on the respective highways.

2.1.2 Effectiveness of Shoulder Rumble Strips

Highway SRS have proven to be an effective measure in reducing run-off-the-road (ROR) crashes on urban and rural highways. ROR crashes may be reduced by as much as 20 to 50% when rumble strips are installed (Torbic et al., 2003). Many states continue to research the effectiveness of installed SRS by using before and after studies. Milled-in rumble strips in Michigan reduced ROR by 40%. The two older designs, rolled-in and corrugated, were approximately 20% effective in reducing ROR (Morena, 2003). Pennsylvania and New York concluded a reduction of ROR crashes of 60 and 80% percent, respectively, afterb the installation of milled-in SRS (Brin, 2001;

Morena, 2003). Annino (2003) found a 40% decrease in fatality accidents related to ROR in Connecticut. Overall ROR accidents decreased by 12% in areas of Connecticut with SRS. Finally, the Virginia DOT reported a 42% reduction in fatal ROR crashes and overall 32% reduction in ROR due to the installation of milled-in SRS (Chen et al., 2003). Virginia also reported a benefit/cost ratio of +45, meaning every dollar invested returns $45 dollars of benefits. According to the FHWA, studies indicate benefit/cost ratios between 60:1 and 128:1 from the use of milled-in SRS as a road treatment for reducing ROR accidents (Neumann, 2002).

Not only is there a comparison of crashes before and after the installation of SRS, but there is also a comparison in the effectiveness of the different types of SRS. The three types, milled-in, rolled-in, and corrugated, all give different noise and tactile levels directed towards the driver. The difference between milled-in and rolled-in continuous SRS was more than 12 times for the excess of the vibration levels and 3 times for the excess of the sound levels. The difference between milled-in and corrugated continuous SRS was more than 7 times for the excess of the vibration levels and 0.5 times for the sound levels (Chen et al., 2003). Therefore it can be concluded that the milled-in type of SRS provides greater noise and vibration.

Run-off-the-road accidents have become an issue since the early 1990s. Recently, the Federal Government has made an effort to get involved. In February 2003, House Bill 968 was introduced to amend Title 23 of the U.S. code. Rep. Robert Andrews (D) of New Jersey proposed the bill to provide incentives to States for the development of traffic safety programs to reduce crashes related to driver fatigue and sleep deprivation. In the bill, money is to be given to states to develop education on

drowsy driving, training against drowsy driving, and, more importantly, adoption of formal policy for the use of rumbles strips. Section 412.b.4 states that funds provided under a contract, cooperative agreement, or grant under subsection shall be used to adopt formal policy statements and work plans for the installation and expansion of continuous rumble strips during highway resurfacing and new construction programs for interstate highways (Andrews, 2003). Simply stated, the Federal Government will provide funding for each state to make policies regarding the use of continuous SRS.

2.1.3 Environmental Noise Created by Shoulder Rumble Strips

Not much research has been completed in determining the external noise level created by traveling over SRS. Only subjective responses have been collected on the noise level created by SRS. In Connecticut, several noise complaints were received from residents in the vicinity of the installed, milled-in SRS. To accommodate the complaints, the rumble strips were moved offset to the edge line from 6 to 12 inches (Annino, 2003). Recording and monitoring of sound levels at a distance from the travel surface is difficult in distinguishing the noise created by the SRS and the surroundings. However, Chen, Darko, and Richardson (2003) concluded that the environmental noise impact was minimal. The noise resulting from the rumble strips at 200 feet from the roadway was low and could be ignored because it was a random event. The sound level was 9 dB lower than the sound level recorded at the same distance of a tractor-trailer traveling along the highway. Since people do not intend to drive over the SRS, it can be reasonably assumed that the safety effects outweigh the environmental noise effects.

2.2 The Debate over Bicycle Friendly Rumble Strips

Since the first installation of rumble strips, the concern for bicyclist safety along highways with rumble strips has increased. Many of the controversies over shoulder rumble strips (SRS) vs. bicycles occur in places where SRS were installed on narrow / rural roads with narrow or no paved shoulder, and/or on roads with frequent curves. SRS cannot significantly improve motor vehicle safety on these roads (in the absence of new or wider shoulders), but they dramatically reduce the level of service on those roads for bicycling (Zalph, 2005). Researchers from universities, state and federal transportation agencies, and independent firms have investigated ways to improve roadway safety for both drivers and riders. Many bicyclists and bicycle groups have voiced their concerns and opinions, both positive and negative.

Currently, there is no federal standard for rumble strips, only recommendations from the Federal Highway Administration (FHWA). States have adopted their own policies based upon current research and trends. From this, different designs of rumble strips have been created to become more "bicycle-friendly" on today's highways. What follows is a summary of current findings dealing with bicyclist concerns and opinions, States' policies, Federal recommendations, and different "bicycle-friendly" rumble strip designs.

2.2.1 Bicyclists' Opinions, Concerns, and Recommendations

If you look up "Bicyclists and Rumble Strips" on any Internet search engine, you are guaranteed to find at least 200 sites devoted to bicyclists, bicyclist groups, and bicyclist magazines voicing opinions about SRS along highways. What you will also find is mixed opinion from bicycling parties. The first opinions given are negative

towards SRS. Below are a few examples from an online debate sponsored by the Bicyclist and Pedestrian Advisory Committee in Ithaca, NY (2003).

- "Rumble strips are not good for cyclists. And I would argue that they are not only bad for cyclists but they can be bad for motorists too. If cyclists do ride on a road with rumbles, they are likely to ride further into the car lane to avoid the rumbles"

- "The problem is that a lot of rumble strips are done incorrectly: 1. A rumble strip on a shoulder that is so narrow that the rumble strip occupies the entire shoulder. Terrible! ... 2. A rumble strip placed in the middle of the shoulder, so neither side of the rumble strip is safe for cycling. Stupid!"
- "Be gone with you, darn rumble strips! They have them in some parts of California. They are great…as long as you do not have to ride on them or cross them…The experience is bone-jarring, can lead to some loss of control (wheels catch in grooves if you are not perpendicular enough) and is just plain uncomfortable."

- "What happens when a cyclist encounters portions of the shoulder that are covered in debris/glass/other hazards? The rumble strips prevent the cyclist from safely moving left to avoid this debris, even though it is legal to do so."

Similarly in an article for cyclingutah.com, Chris Quann (2004) states the worst thing (over the last twenty fives years of cycling) has been the proliferation of milled shoulder rumble strips. In his opinion, there is very little good about rumble strips from

a bicyclist's point of view. He believes that the presence of a rumble strip disrupts the wind from vehicles that typically blows debris from the road surface. The debris tends to collect in the area to the right of the rumble strip that cyclists are expected to use (Quann, 2004). Fortunately not all opinions are negative. Below are some positive responses and recommendations from the Ithaca, NY Bicycle and Pedestrian Advisory Committee debate (2003).

- "I have no problem with rumble strips when they are done correctly: 1. The rumble strip should be as close to the white line of the high-speed travel lane. 2. There should be enough pavement to the right of the rumble strip to be safe for cycling…With 4 or more feet of pavement, you don't need much concentration, it's okay at high speeds, and it's wide enough to go around most debris without crossing the rumble strip. Two feet is tolerable on a road that doesn't have steep downhills, but it requires more concentration and you sometimes have to go into the rumble strip to avoid debris"

- "Besides being installed correctly, I would say that the type of strip and the amount of traffic is also important."

- "Is moving across "correct" rumble strips dangerous? I've ridden on them during a tour in Colorado, and it seemed to me they were uncomfortable, but hardly dangerous. While I'm not a big fan of rumble strips, if they prevent a driver from drifting off and thereby drifting out of his lane, there is benefit offsetting the

inconvenience. But I wouldn't call them a safety hazard…A momentary encounter with rumble strips shouldn't be enough to take you down."

- "We've always used large enough tires that we'd just roll over them. Where we live our cycling club asked the county road commissioner to change them to help make them safer for the cyclists. So they stopped cutting them all the way to the pavement's edge which left us a space where cyclists could pass the rumbles. Sometimes speaking with your local government officials do help."

The last comment brings up an important issue, cycling groups interacting with government agencies and state policies to find a balanced solution to the rumble strip vs. bicyclist debate. The next section details what some State Departments of Transportation have done through the advice and lobbying from bicycle groups.

2.2.2 State's Policies and Bicyclist Recommendations

In Arizona, the Tucson-Pima County Bicycle Advisory Committee is working with the Arizona Department of Transportation (ADOT) to revise and improve current shoulder rumble strip standards. They hope that ADOT will soon follow a policy of "First do no harm" and only allow rumble strips that are bicycle-safe and leave at least a 5-foot paved shoulder (2005).

In Colorado, One of the largest American bicyclist groups, Bicycle Colorado, is lobbying for the Colorado Department of Transportation (CDOT) to add more signage and pavement markings to alert road users of rumble strips. Bicycle Colorado helped design these alerts in 2002 (BC News, 2004). Colorado is one of the leading states in finding a balance for motorists and bicyclists concerning SRS.

In Missouri, the Missouri Department of Transportation (MoDOT) is trying to install more shoulders on routes and place rumble strips so that they are affective at deterring run off the road accidents yet not a problem for bicyclists. The current rumble strip policy provides for the placement of rumble strips on all shoulders that are two feet or wider (however, Missouri's current standards do not provide for the placement of rumble strips on all shoulders less than eight feet wide). The milled rumble strips are to located four inches outside the edge line, 16" long, 7" wide, and continuous. This policy was added to the Standard Plans July, 1 2004 (Snider, 2004). Also, the MoDOT Bicycle and Pedestrian Advisory Committee recently submitted a project to be considered for funding to the American Association of State Highway and Transportation Officials (AASHTO). The project is entitled Rumble Strip Design to Optimize Both Highway and Bicycle Safety (Giarratano, 2004).

In Georgia, The Atlanta Bicycle Campaign made the following recommendations to the Georgia Department of Transportation (GDOT): 1. Reduce depth or rumbles from 1/2" to 3/8" as done in Colorado, and Pennsylvania, and reduce the width of the rumble gouge from 7" to 5", 2. Reduce length of the rumble from 16" to 12", 3. Increase length of gap (currently 28' of rumble strips, then a 12' gap). All recommendations were well accepted and in process of being implemented into Georgia's rumble strip policy (Georgia, 2003).

In Hawaii, rumble strips along the Queen Ka'ahumanu Highway have been temporarily milled down to 1/4". This is in response to riders concerns over the 1/2" deep milled strips along the Kea'au-Pahoa Highway. A professional and a non-

professional bike rider tested the 1/4" strips, and both were satisfied with the modification (Hawaii, 2004).

West Virginia uses the above design and only places SRS on highways with shoulders greater than or equal to three feet (WVDOT, 2003). Washington uses SRS on divided and undivided highways where shoulder width is greater than four feet. Also, SRS activities must be coordinated with the Washington State Department of Transportation's Bicycle and Pedestrian Advisory Committee (WSDOT, 2002). Bicyclists are still a major factor when designing SRS for use on all highway types.

2.2.3 "Bicycle-friendly" Designs

States have listened to the bicycle community and have started to research patterns that can accommodate both drivers and bicyclists. Colorado is one of the leading states in research of "bicycle friendly" rumble strips. Outcalt (2001) first suggested to CDOT that the SRS be milled to 3/8 inch deep instead of 1/2 to 5/8 inch deep.

Torbic and associates (2003) determined that the optimal design for "bicycle friendly" rumble strips is 7/16 inch deep, 5 inches wide parallel to the travel line, and 12 inches long perpendicular to the travel line. Using SRS with the mentioned dimensions still gives a proper auditory and tactile warning for drivers, as well as creating enough space for bicyclists (Torbic et al, 2003). It should be noted that these SRS were tested and recommended for shoulders greater than four feet wide, and the SRS are offset no more than six inches from the edge-of-travel line. Spring (2003) concurred with Torbic in his proposal to MoDOT. A company called Surface Preparation Technologies

adopted, and recommends the above dimensions for SRS. Surface Preparation Technologies maintains the website www.rumblestrips.com (2005).

2.2.4 Discussion

The biggest problem with rumble strips, in the eyes of bicyclists, is not having enough room on the shoulder to maneuver and still be safe and comfortable. Many cyclists are concerned about the dimensions of the actual rumble strips. Some have recommended a lower depth, narrower width, or longer gap. But, it can be assumed that the majority of cyclists think rumble strips are good for highway safety. Also, the majority are not concerned with rumble strip dimensions as long as they have at least two feet of clear paved shoulder to the right of the rumble strip to ride on.

This is evident in the bicyclist survey test in section four of this report.

2.3 Centerline Rumble Strips

Centerline rumble strips (CRS) are similar to shoulder rumble strips (SRS) in that they are cut indentations used to make drivers aware of their position on the roadway. The difference, however, is the placement on the roadway. As the name suggests, centerline rumble strips are placed along the center of the roadway, particularly rural highways, to warn drivers who may be into oncoming traffic. CRS are installed in 22 U.S. States, including Kansas (Noyce et al., 2004). States have indicated that the most important reason for installing CRS is a countermeasure to high crash locations or general enhancement to improve safety (Noyce et al., 2004). This report discusses states' designs of CRS, effectiveness of CRS, and some issues and concerns stemming from the use of CRS.

2.3.1 Centerline Rumble Strip Designs by State

Although many states use CRS, not all states use the same design, pattern or placement. From a 2003 survey (Russell and Rys, 2005) twenty-two of the fifty U.S. States and two Canadian Province responded that they have CRS installed at various locations in their respective states. The dimensions and patterns for these states and province can be seen in Table 2.2.

Table 2.2: Milled Centerline Rumble Strips by U.S. States and Canadian Province (Russell and Rys, 2005)

	Dimensions			
State	Length[a]	Width[b]	Depth	Edge-to-Edge Spacing
Alabama				10 in.
Alaska	12 in.	5-7 in.	0.5 in.	5 in.
Alberta	12 in.	6-8 in.	0.2-0.35 in.	6-8 in.
Saskatchewan[c]	12 in.	5-7 in.	2 in.	7 in.
	12 in.	4-6 in.	0.4-2 in.	6-7 in.
California[d]				
Colorado	12 in.	5 in.	0.375 in.	7 in. = 12 in. on center
Delaware	16 in.	7 in.	0.5 in.	12 in.
Hawaii	18-24 in.	4 in.	N/A	20 in.
Kansas[e]	12 in.	6.5 in.	0.5 in.	Type 1: 12 in., Type 2: 12 and 24 in.
Kentucky	24 in.	7 in.	0.5-0.675 in.	17 in.
Maryland	18-24 in.	4 in.	0.5 in.	varies
Massachusetts	16 in.	6 in.	0.5 in.	12 in. on centers
Michigan	16 in.	7 in.	0.375 in.	12 in.
Minnesota	12- 16 in.	7 in.	0.5 in.	12 in.
Missouri	12 in.	6.5 in.	0.5 in.	6 in.
Nebraska	16 in.	7 in.	0.5-0.675 in.	5 in.
Oregon	16 in.	7 in.	0.5 in.	12 in.
Pennsylvania	16 in.	7 in.	0.5 in.	4 in.
Rhode Island	16 in.	7 in.	0.5 in.	5 in.
Utah	12 in.	8 in.	0.675-0.75 in.	4 in.
Virginia	16 in.	6 in.	0.5 in.	12 in.
Washington	16 in.	5 in.	0.375 in.	7 in.
Wisconsin	dimensions are irregular		1.25 in.	none reported
Wyoming	12 in.	7.5 in.	0.5 in.	7 in.

Note:N/A = not available
[a]Length represents dimension parallel to travel surface centerline
[b]Width represents dimension perpendicular to travel surface centerline
[c]The first and second row represents two- and four lane sections respectively
[d]Currently there are no standards regarding dimensions
[e]Kansas uses center-to-center and not edge-to-edge dimensions. Type 1 - continuous: 12 in. on center; Type 2: alternating: 12 in. and 24 in. on center.

Delaware uses a CRS design that is 16 inches long perpendicular to the roadway centerline, 7 inches wide parallel to the roadway centerline, and 1/2 in deep. Delaware

also use a continuous pattern of rumble strips 12 inches center to center (DelDOT, 2003).

2.2.2 Effectiveness of Centerline Rumble Strips

More important than each state's designs is the effectiveness of the centerline rumble strips. According to the National Highway Traffic Safety Administration (NHTSA) (Persaud et al., 2004; NHTSA, 2003a) on a national basis, rural roads account for approxiamately 40% of all motor vehicle travel but 60% of fatal crashes. Also, the fatality rate per 100 million vehicle-miles of travel on rural roads is 2.3 versus 1.0 for urban areas (Persaud et al., 2004; NHTSA, 2002). Opposing direction crashes account for 20% of all fatal crashes on rural two-lane roads and result in about 4500 fatalities annually (Persaud et al., 2004; NHTSA, 2003b)

Delaware first installed CRS in 1994. The Delaware Department of Transportation (DelDOT) did a comparative study of average yearly accidents for the three years before installation and the eight years after installation of CRS along U.S. Route 301. During the before period, six fatal accidents were reported, resulting in nine fatalities (DelDOT, 2002). DelDOT found that the average yearly head on collisions decreased by 95% after the installation of centerline rumble strips. Accidents caused by motorists crossing the centerline decreased by 60%. Most significantly, even with a four percent average yearly increase in traffic volumes, there were no fatal accidents reported during the eight-year period after installation of the centerline rumble strips (DelDOT, 2002). DelDOT also reported a benefit to cost ratio of positive 110 (DelDOT, 2002).

Similar findings were found in Colorado. The Colorado Department of Transportation (CDOT) completed a 44-month before and after study on a 17-mile section of State Highway 119 where CRS were installed. CDOT found a 34% decrease in head-on collisions and a 36.5% decrease in sideswipe collisions while the average daily traffic increased 18% (Outcalt, 2001).

The California Department of Transportation (CalTrans) tested the effects of centerline rumble strips in no passing zones (Noyce et al., 2003; Bahar et al., 2001). A review of 36 months of before and after crash data found that crashes were reduced by 11% and fatalities were reduced by 77%.

Noyce and Elango (2003, 2004) completed a study for The Massachusetts Highway Department (MassHighway) evaluating before and after CRS installation crash data and the safety of the CRS. Noyce and Elango found that there was no evidence from the before and after study that suggested the installation of centerline rumble strips significantly reduced crash rates. However, they did find that the CRS were effective at gaining driver's attention during the simulator trials, and they stated that CRS are an effective traffic control device and safety countermeasure in areas with a history of cross-over-the-centerline fatal and severe injury crashes (Noyce et al., 2004).

Persaud, Retting, and Lyon (2004) took crash data from seven U.S. States including California, Colorado, Delaware, Maryland, Minnesota, Oregon, and Washington and analyzed before and after CRS installation periods for each state. They also showed the effectiveness of CRS by concluding a 25% reduction of frontal and opposing-direction sideswipe crashes. The overall reduction in rural two-lane crashes attributable to centerline rumble strips was 12% (Persaud et al., 2004).

In 2003, CRS were installed on SR 904 and SR 270 in Washington. A one year history for the project shows a 46% decrease in total collisions, and a 57% decrease in injury collisions (WSDOT, 2005). It should be noted that these are short-term results.

2.3.3 Concerns Stemming from Centerline Rumble Strips

One of the concerns with the use of CRS (and inside SRS on divided highways) is a driver's expectancies derived from previous experiences with SRS (Noyce et al., 2003, 2004). Because of this expectancy, driver's subconscious reaction to an unexpected encounter with SRS is to correct the trajectory of the vehicle by turning left, away from the SRS. Drivers who encounter a CRS, and are unaware of their lane position, may assume that they are encountering a SRS and reactively turn left (Noyce et al., 2003, 2004). In Noyce and Elango's study (2003, 2004), a driving simulator was used to determine the safety of drivers when crossing the centerline rumble strips and the possibility of correcting steering in the wrong direction, i.e., further into the oncoming traffic lane. The results of the analysis found that drivers took more time to return to the travel lane when CRS were present as compared to when CRS were not present. Also, drivers reacted to and corrected the vehicle trajectory more quickly with CRS than SRS. However, 27% of the drivers made an initial leftward correction of the vehicle when encountering CRS (Noyce et al., 2003, Noyce et al., 2004). No improper or rightward corrections were made with the SRS.

As with SRS, there is the concern of noise and the impact on the environment. Always consider potential noise impacts when contemplating an installation of centerline rumble strips in residential and urban areas, and do not install them on bridges (Hood, 2002). Along with the noise concern, DelDOT (2002) states that the use of CRS

potentially transfers a head-on collision problem further down the roadway to locations without CRS.

2.4 Noise and Vibration

In order to understand results collected in the experimental section of this report, the definitions and limits of noise and vibration on the human body must be understood. Amplitude is the energy level or “loudness” of a sound wave, measured in decibels (Minor, 2005). Because the human ear is efficient at blocking very high and very low frequency sound, the sensitivity of the ear to sounds of different frequencies is measured by the A-weighted decibel scale (dBA) (Minor, 2005). The smallest change in noise level that a human ear can perceive is about three dBA; increases of five dBA or more are more clearly noticeable (Minor, 2005). To become aware of a sound and be “alerted” to the presence of that sound, the sound must typically rise 9 to 10 dBA above the sound of the environment (Lipscomb, 1995). Human response to noise is subjective and can vary from person to person. Factors that can influence individual response include the loudness, frequency, and time pattern; the amount of background noise present before intruding noise; and the nature of the activity that the noise affects (Minor, 2005).

For the evaluation of the football rumble strips as compared to rectangular rumble strips, the tactile feeling, or vibration felt in the steering wheel when traversing the two types of rumble strips was measured. Hand-transmitted vibration is the vibration that enters the body through the hands (Griffin, 1998). The magnitude of a vibration can be quantified by its displacement, its velocity, or its acceleration. For practical convenience, the acceleration is measured with accelerometers, in meters per

second squared, m/s^2, or g's (1 g = 9.8 m/s^2) (Griffin, 1998). Vibration measurements should be made on the tool handle or workpiece close to the surface of the hand(s) where the vibration enters the body and should be measured and reported in the appropriate directions of an orthogonal coordinate system (Bovenzi, 1998). This will aid in the experimental design discussed below. Threshold limit values for exposure to hand-transmitted vibration are calculated based on an eight hour period. For an eight hour continuous period, the minimum threshold value is four m/s^2 or 0.40 g. For a one hour period, the threshold value is 12 m/s^2 or 1.22 g (Bovenzi, 1998). These values are set to minimize and eliminate risks or injury and long-term disorders caused by extended vibration exposure. Human response to vibration depends on the total duration of vibration exposure (Griffin, 1998).

Chapter 3: Research Methodology

For this project, two methods were used to evaluate the football shaped rumble strips versus the rectangular rumble strips. A combination of experiments and surveys were used to test the different aspects of the two types of rumble strips. The private company that designed the football shaped rumble strip claims several benefits of the football shaped rumble strip over the rectangular rumble strip. Each of these claims was examined throughout the project. The first claim is that the unique rounded design of football rumble strips allows wind and rain to clean the self-draining indentations. The second claim is that the football shaped rumble strips produced the same audible and vibratory warning for drivers crossing over the indentations as compared to the rectangular rumble strips. The final claim is that the football shaped rumble strip is more bicycle friendly. Along with the mentioned claims, this project addressed the external noise produced by centerline rumble strips placed in residential areas.

To test the first claim, an experiment was designed to simulate the collection of water and debris in the rumble strip indentations. Both types of rumble strips, football and rectangular, were examined and evaluated based on the time it takes for the material in the indentations to be removed. The time of removal, the wind speed, and the number of passing vehicles were collected to evaluate the removal of water and debris from the rumble strips. Only rumble strips along K-96 in Wichita were examined for the water and debris removal test.

To test the second claim, an experiment was designed to measure to the noise and vibration produced by the rumble strips as felt by a vehicle's driver. A noise dosimeter measured the noise as heard by the driver while an accelerometer attached

to the steering wheel measured the vibration felt by the driver. Several different vehicles were used and both types of rumble strips were tested. The strips were compared for any statistical difference between the noise and vibration measurements. Rumble strips along K-96 near Wichita, KS and along US Highway 40 near Lawrence, KS were tested for noise and vibration.

To test the third claim, a survey was designed to accurately judge bicyclists' opinions of the two types of rumble strips. A bicyclist group from Wichita, KS was given the survey and asked to compare the football and rectangular shaped rumble strips based on the safety of riding over the strips. Only the rumble strips along K-96 were evaluated by the bicyclist survey because the rumble strips are on the shoulder.

To test the external noise produced from centerline rumble strips in residential areas, a survey was designed to judge the opinions of residents in those areas. The survey was distributed to residents along US Highway 40 between Lawrence and Topeka, KS. The survey determined if the noise produced from vehicles crossing the rumble strips was loud enough to cause a problem or distraction in the residential area.

Chapter 4: Experimentation

4.1 Rumble Strips along K-96

The football shaped rumble strips were first installed in Kansas along K-96 (on the shoulder) between Maize and Wichita on October 19th, 2004. The research team was there to observe the installation along the left and right shoulders of the eastbound side of K-96. There are rectangular rumble strips located on the westbound side of K-96 and the football shaped rumble strips are located on the eastbound side. The team collected several photographs, a video recording, and the football shaped rumble strip dimensions. A single football indentation has a depth of approximately 0.5 inches, a width of 9 inches parallel to the line of travel, and a length of 16 inches perpendicular to the line of travel. Detailed drawings can be found in Figures B1 and B2 in Appendix B. As stated before, several photographs were taken of the installation. The photos can be found in Figures A1-A8 in Appendix A. The objective of the team was to determine a positive or negative difference between the two types of rumble strips.

4.1.1 Water and Debris Removal Tests

Several tests were conducted using water and sand debris to determine if there was a difference between the two designs of rumble strips, football shaped and rectangular shaped. The tests were conducted over three days and for different amounts of times. All tests were conducted along the section of K-96, a multilane divided highway, between Wichita and Maize, KS. This section of K-96 has a high traffic flow that averages approximately 600 vehicles per hour. Below is a discussion of each trial with detailed photographs and collected data.

4.1.1.1 Debris Test Trial 1

For the debris test, one-quarter cup of Quikrete Multi-Purpose sand was poured into three consecutive divots of each rumble strip design. This simulated road debris collecting in the rumble strips from traffic, wind, tire particulates, and dust. The rumble strips were then videotaped for 30 minutes. Both types could not be tested simultaneously so the rectangular rumble strips were tested first then the football shaped rumble strips. The number of vehicles passing by was tallied. The maximum and average wind speed for the 30-minute period was measured using a Kestrel 1000 pocket wind meter. Initially it was thought that these measures could give a quantifiable difference between the two types of rumble strips. Table 4.1 shows the collected data for each rumble strip design.

Table 4.1: Collected data of Debris Test Trial 1.

	Rectangular Rumble Strips	Football Rumble Strips
Maximum Wind Speed	7.7 mph	7.1 mph
Average Wind Speed	2.2 mph	2.3 mph
Total Vehicles Passed	267	295

Figure 4.1 shows the rectangular rumble strips at time t = 0 min. and at time t = 30 min. As one can see, there appears to be no noticeable difference in debris removal.

Figure 4.1: Rectangular Rumble Strips, Debris Test Trial 1 at time = 0 min. (left) and at time = 30 min. (right).

Figure 4.2 shows the football shaped rumble strips at t =0 min. and at time t = 30 min. Again, one can see that there appears to be no noticeable difference in debris removal.

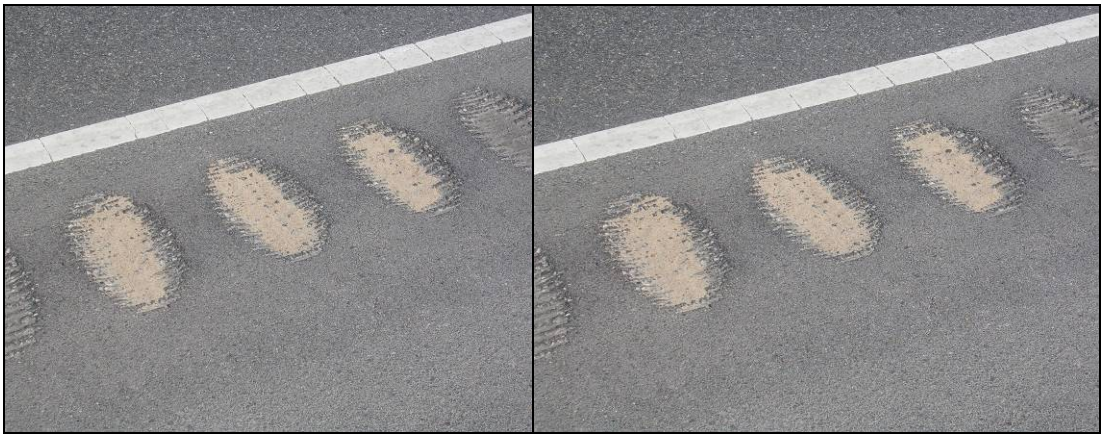

Figure 4.2: Football Rumble Strips, Debris Test Trial 1 at time = 0 min. (left) and time = 30 min. (right).

It was concluded that there was no difference in either type in the 30 min. time frame. So, a second trial was conducted. It is discussed in the next section.

4.1.1.2 Debris Test Trial 2

The setup for the second trial was similar to the first. One-quarter cup of Quikrete Multi-Purpose sand was poured into three consecutive divots of each rumble strip design. Both types of strips were tested at the same time. The largest difference between each trial was the length of time. For trial two, the strips were tested for 18 hours. Neither design was videotaped, nor was the wind speed measured. The number of vehicles was also not collected. It was not feasible to observe each strip design for that amount of time. However, photographs were taken at time t =0 hr. and at time t = 18 hrs. Figure 4.3 shows the rectangular rumble strips at time t = 0 hr. and time t = 18 hrs. Figure 4.4 shows the football shaped rumble strips at time t = 0 hr. and time t = 18 hrs.

Figure 4.3: Rectangular Rumble Strips, Debris Test Trial 2 at time = 0 hr. (left) and at time = 18 hrs. (right).

Figure 4.4: Football Rumble Strips, Debris Test Trial 2 at time = 0 hr. (left) and at time = 18 hrs. (right).

It was subjectively determined that there is definitely debris removal from both types of rumble strips. However, no quantifiable difference was determined in either. It was determined there would be no benefit in testing the two types of rumble strips for any longer period.

4.1.1.3 Water Test Trial 1

For the water test, one-quarter cup of water was poured into three consecutive divots of each rumble strip design. This simulated water collecting in the rumble strips from rainy weather and snowmelt in winter weather. The rumble strips were then videotaped for 30 minutes. Again since each type of strip could not be tested simultaneously, the rectangular rumble strips were tested first then the football shaped rumble strips. The number of vehicles passing by was tallied and the average wind speed for the 30-minute period was measured using a Kestrel 1000 pocket wind meter. Also the maximum wind speed was measured using the same meter. Initially it was thought that these measures could give a quantifiable difference between the two types of rumble strips. Table 4.2 shows the collected data for each rumble strip design.

Table 4.2: Collected data of Water Test Trial 1.

	Rectangular Rumble Strips	Football Rumble Strips
Maximum Wind Speed	11.9 mph	9.1 mph
Average Wind Speed	3.3 mph	2.2 mph
Total Vehicles Passed	308	362

Figure 4.5 shows the rectangular rumble strips at time t = 0 min. and at time t = 30 min. As one can see, there appears to be no noticeable difference in water removal.

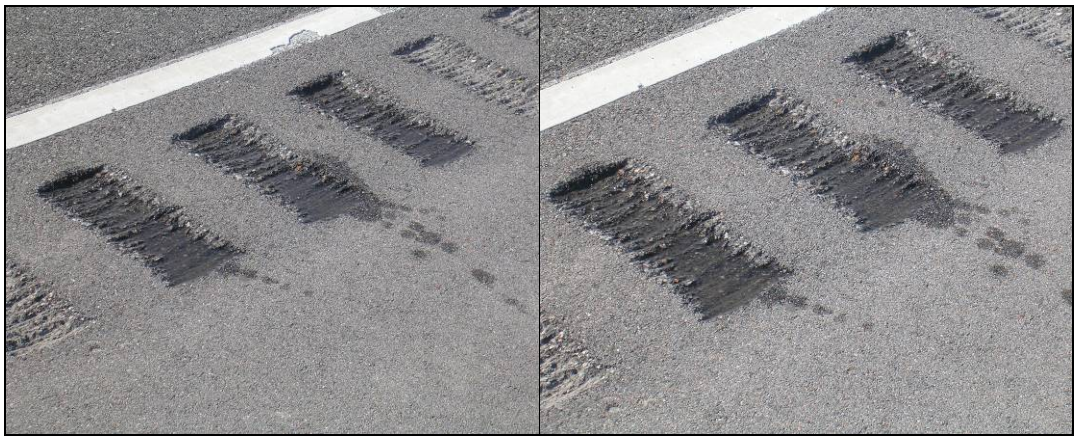

Figure 4.5: Rectangular Rumble Strips, Water Test Trial 1 at time = 0 hr. (left) and at time = 30 min. (right).

Figure 4.6 shows the football shaped rumble strips at t =0 min. and at time t = 30 min. Again, one can see that there appears to be no noticeable difference in water removal.

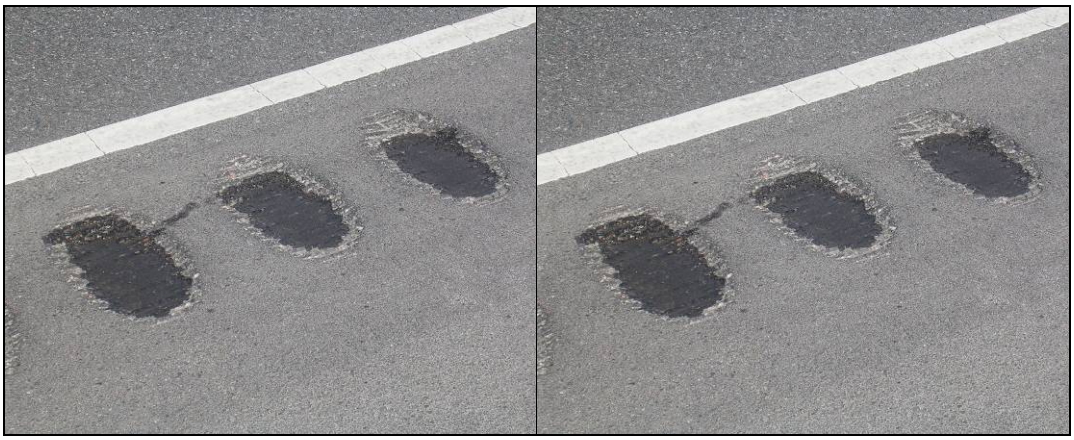

Figure 4.6: Football Rumble Strips, Water Test Trial 1 at time = 0 min. (left) and at time = 30 min. (right).

It was concluded that there was no difference in either type in a 30 min. time frame. A second trial was conducted. It is discussed in the next section.

4.1.1.4 Water Test Trial 2

The setup for the second trial was similar to the first. One-quarter cup of water was poured into three consecutive divots of each rumble strip design. Both types of strips were tested at the same time. The largest difference between each trial is the length of time. For trial two, the strips were tested for 18 hours. Neither design was videotaped, nor was the wind speed measured. The number of vehicles was also not collected. It was not feasible to observe each strip design for that amount of time. However, photographs were taken at time t = 0 and at time t = 18 hrs. Figure 4.7 shows the rectangular rumble strips at time t = 0 and time t = 18 hrs. Figure 4.8 shows the football shaped rumble strips at time t = 0 and time t = 18 hrs.

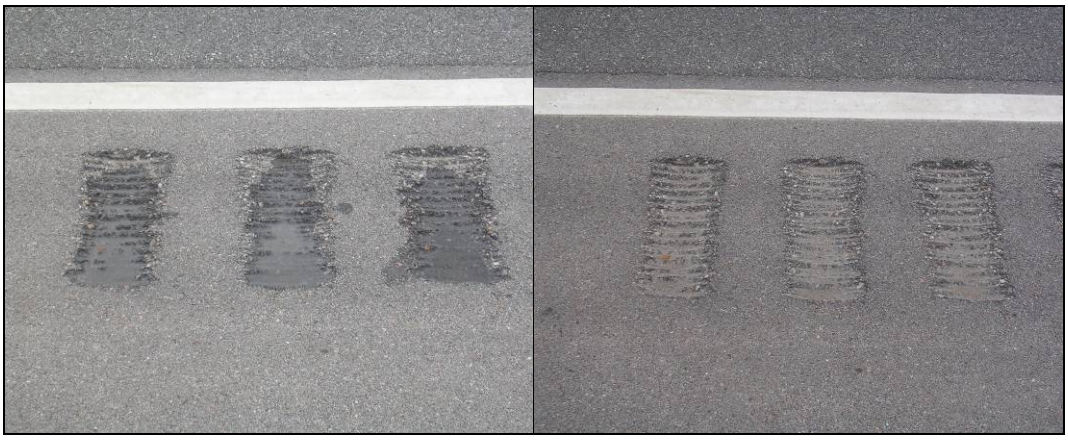

Figure 4.7: Rectangular Rumble Strips, Water Test Trial 2 at time = 0 hr. (left) and at time = 18 hrs. (right).

Figure 4.8: Football Rumble Strips, Water Test Trial 2 at time = 0 hr. (left) and at time = 18 hrs. (right).

Eighteen hours was enough time for complete removal of all water in each type of rumble strips, through evaporation or wind and traffic blowing the water out of the divot. A third trial was completed to determine a time of removal in between 30 min. and 18 hrs. The discussion of trial 3 is given in the next section.

4.1.1.5 Water Test Trial 3

For the third water test, one-quarter cup of water was poured into three consecutive divots of each rumble strip design. The rumble strips were then videotaped for 90 minutes. Ninety minutes was determined as the most feasible time based on videotape and time availability. The two types of strips could not be tested simultaneously so the rectangular rumble strips were tested first then the football shaped rumble strips. The number of vehicles passing by was tallied and the average wind speed for the 90-minute period was measured using a Kestrel 1000 pocket wind meter. Also the maximum wind speed was measured using the same meter. Table 4.3 shows the collected data for each rumble strip design.

Table 4.3: Collected data of Water Test Trial 3.

	Rectangular Rumble Strips	Football Rumble Strips
Maximum Wind Speed	5.4 mph	10.7 mph
Average Wind Speed	2.7 mph	4.2 mph
Total Vehicles Passed	911	892

Figure 4.9 shows the rectangular rumble strips at time t = 0 min., time t = 45 min., and at time t = 90 min. As one can see, there appears to be some noticeable difference in water removal. The slope of the shoulder can explain the way the water is dispersing downwards away from the white travel line. Also, the wind force created by passing vehicles (specifically semi tractor-trailers) spreads out the water.

Figure 4.9: Rectangular Rumble Strips, Water Test Trial 3 at time = 0 min. (top), at time = 45 min. (middle), and at time = 90 min. (bottom).

Figure 4.10 shows the football shaped rumble strips at time t =0 min., time t = 45 min., and at time t = 90 min. Again, one can see that there appears to be some noticeable difference in water removal. In Figure 4.10, again the slope of the shoulder and the higher wind force is dispersing the water away from the white edge line. In the

bottom picture of Figure 4.10, the water appears to be standing stagnant and the water outside of the divot has evaporated or soaked into the pavement.

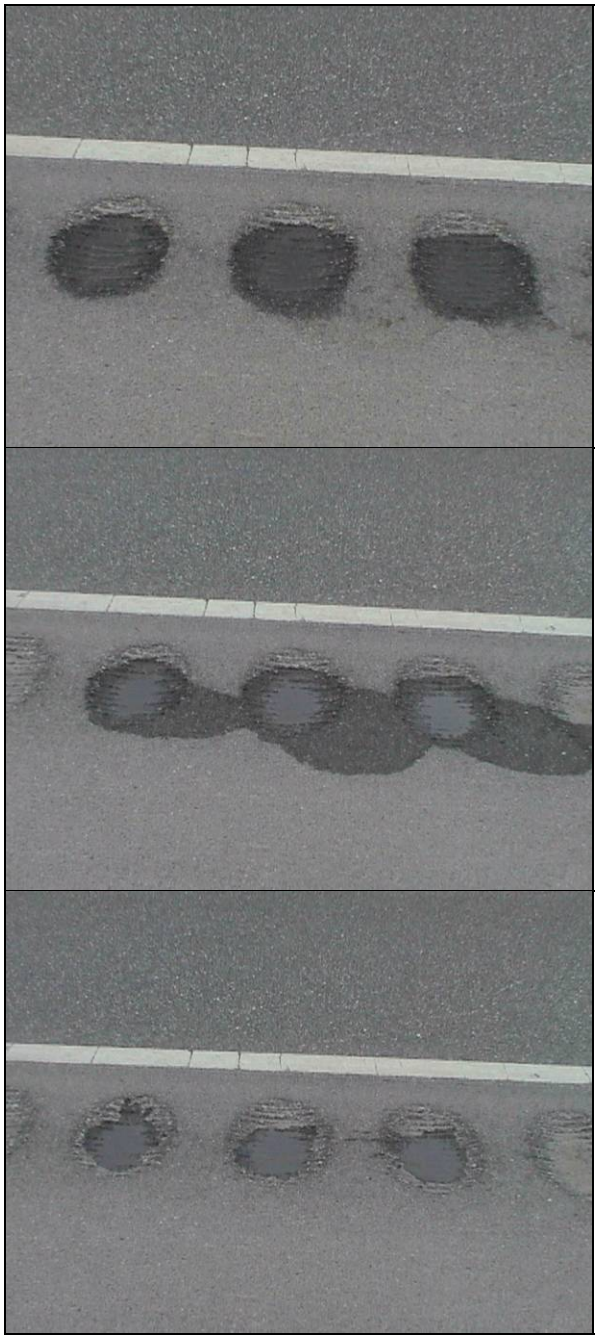

Figure 4.10: Football Rumble Strips, Water Test Trial 3 at time = 0 min. (top), at time = 45 min. (middle), and at time = 90 min. (bottom).

Each set of figures show that each rumble strip design had some noticeable water removal during the 90 min. period. However, no quantifiable difference could be measured in either design based on the removal of water during the 90 min. period.

4.1.1.6 Discussion

As previously stated, there appears to be no difference in the two designs of rumble strips based on the water and debris tests. In the first debris trial, no sand appeared to be removed from either type of rumble strips' divots after 30 minutes. In the second debris trial, there was still some sand left in each design after 18 hours. It was determined unfeasible to observe for any longer period due to project resource constraints.

As with the first debris trial, the first water trial showed no observable removal of water from either rumble strip type after 30 minutes. However, there was complete removal of water from both types of rumble strips during the second water trial. This suggests that water collecting in either design and standing for long periods is not a problem. Subjectively, it was concluded there was no difference between either rumble strip designs. In the third water trial, it was again observed that there is a gradual removal of water over time, although a definite time for complete removal was not determined. From the limited testing and subjective evaluation conducted in these trials, neither type of rumble strip appears to be better or worse than the other in regard to retaining debris or water.

4.1.2 Noise and Vibration Tests

In this comparison, the noise and vibration produced from vehicle crossover of the rectangular rumble strips was compared to the noise and vibration produced from vehicle crossover of the football shaped rumble strips. The interior noise levels and steering wheel vibration were tested because hearing and touch are the two senses that the rumble strips alert when the driver's visual senses become impaired (falling asleep, become distracted, etc.) (Brin, 2001).

4.1.2.1 Noise Test Experimental Design

For this experiment, it was decided that several different vehicles would need to be tested to represent the various vehicles that travel along the tested stretch of road, as well as all US highways. Six vehicles were selected and tested. They included a 1996 International 4900 DT466 Dump Truck, a 1999 Chevrolet 2500 Diesel Pickup Truck, a 2000 Ford Ranger XLT 2WD Pickup Truck, a 2002 Dodge Caravan, a 1996 Ford Taurus LX, and a 2005 Lexus RX 300 Sport Utility Vehicle. To measure the noise level a driver would hear when traversing a rumble strip, a Quest Technologies Q-300 Noise Dosimeter with an external microphone was attached to the driver's collar. A picture of the noise dosimeter can be seen in Figure 4.11, below.

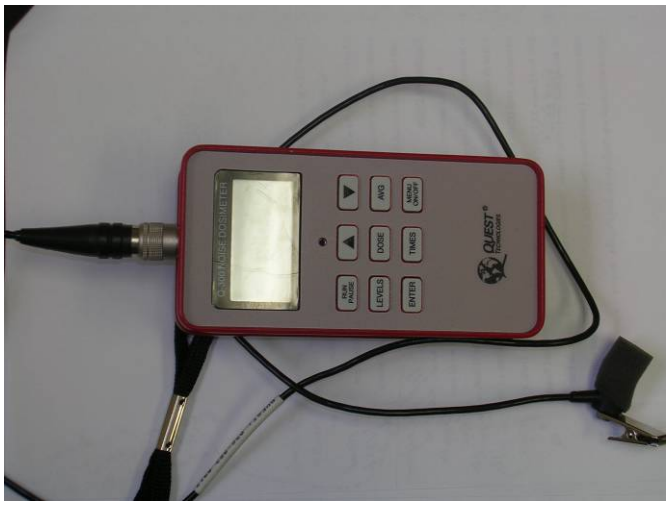

Figure 4.11: Quest Technologies Q-300 Noise Dosimeter with an external microphone

In order to accurately operate the noise dosimeter, an investigator went along for each ride. All interior noise including radio, air ventilation, and conversation was kept at a minimum. Three tests were completed for each vehicle: a base pass on smooth pavement to determine a normal average noise level for the vehicle, a pass across the rectangular rumble strips, and a pass along the football rumble strips. The driver of each vehicle maintained a speed of approximately 65 miles per hour (mph) for each trial of each vehicle. (Sixty-five mph is the speed limit on the section tested, as well as on many U.S. highways.) The driver maintained the speed while keeping the driver's side tires running along the rumble strips for a distance of approximately 900 feet. The average noise level in decibels (dBA) was collected and recorded with a laptop computer for each trial on each of the six vehicles. Figures 4.12, 4.13, and 4.14 show several of the vehicles crossing the different rumble strips.

Figure 4.12: 1996 International 4900 DT466 Dump Truck crossing rectangular rumble strips

Figure 4.13: 2002 Dodge Caravan crossing rectangular rumble strips

Figure 4.14: 2005 Lexus RX300 Sport Utility Vehicle crossing football shaped rumble strips

All tests were conducted along the section of K-96 multilane, divided highway between Wichita and Maize, KS. The rectangular rumble strips are along the eastbound lanes and the football shaped rumble strips are along the westbound lanes. The passing lane of each direction was barricaded off for safety purposes during testing. Each vehicle made the base noise level pass first along the westbound lane, turned around across the median, made the pass along the football rumble strips, turned around across the median, and finally made the pass along the rectangular rumble strips. The results of the tests on each vehicle are discussed in the next section.

4.1.2.2 Noise Test Data Analysis

Table 4.4 shows the data collected from each different run for each different vehicle.

Table 4.4: Average noise levels produced by driving over surfaces on K-96 as heard by the driver (dBA), the percent difference from the base is in parentheses

Vehicle Type	Base run	Rectangular Rumble Strips	Football Rumble Strips
1996 International 4900 DT 466 Dump Truck	85.9	109.0 (26.9%)	117.3 (36.6%)
1999 Chevrolet 2500 Diesel Pickup Truck	78.5	86.2 (9.8%)	86.2 (9.8%)
1996 Ford Taurus LX	69.6	78.9 (13.4%)	83.3 (19.7%)
2000 Ford Ranger XLT 2WD Pickup Truck	70.4	78.2 (11.1%)	78.9 (12.1%)
2002 Dodge Caravan	67.3	79.6 (18.3%)	83.5 (24.1%)
2005 Lexus RX 300 SUV	67.4	83.6 (24%)	83.3 (23.6%)

It was expected that the larger vehicles, i.e., the International and Chevrolet trucks, would give a higher base level based on noise produced from tire contact with the road surface, cab design, exterior wind resistance, and diesel engines. The four

other vehicles produced similar base noise levels, with a range of 67.3 dBA to 70.4 dBA.

Table 4.5: Differences in noise levels for each type of rumble strip and the base level (dBA) on K-96.

Vehicle Type	Rectangular Rumble Strips vs. Base	Football Rumble Strips vs. Base	Football Rumble Strips vs. Rectangular Rumble Strips
1996 International 4900 DT 466 Dump Truck	23.1	31.4	8.3
1999 Chevrolet 2500 Diesel Pickup Truck	7.7	7.7	0.0
1996 Ford Taurus LX	9.3	13.7	4.4
2000 Ford Ranger XLT 2WD Pickup Truck	7.8	8.5	0.7
2002 Dodge Caravan	12.3	16.2	3.9
2005 Lexus RX 300 SUV	16.2	15.9	-0.3

Table 4.5 shows the differences in noise levels for each type of rumble strip versus the base run and versus each other for each vehicle. For the rectangular rumble strip tests, each vehicle showed an increase in sound produced as compared to each respective base level. The International Dump Truck showed the largest increase of 23.1 dBA, and the Chevrolet Pickup Truck showed the least amount of increase of 7.7 dBA. The Ford Ranger Pickup Truck was close to the Chevrolet with an increase of only 7.8 dBA. The Ford Taurus, Dodge Caravan and Lexus SUV increased by 9.3 dBA, 12.3 dBA, and 16.2 dBA, respectively.

For the football shaped rumble strips, each vehicle also showed an increase in sound produced as compared to each respective base level. Again, the International Dump Truck showed the largest increase of 31.4 dBA, and the Chevrolet Pickup Truck showed the lowest increase of only 7.7 dBA. The Ford Ranger, Ford Taurus, Dodge

Caravan, and Lexus SUV increase by 8.5 dBA, 13.7 dBA, 16.2 dBA, and 15.9dBA, respectively.

In comparing the rectangular rumble strips to the football shaped rumble strips for each vehicle, some vehicles did better and some vehicles did similar. The International, the Ford Taurus, and the Dodge Caravan all experienced increased noise levels when driven over the football shaped rumble strips as compared to the rectangular rumble strips. They increased by 8.3 dBA, 4.4 dBA, and 3.9 dBA, respectively. The Ford Ranger only had an increase in noise level of 0.7 dBA. The Chevrolet Pickup Truck showed no increase or decrease. Both types of rumble strips produced an average noise level of 86.2 dBA, still recognizable to the human ear. The Lexus SUV showed a decrease in noise when comparing the football shaped rumble strips to the rectangular rumble strips. The Lexus decreased by 0.3 dBA, but both types produced a noise level approximately 16 dBA higher than the smooth surface base level for the same vehicle.

4.1.2.3 Noise Test Discussion

Human response to noise is subjective and can vary from person to person. Factors that can influence individual response include the loudness, frequency, and time pattern; the amount of background noise present before intruding noise; and the nature of the activity that the noise affects (Minor, 2005). For this experiment, the background noise was collected from the base run, i.e., the noise attributed to each car driving over smooth pavement. The nature of the activity for this experiment was driving and the potential hazard of running off the road. The noise created from the rumble strips has an effect on alerting drivers of running off the road.

As discussed earlier, to become aware of a sound and be "alerted to the presence of that sound, the sound must typically rise 9 to 10 dBA above the sound of the environment (Lipscomb, 1995). In the case of this experiment, the sound of the environment refers to the base level when normally driving over smooth surface pavement. The International, Ford Taurus, Dodge Caravan, and Lexus SUV all produced noise levels greater than nine decibels for both types of rumble strips when compared to the base level. Therefore, it is possible that drivers of these vehicles would be audibly alerted when crossing over either type of rumble strip on a shoulder or centerline of a highway. This is beneficial to a large portion of American motorists including truck drivers and families who typically operate heavy duty semi-trucks and sedans/minivans/SUVs, respectively. For the Ford Ranger and Chevrolet Pickup Truck, neither reached an increase of at least nine decibels for either rumble strip type, but there was a definite increase over the base level for each vehicle and rumble strip type.

As far as comparison between each type of rumble strip, there was only a noticeable difference in three of the six vehicles tested or 50%. The other three vehicles had similar noise levels for each rumble strip type. It can be concluded that each type of rumble strip produces a recognizable amount of noise when crossed over, and the football shaped rumble strips produce at least as much noise as the rectangular shaped rumble strips.

4.1.2.4 Vibration Test Experimental Design

For this experiment, like the noise tests, it was determined that several different vehicles would need to be tested to represent the various vehicles that travel along the tested stretch of road, as well as all American highways. The same six vehicles were

selected and tested. To measure the vibration level a driver would feel when traversing a rumble strip, a Summit Instruments 35203A Digital Accelerometer was attached to the center of the steering wheel. Figure 4.15 shows the accelerometer.

Figure 4.15: Summit Instruments 35203A Digital Accelerometer

The accelerometer was directly connected to a laptop computer to collect readings. In order to accurately operate the accelerometer, an investigator was along for each ride. Three tests were completed for each vehicle: a base pass on smooth pavement to determine a normal vibration level for the vehicle, a pass on the rectangular rumble strips, and a pass on the football rumble strips. The driver of each vehicle maintained a speed of approximately 65 miles per hour (mph) for each trial of each vehicle. The driver maintained the speed while keeping the driver's side tires running along the rumble strips for a distance of approximately 900 feet. Approximately 200 samples were collected for each trial on each vehicle. The accelerometer measured the instantaneous vibration (or g-force) in three axes, x, y, and z. All tests were conducted along the section of K-96 multilane divided highway between Wichita and Maize, KS. The rectangular rumble strips are along the eastbound lanes and the

football shaped rumble strips are along the westbound lanes. Each vehicle made the base vibration level pass first along the westbound lane, turned around across the median, made the pass along the football rumble strips, turned around across the median, and finally made the pass along the rectangular rumble strips. The results of the tests on each vehicle are discussed in the next section.

4.1.2.5 Vibration Test Data Analysis

The Summit Instruments accelerometer collected vibration along three axes. In order to make comparisons, the three axis data was combined into a single resultant (f(x,y,z)) using the equation:

$$f(x, y, z) = \sqrt{x^2 + y^2 + z^2} \qquad \text{(Equation 1)}$$

This equation was used for each sample collected for each trial on each vehicle. Table 4.6 shows the average f(x,y,z) for the base, football shaped rumble strip, and rectangular shaped rumble strip runs.

Table 4.6: Average f(x,y,z) for vibration trials (g) on K-96, the percent difference from the base is given in parentheses

Vehicle Type	Base run	Football rumble strips	Rectangular rumble strips
1996 International 4900 DT 466 Dump Truck	1.027	1.074 (4.5%)	1.084 (5.5%)
1999 Chevrolet 2500 Diesel Truck	1.02	1.036 (1.6%)	1.049 (2.8%)
1996 Ford Taurus LX	1.003	1.089 (8.6%)	1.027 (2.4%)
2000 Ford Ranger XLT 2WD Pickup Truck	1.015	1.053 (3.7%)	1.081 (6.5%)
2002 Dodge Caravan	1.001	1.043 (4.2%)	1.021 (2%)
2005 Lexus RX330 SUV	1.012	1.115 (10.2%)	1.128 (11.5%)

There does not seem to be any difference when looking at plots of the resultant data for each vehicle and rumble strip type. An example of this can be seen when

comparing Figures 4.16 and 4.17. They are the resultant plots for the Dodge Caravan for each type of rumble strip trial.

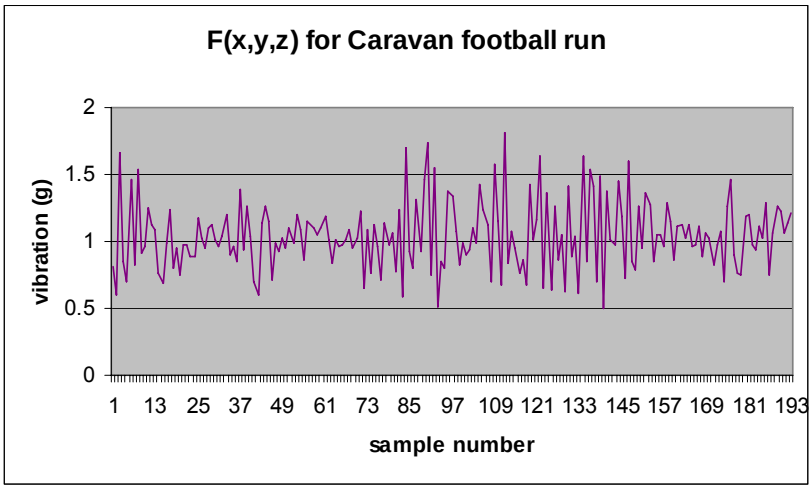

Figure 4.16: Resultant plot for Dodge Caravan football rumble strip trial

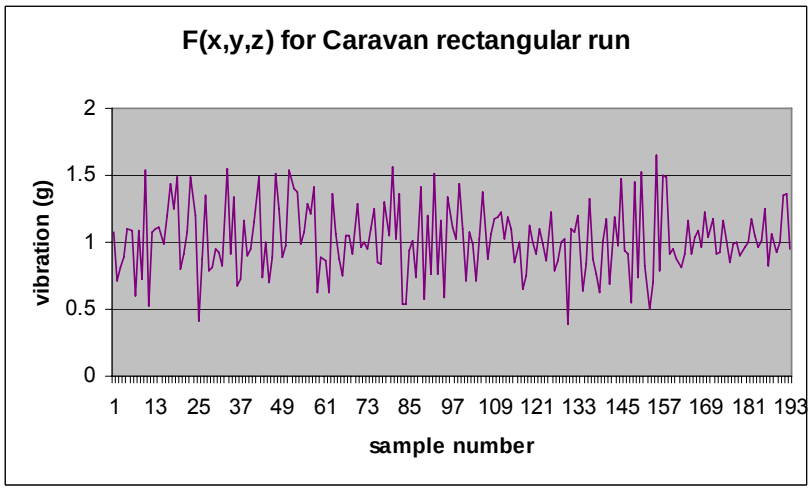

Figure 4.17: Resultant plot for Dodge Caravan rectangular rumble strip trial

When compared visually, there does not seem to be any difference in the two plots as far as amplitude, maximum, and minimum values. Both types of rumble strips show properties of causing comparable vibration and tactile response. The remaining resultant plots for the other vehicles can be found in Appendix C.

In order to compare the rectangular rumble strips to the football shaped rumble strips, two sample t-tests were conducted with the data from each vehicle. Each test was run at a 95% confidence level, i.e., alpha level of 0.05. For each test, the null hypothesis was that the means of the resultant for each of the two runs were equal. The alternate hypothesis was that the means were not equal. Table 4.7 shows the results of each paired t-test for each vehicle.

Table 4.7: Two-Sample T-Test results for each vehicle and rumble strip type on K-96

Vehicle	Football Shaped Rumble Strip Mean	Rectangular Rumble Strip Mean	P-Value
1996 International 4900 DT 466 Dump Truck	1.074	1.084	0.658
1999 Chevrolet 2500 Diesel Truck	1.036	1.049	0.428
1996 Ford Taurus LX	1.089	1.027	0.018
2000 Ford Ranger XLT 2WD Pickup Truck	1.053	1.081	0.141
2002 Dodge Caravan	1.043	1.021	0.407
2005 Lexus RX330 SUV	1.115	1.128	0.526

For five of the six vehicles, there was no statistical difference between the football shaped rumble strips and the rectangular rumble strips, as determined by the p-value being less than the alpha value of 0.05 for the five vehicles. The five vehicles were the International Dump Truck, the Chevy Diesel Truck, the Ford Ranger Pickup Truck, the Lexus SUV, and the Dodge Caravan. The tests showed that the means could be equal at a 95% confidence level for the five vehicles. For the Ford Taurus, the p-value was lower than the alpha of 0.05, showing that the means of the resultants were not equal at a 95% confidence level.

4.1.2.6 Vibration Test Discussion

Each type of rumble strip produced a considerable vibratory response for each vehicle tested. When compared visually, there is no noticeable difference, i.e., the

resultant plots for each rumble strip type appear similar with respect to each vehicle. For four of the vehicles, the International Dump Truck, the Chevrolet Diesel Truck, the Ford Ranger Pickup Truck, and the Lexus SUV, the rectangular rumble strips produced a higher vibratory level as compared to the football rumble strips. Also, for the four vehicles, the rectangular rumble strips produced a greater percent difference in vibration from the base value than did the football rumble strips. For the Ford Taurus and the Dodge Caravan, the football rumble strips produced a higher vibratory response and percent difference from the base value as compared to the rectangular rumble strips.

Next, statistical analysis was performed to compare the means of the resultants for each vehicle on each type of rumble strip. For five of the vehicles, no statistical difference was found between the means of the resultants at a 95% confidence level. The five vehicles were the International Dump Truck, the Chevy Diesel Truck, the Ford Ranger Pickup Truck, the Lexus SUV, and The Dodge Caravan. For the Ford Taurus, the means were found to be significantly different at a 95% confidence level. The Ford Taurus had a higher mean vibration resultant on the football shaped rumble strips. For the other five vehicles there is statistically no difference, nor is there visually a difference in the resultant plots. It can be concluded that both types of rumble strip produces a significant tactile response; however, there is no statistical difference between the mean values of vibration for five of the six tested vehicles.

4.1.2.7 Noise and Vibration Correlation with Vehicle Tires

The tire sizes and air pressure for the front driver's side tire from each vehicle was collected using a standard tire gauge. The tire sizes were collected by reading the size off of each vehicle's tire. Figure 4.18 shows how to read the dimensions of a tire

from the imprint on the tire. Goodyear (2006) defines the tire width as measured from sidewall to side wall measure in millimeters (mm). Tire width is the first number in the code, so the width of the tire in Figure 4.18 is 215 mm. The second number describes the aspect ratio of the tire's height to the tire's width. For the tire in Figure 4.18, the height of the tire is 65% of the tire's width, or 139.75 mm. All numbers given in millimeters were converted to inches. The tire's height is measured from where the wheel and tire meet to the outer most edge of the tire. By adding the wheel diameter (measured in inches on tire sidewall) to twice the tire's height, we get the tire's diameter.

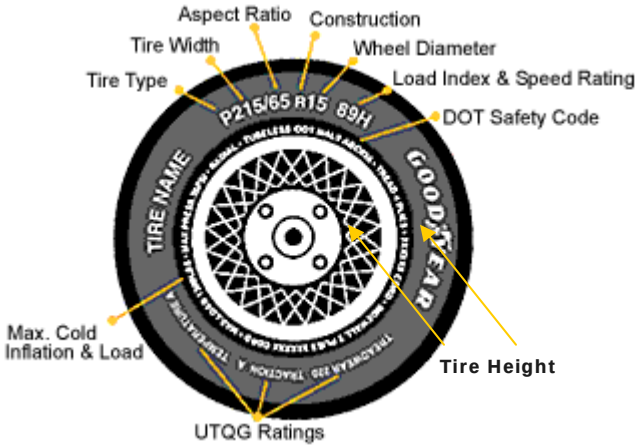

Figure 4.18: How to read the measurements of a tire (Goodyear, 2006)

The values for each vehicle's tire pressure, tire width, and tire diameter are given in Table 4.8. Figures 4.19 and 4.20 show measurements being collected from two of the vehicles.

Figure 4.19: Measuring the air pressure on the 1996 International 4900 DT 466 Dump Truck

Figure 4.20: Measuring the air pressure on the 1996 Ford Taurus LX

Table 4.8: Tire pressure, tire width and tire diameter for the tested vehicles

Vehicle	Tire Pressure (psi)	Tire Width (in.)	Tire Diameter (in.)
1996 International 4900 DT466 Dump Truck	100	40.00	11.61
1999 Chevrolet 2500 Diesel Pickup Truck	50	30.50	9.65
1996 Ford Taurus LX	30	25.50	8.07
2000 Ford Ranger XLT 2WD Pickup Truck	34	27.40	8.86
2002 Dodge Caravan	30	26.80	8.46
2005 Lexus RX 300 SUV	31	28.50	8.86

From this data and the average noise and vibration for each type of vehicle on each type of strip, a simple correlation analysis was performed. Table 4.9 shows the Pearson correlation values for the average noise and vibration for each type of rumble strip versus tire pressure, tire width, and tire diameter.

Table 4.9: Average noise and vibration by rumble strip type versus tire pressure, tire width, and tire diameter

Test	Type of Rumble Strip	Pressure (p-value)	Tire Width (p-value)	Tire Diameter (p-value)
Noise	Rectangular	0.981 (0.001)	0.965 (0.002)	0.990 (0.000)
	Football	0.971 (0.001)	0.920 (0.009)	0.958 (0.003)
Vibration	Rectangular	0.204 (0.699)	0.339 (0.511)	0.335 (0.516)
	Football	-0.06 (0.910)	-0.081 (0.879)	0.001 (0.998)

The values for the average noise collected for each type of rumble strip are all close to 1 with p-values close to zero. Based on the six vehicles used, there is a definite positive correlation between noise and tire pressure, noise and tire width, and noise and tire diameter for both types of rumble strips. As far as vibration, there is no correlation with tire pressure, tire width, and tire diameter as the values are close to zero with high p-values for each type of rumble strip. There are several possible reasons for the obtained results. First, the vehicles used all vary in suspension

flexibility; therefore the vibration in each car is going to drastically vary. Second, the driver of the vehicles had to maintain minimum control of the steering wheel, causing some inertial dampening on the vibration. The noise was controlled, in a sense, from vehicle to vehicle. All outside conditions and possible internal vehicle noise was kept a minimum. This gave more accurate noise readings for each vehicle. Conducting more trials and the measurement of noise, vibration, tire pressure, tire width, and tire diameter, could give more accurate results.

4.1.3 Average Daily Traffic and Accident Analysis

With the help of the KDOT Bureau of Transportation Planning, the daily traffic volumes, including trucks, for the section of K-96 was acquired and the Annual Average Daily Traffic (AADT) for the highway was computed. Figure 4.21 shows the volumes distributed along the section of K-96.

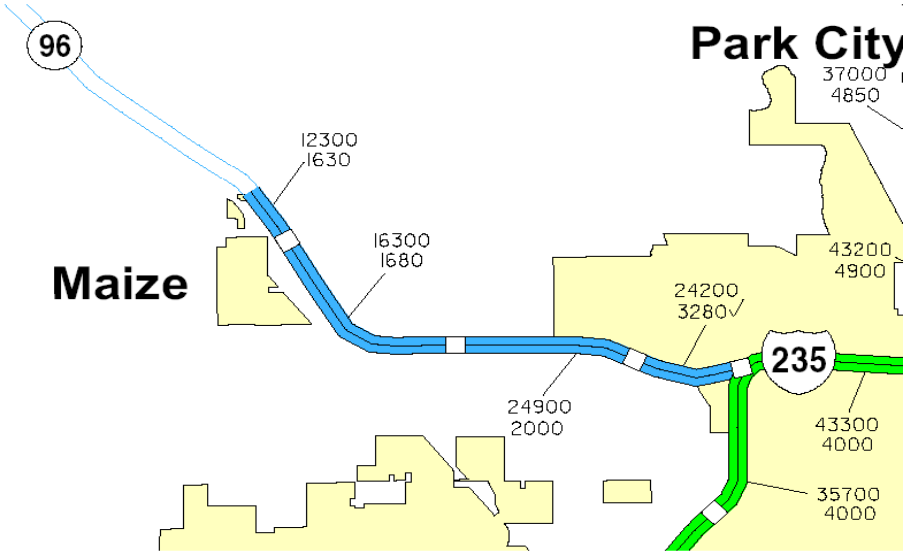

Figure 4.21: Average Daily Traffic Volumes (top number) and Truck Volumes (bottom number) for K-96 (Spicer, 2006a)

The traffic volumes were measured at different locations along K-96. The average daily total traffic for the section of K-96 is 19,425 vehicles per day. The average daily truck traffic for the section of K-96 is 2,148 trucks per day.

In 2004, there were 880 accidents that involved drivers who fell asleep at the wheel. The accidents cost $137,195,750 in property damage, medical expenses, and unclassified indirect costs. With the help of the KDOT Crash and Accident Statisticians, accidents along K-96 were analyzed to determine if they qualified as run-off-the road accidents. Accidents involving both passenger vehicles and trucks were looked at and evaluated. Eliminated from qualifying accidents were those attributed to weather conditions (rain, snow, fog, ice, etc.), those attributed to problems with the driver's vehicle (brakes tires, wheels, headlights, cargo, etc.), and those attributed to pedestrian, bicyclist or animals (deer). Any accident attributed to driving while intoxicated, changing lanes, speeding, failure to signal, driver illness, or a medical condition was also eliminated. Included in the qualifying accidents were those only occurring at non-intersection locations, as well as those occurring on the roadside, those that were attributed to the circumstances surrounding the drivers condition (fell asleep at wheel, distracted by something in or around vehicle, failed to give full time and attention).

For K-96, the analysis period was from October 2003 to October 2005, this is equal to one year before and one year after the installation of the rumble strips along K-96). There were no rumble strips along K-96 prior to the installation in October of 2004. There were nine qualifying accidents for the analysis period, all involving passenger vehicles. Five of the accidents occurred before the installation of the rumble strips along K-96, and the other four occurred after the installation. Therefore there was a

20% reduction in run-off-the-road accidents from October 2003 to October 2005. Two of the five accidents before the installation of the rectangular rumble strips occurred on the eastbound side of K-96. Only one of the accidents after the installation of the rectangular rumble strips occurred on the eastbound side of K-96, a decrease of 50%. Three of the five accidents before the installation of the football shaped rumble strips occurred on the westbound side of K-96. After the installation of the football shaped rumble strips, there were three qualifying accidents that occurred on the westbound side of K-96, showing no change. Of the five qualifying accidents before the installation, three caused property damage and two caused injuries to the vehicles' occupants. None of the five accidents were fatal. Of the four qualifying accidents after the installation, two caused property damage and three caused injuries to the vehicles' occupants. There is not enough data to show if one type of rumble strip is more effective on K-96. Therefore, no conclusion can be reached about which type of rumble strip can reduce accidents more. A study should be done for a longer analysis period.

4.2 Rumble Strips along US 40

The centerline rumble strips along US Highway 40 between Lawrence and Topeka, KS were installed in May of 2005. The section of US 40 is a two-lane, two-way highway with several no passing zones. The research team was there to observe the installation and collected photographs and the football shaped rumble strip dimensions. A single football rumble strip indentation has a depth of approximately 0.375 inches, a width of 8 inches parallel to the line of travel, and a length of 12 inches perpendicular to the line of travel. The rumble strips are placed in a continuous pattern 12 in center to center.

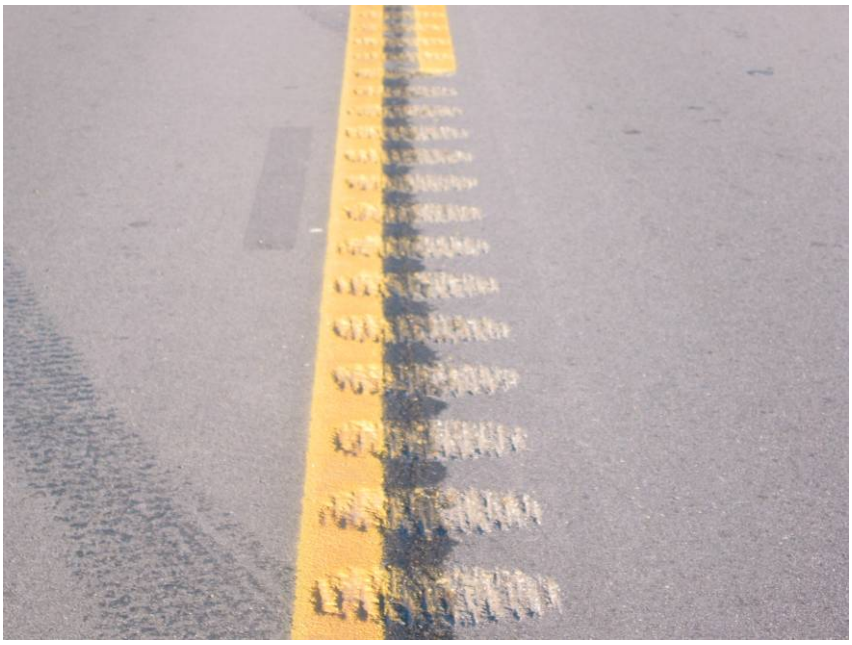

Figure 4.22: Centerline football shaped rumble strips along US Highway 40 (viewed parallel to the path of travel)

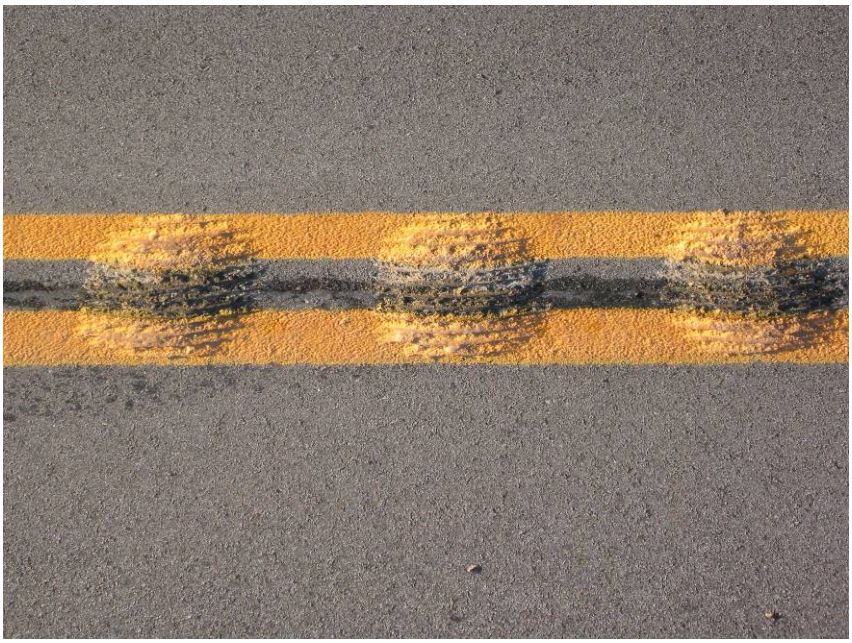

Figure 4.23: Centerline football shaped rumble strips along US Highway 40 (viewed perpendicular to path of travel)

Figures 4.22 and 4.23 show the football shaped rumble strips along the centerline of US 40. The noise and vibration produced by the centerline rumble strips

were collected using similar vehicles as on K-96. The Ford Taurus, the Dodge Caravan, the Lexus SUV, and the Ford Ranger Truck were the exact same as used on K-96. The International Dump Truck and the Chevrolet Truck were exact makes and models of each, but were not the exact same vehicles used on K-96.

4.2.1 Noise and Vibration Tests

Noise and vibration levels were collected for the set of vehicles using the same procedure as with K-96. However, since there were no rectangular rumble strips to compare against, only a base noise and vibration level and a football rumble strip noise and vibration level were collected for each vehicle. Also, the vehicles were tested at 55 mph instead of 65 mph since 55 mph is the speed limit for the section of US 40.

4.2.1.2 Noise Test Data Analysis

Table 4.10 shows the data collected from each different run for each different vehicle.

Table 4.10: Average noise levels produced by driving over surfaces on US 40 as heard by the driver (dBA)

Vehicle Type	Base run	Football Rumble Strips	Difference	% Difference
1996 International 4900 DT 466 Dump Truck	75.4	84.6	9.2	12.2
1999 Chevrolet 2500 Diesel Pickup Truck	68.3	82.1	13.8	20.2
1996 Ford Taurus LX	64.7	76.6	11.9	18.4
2000 Ford Ranger XLT 2WD Pickup Truck	66.0	80.6	14.6	22.1
2002 Dodge Caravan	63.8	82.3	18.5	29.0
2005 Lexus RX 300 SUV	65.8	76.1	10.3	15.7

It was expected that the larger vehicles, i.e., the International and Chevrolet trucks, would give a higher base level based on noise produced from tire contact with the road surface, cab design, exterior wind resistance, and diesel engines. The four other vehicles produced similar base noise levels, within a range of 63.8 dBA to 66.0

dBA. All of the vehicles showed a percent increase over the base run of at least ten percent. Table 4.11 shows the difference in the noise level at 55 mph and 65 mph for each vehicle tested.

Table 4.11: Noise levels on football shaped rumble strips at different speeds for vehicles tested

Vehicle Type	@ 55 mph	@ 65 mph	Difference	% Difference
1996 International 4900 DT 466 Dump Truck	84.6	117.3	32.7	27.8
1999 Chevrolet 2500 Diesel Pickup Truck	82.1	86.2	4.1	4.8
1996 Ford Taurus LX	76.6	83.3	6.7	8
2000 Ford Ranger XLT 2WD Pickup Truck	80.6	78.9	-1.7	-2.2
2002 Dodge Caravan	82.3	83.5	1.2	1.4
2005 Lexus RX 300 SUV	76.1	83.3	7.2	8.6

4.2.1.2 Noise Test Discussion

For five of the six vehicles tested, there was a minimal change in the noise produced by the football shaped rumble strips at the higher speed. None of the vehicles had a percent difference in the noise produced at 55 mph vs. 65 mph greater than 9%. For the International Dump Truck, the noise produced increased by a large amount, i.e., 32.7 decibels or 27.8% from 55 mph to 65 mph. This could be due to the design and noise caused directly from the truck (diesel engine noise, exterior wind noise from increased speed, etc.).

As discussed in a previous section, to become aware of a sound and be “alerted to the presence of that sound, the sound must typically rise 9 to 10 dBA above the sound of the environment (Lipscomb, 1995). In the case of this experiment, the sound of the environment would be the base level when normally driving over smooth surface pavement. All of the vehicles produced noise levels greater than nine decibels for the football shaped rumble strips when compared to the base level. Therefore, it is

reasonable to believe that drivers of these vehicles would be audibly alerted when crossing over the centerline of a highway.

4.2.1.3 Vibration Test Data Analysis

The Summit Instruments accelerometer used collected vibration along three axes. In order to make comparisons, the three axis data was combined into a single resultant (f(x,y,z)) using the equation:

$$f(x, y, z) = \sqrt{x^2 + y^2 + z^2} \qquad \text{(equation 1)}$$

This equation was used for each sample collected for each trial on each vehicle. Table 4.12 shows the average f(x,y,z) for the base and the football shaped rumble strip runs.

Table 4.12: Average f(x,y,z) for vibration trials (g) on US 40

Vehicle Type	Base run	Football rumble strips	Difference	% Difference
1996 International 4900 DT 466 Dump Truck	1.011	1.004	-0.007	-0.7
1999 Chevrolet 2500 Diesel Truck	1.032	1.058	0.025	2.5
1996 Ford Taurus LX	1.003	1.140	0.137	13.7
2000 Ford Ranger XLT 2WD Pickup Truck	0.998	1.211	0.213	21.3
2002 Dodge Caravan	0.991	1.246	0.255	25.7
2005 Lexus RX330 SUV	0.993	1.018	0.025	2.5

Again, this test was run at 55 mph, instead of 65 mph as was the first experiment. Table 4.13 shows the difference in the vibration level from 55 mph to 65 mph.

Table 4.13: Vibration levels on football shaped rumble strips at different speeds for vehicles tested

Vehicle Type	@ 55 mph	@ 65 mph	Difference	% Difference
1996 International 4900 DT 466 Dump Truck	1.004	1.074	0.070	6.5
1999 Chevrolet 2500 Diesel Truck	1.058	1.036	-0.022	-2.1
1996 Ford Taurus LX	1.140	1.089	-0.051	-4.9
2000 Ford Ranger XLT 2WD Pickup Truck	1.211	1.053	-0.158	-15.0
2002 Dodge Caravan	1.246	1.043	-0.203	-19.5
2005 Lexus RX330 SUV	1.018	1.115	0.097	8.7

4.2.1.4 Vibration Test Discussion

All of the vehicles experienced an increase in average vibration in the steering wheel from the base to the football rumble strips except for the International Dump Truck. The International Dump Truck experienced a decrease in the resultant vibration of 0.007g's, or -0.7%, from the base trial to the football shaped rumble strips trial. An explanation for this could be the speed at which the test was performed. Furthermore, a look at the resultant plots in Figure 4.24 for the International Dump Truck base run and rumble strips test run will show that there is no noticeable difference between the base run and the football shaped rumble strip run at 55 mph. All other resultant plots can be found in Appendix C.

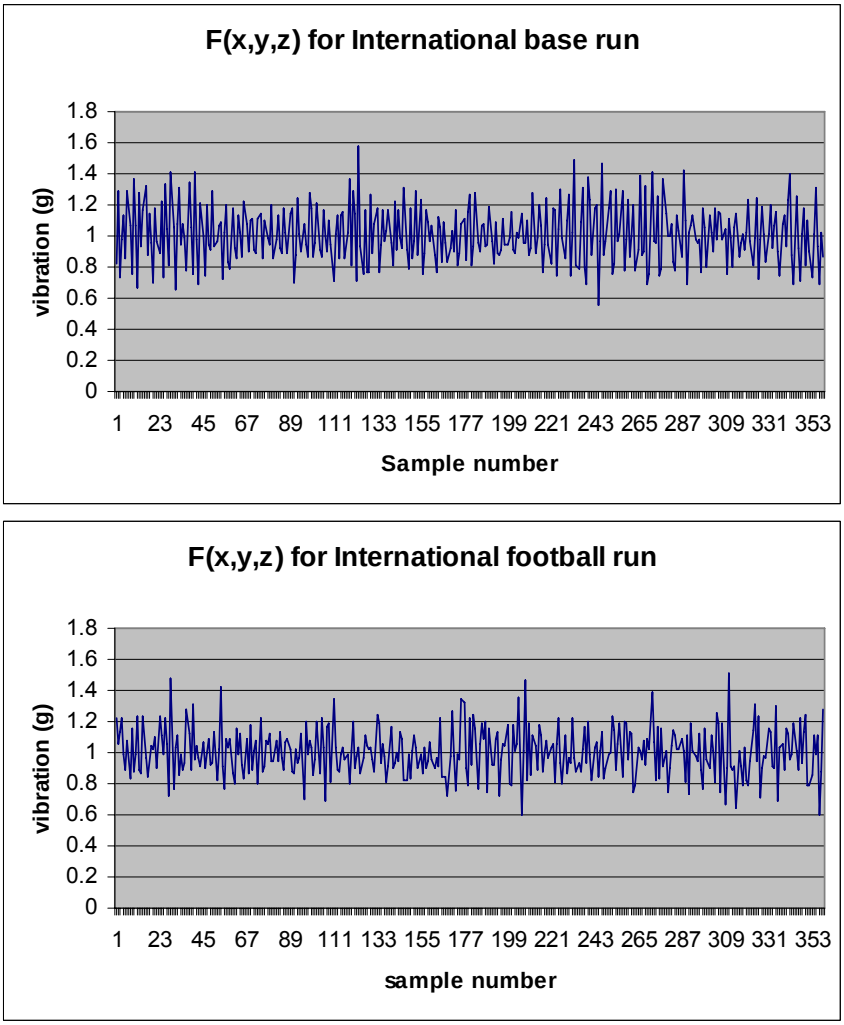

Figure 4.24: Vibration resultant plots for the International base run (top) and rumble strips test run (bottom)

For the Chevrolet Truck and the Lexus SUV, a 2.5% increase in vibration was measured from the rumble strips over the base. It is undetermined if this is enough of an increase from the base level to warn drivers at 55 mph. The result is comparable to the vibration values measured for the vehicles on K-96. For the last three vehicles, the Ford Taurus, the Ford Ranger, and the Dodge minivan, increases of 13.7%, 21.3%, and 25.7% were calculated for the rumble strips over the base. These are large increases as compared to the measurements from K-96.

The average vibration readings for four of the six vehicles tested (Ford Taurus, Ford Ranger, Chevrolet Pickup, and Dodge Caravan) were higher at the lower speed. For the International Dump Truck and the Lexus SUV, the average vibration increased by 6.5% and 8.7% at the higher speed, respectively. A reasonable explanation might be that since this test was at a slower speed, the four vehicles with higher vibration levels at a lower speed had more tire contact with the rumble strip indentations.

4.2.2 Average Daily Traffic and Accident Analysis

With the help of the KDOT Bureau of Transportation Planning, the daily traffic volume, including trucks, for the section of US 40 was acquired and the AADT for the highway was computed. Figure 4.25 shows the distributed volumes for US 40.

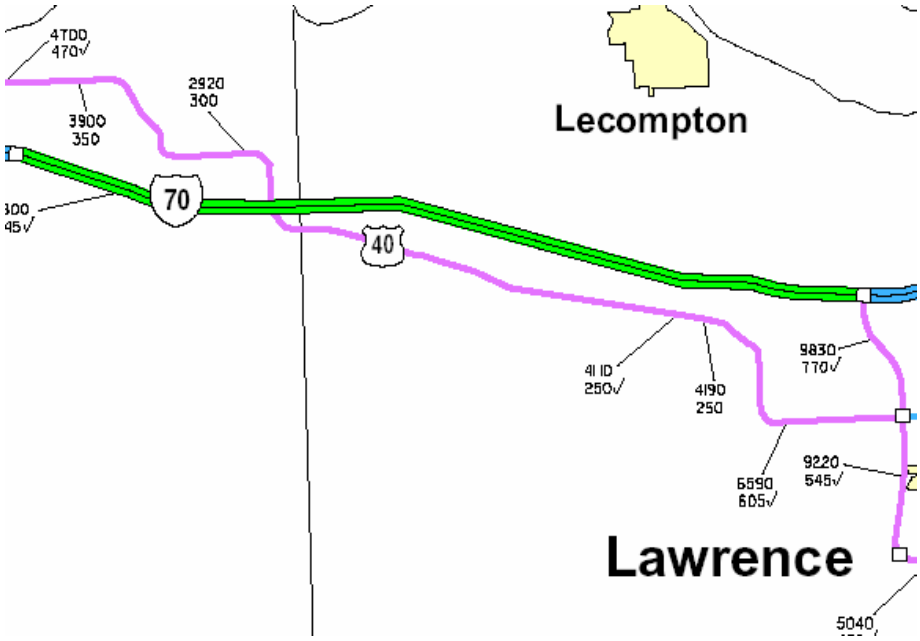

Figure 4.25: Average Daily Traffic Volumes (top number) and Truck Volumes (bottom number) for US Highway 40 (Spicer, 2006b)

The traffic volumes were measured at different locations along US 40. For the section of US 40, the average daily total traffic is 3740 vehicles per day. The average daily truck traffic for the section of US 40 is 270 trucks per day.

With the help of the KDOT Crash and Accident Statisticians, accidents along US 40 for a six month period before and after the installation were analyzed to determine if they qualified as center-crossover accidents. Accidents involving both passenger vehicles and trucks were looked at and evaluated. Eliminated from qualifying accidents were those attributed to weather conditions (rain, snow, fog, ice, etc.), those attributed to problems with the driver's vehicle (brakes tires, wheels, headlights, cargo, etc.), and those attributed to pedestrian, bicyclist or animals (deer). Any accident attributed to driving while intoxicated, driver illness, or a medical condition was also eliminated. Included in the qualifying accidents were those only occurring at non-intersection locations, as well as those that were attributed to the circumstances surrounding the drivers condition (fell asleep at wheel, distracted by something in or around vehicle, failed to give full time and attention). No qualifying accidents were found for the section of US 40.

Chapter 5: Surveys

5.1 Bicyclist Survey

The KSU rumble strip research team distributed a survey to a Wichita based bicyclist group. The purpose of the survey was to gage the like or dislike of football shaped rumble strips as compared to rectangular rumble strips. Responses were collected and the data was analyzed to determine if one type of strip is preferred over the other.

5.1.1 Data Analysis

The bicyclist opinion surveys were distributed at a monthly meeting held by the bicyclist group. The bicyclists had all become familiar with the football rumble strips and rectangular rumble strips installed along K-96 highway between Wichita and Maize, KS. Members had either ridden or driven by each type of strip located on the test section of highway. Twenty-three responses were gathered from the attending members. These responses are believed to be representative of the bicyclist group's entire membership. The survey consisted of eight questions, and participants were asked to rank their opinion on a scale of one to five for each question. A copy of the survey can be found in Appendix D. Each question and answers received will be discussed in detail. Also, any comments made by the bicyclists are included.

Question 1: What do you think of the rectangular rumble strips?

Participants were asked to rank their opinions from one (definitely dislike) to five (definitely like) about the rectangular rumble strips. The distribution can be seen in Figure 5.1.

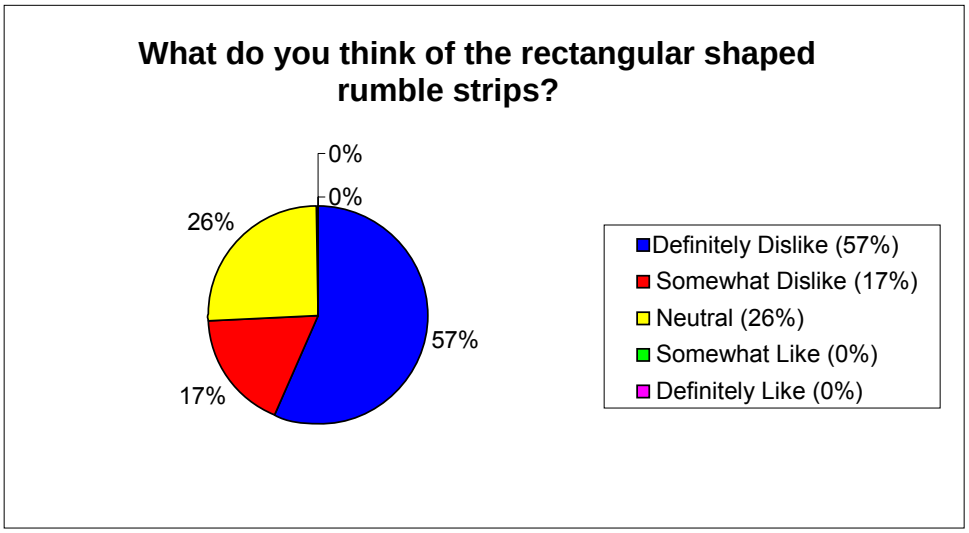

Figure 5.1: Response distribution for Question 1, bicyclist survey

Seen in Figure 5.1, 74% (n = 17) of the respondents somewhat dislike or definitely dislike the rectangular rumble strips. Fifty-seven percent (n = 13) responded that they definitely dislike the rectangular rumble strips. Seventeen percent (n = 4) responded dislike and twenty-six percent (n = 6) responded neutral.

Question 2: What do you think of the football shaped rumble strips?

Participants were asked to rank their opinions from one (definitely dislike) to five (definitely like) about the football shaped rumble strips. The distribution can be seen in Figure 5.2.

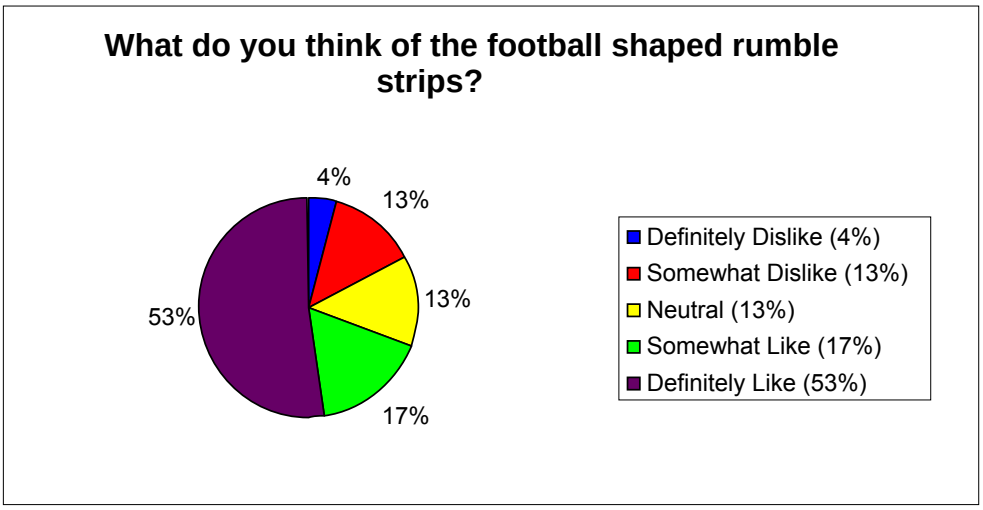

Figure 5.2: Response distribution for Question 2, bicyclist survey

Fifty-three percent (n = 12) of those surveyed said that they definitely like the football shaped rumble strips. A total of 70% (n = 16) said they either somewhat liked or definitely like the football shaped rumble strips. Thirteen percent (n = 3) responded they had no opinion and thirteen percent (n = 3) responded they somewhat disliked the football rumble strips. Only four percent (n = 1) responded that he/she definitely disliked the football rumble strips.

Question 3: How do the football shaped rumble strips compare to the rectangular rumble strips?

Participants were asked to rank their opinions from one (definitely worse) to five (definitely better) about the football shaped rumble strips as compared to the rectangular rumble strips. The distribution can be seen in Figure 5.3.

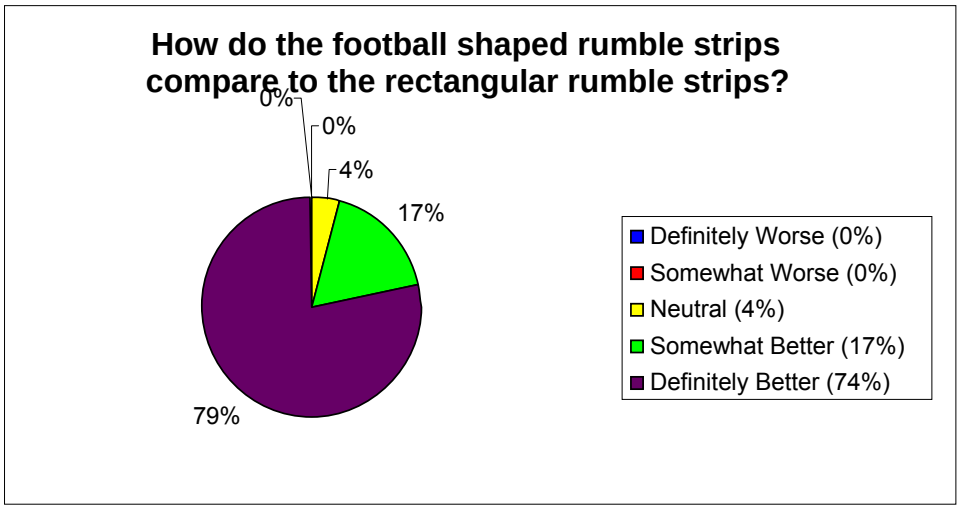

Figure 5.3: Response distribution for Question 3, bicyclist survey

A majority of 79% (n = 18) stated that the football rumble strips were definitely better than the rectangular rumble strips. An additional 17% (n = 4) stated that the football rumble strips were better than the rectangular rumble strips, i.e., 96% (n = 22) felt the football shaped rumble strips were somewhat or definitely better than the rectangular rumble strips. None of those surveyed responded that they somewhat or definitely disliked the football rumble strips as compared to the rectangular rumble strips.

Question 4: The placement of the football shaped rumble strips gave me plenty of room to ride on the shoulder.

Participants were asked to rank their opinions from one (definitely disagree) to five (definitely agree) about the placement of the football shaped rumble strips along the shoulder. The distribution can be seen in Figure 5.4.

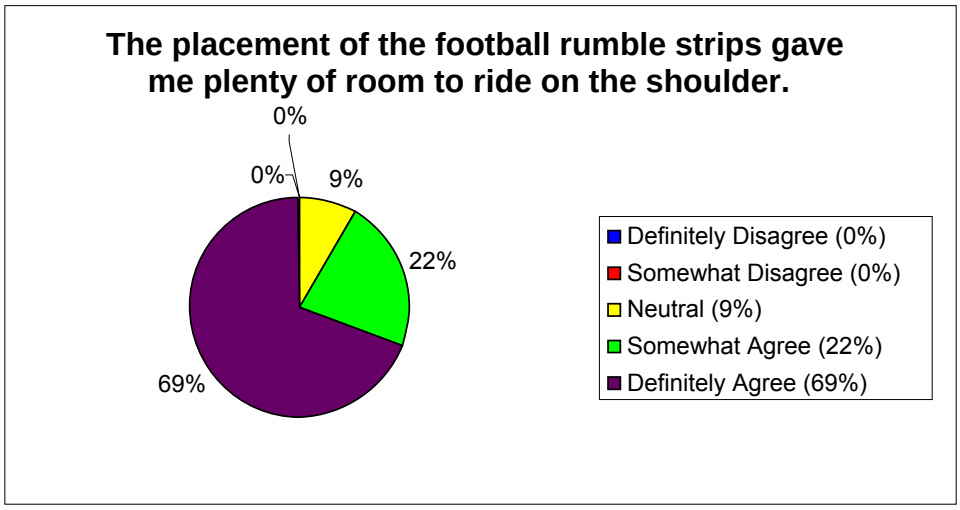

Figure 5.4: Response distribution for Question 4, bicyclist survey

The distance from the shoulder edge and the football rumble strips' edge was 49 in., and the distance from the shoulder edge and the rectangular rumble strips' edge was 45 inches. Again, the majority of people surveyed said that they either somewhat agree or definitely agree that the placement of the football rumble strips gave the bicyclists room to ride on the shoulder. Sixty-nine percent (n = 16) answered that they definitely agree and twenty-two percent (n = 5) stated they somewhat agree they had enough room to ride on the shoulder. Nine percent (n = 2) answered no opinion, and no one answered somewhat disagree or definitely disagree to the question. It should be noted that the distance between the edge of the shoulder and the edge of the football

rumble strips was close to the same length as the distance between the edge of the shoulder and the edge of the rectangular rumble strips on the opposite lanes.

Question 5: The size of the football rumble strips did not distract from the safety of my riding.

Participants were asked to rank their opinions from one (definitely disagree) to five (definitely agree) about the size of the football shaped rumble strips in relation to the bicyclist's safety while riding. The distribution can be seen in Figure 5.5.

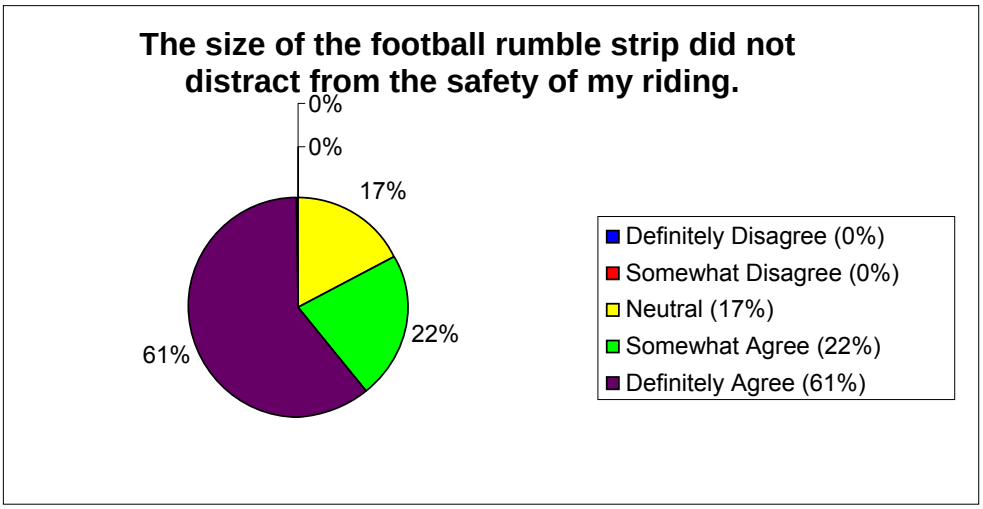

Figure 5.5: Response distribution for Question 5, bicyclist survey

The bicyclists agreed with the stated question. A combined 83% (n = 19) said that they somewhat agreed or definitely agreed the size of the football rumble strip did not deter from the safety of the bicyclists' riding. Four people, or 17%, stated they had no opinion on the size and their safety. None of those surveyed stated that they disagreed with the stated question. The size of the football shaped rumble strips were 16 inches perpendicular to the edge of travel line by 9 inches parallel to the edge of travel line. The size of the rectangular rumble strips were 16 inches perpendicular to the edge of travel line and 7 inches parallel to the edge of travel line.

Question 6: The depth of the football rumble strips (1/2”-5/8”) would not be a problem for me if I rode over them on my bike.

Participants were asked to rank their opinions from one (definitely disagree) to five (definitely agree) about the depth of the football shaped rumble strips along the shoulder and a possible problem when riding over the rumble strips. The distribution can be seen in Figure 5.6.

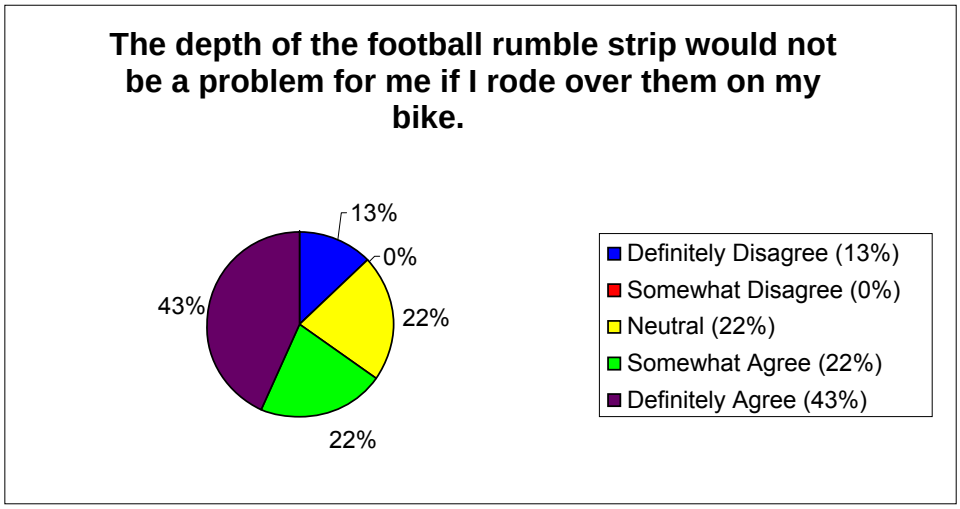

Figure 5.6: Response distribution for Question 6, bicyclist survey

The depth of the football rumble strips was ½ inch ± ⅛ inch. This was the same depth for the rectangular rumble strips. There was a mix distribution with this question. However, the majority of people, 15 people or 65%, still said they somewhat agreed or definitely agreed that the depth of the football rumble strip would not be a problem. Five people, 22%, said they were indifferent to the depth of the football rumble strip. Finally, 13% (n = 3) definitely disagreed that the depth would not be a problem.

Question 7: What is your overall opinion of rumble strips as pertaining to the safety of vehicle drivers from running off the road?

Participants were asked to rank their opinions from one (definitely dislike) to five (definitely like) about rumble strips as they pertain to the safety of drivers from running off the road. The distribution can be seen in Figure 5.7.

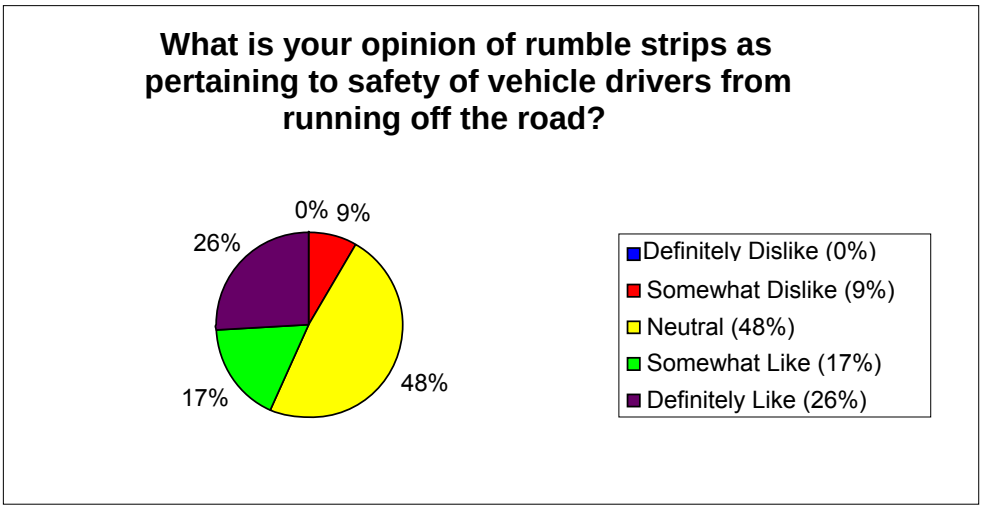

Figure 5.7: Response distribution for Question 7, bicyclist survey

The greatest proportion of bicyclists surveyed, 48% (n = 11) said they had no opinion on rumble strips as pertaining to the safety of vehicle drivers from running off the road. However, a combined 42% (n = 10) said they somewhat like or definitely like rumble strips as a device for driver's safety from running off the road. Only 9% (n = 2) stated that they somewhat disliked the rumble strips for keeping drivers from running off the road.

Question 8: What is your overall opinion of rumble strips?

Participants were asked to rank their overall opinions from one (definitely dislike) to five (definitely like) about rumble strips, rectangular and football shaped. The distribution can be seen in Figure 5.8.

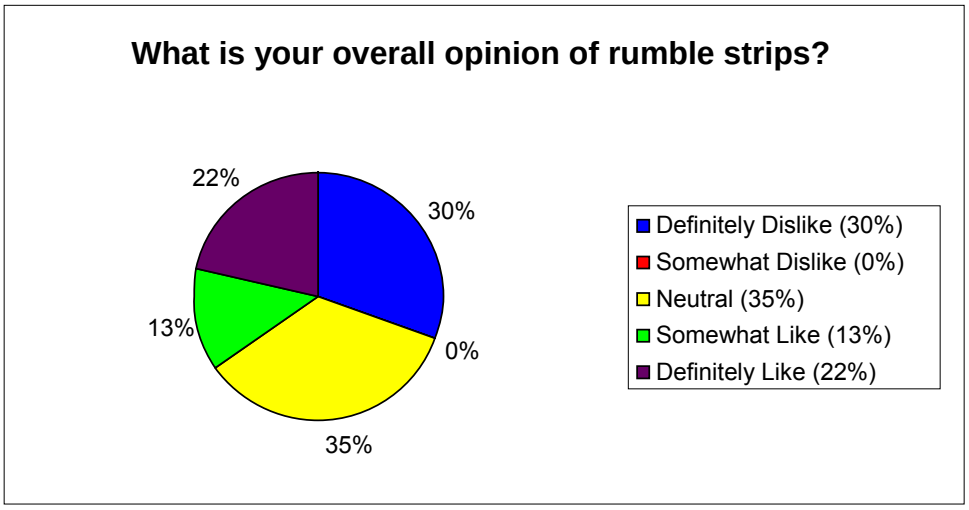

Figure 5.8: Response distribution for Question 8, bicyclist survey

There is almost an even distribution of opinions for Question 8. 35% (n = 11) of bicyclists stated they somewhat or definitely liked rumble strips, 35% (n = 11) had no opinion, and 30% (n = 7) said they definitely disliked rumbles strips.

5.1.2 Additional Comments

- *"As a biker, I dislike any rumble strip, but I know they are a necessity."*
- *"The football shaped rumble strips provide more room on the shoulder for riders and seem to be louder when vehicles ride over them. A definite improvement."*
- *"I think they (rumble strips) are good as long as they do not run all the way across the shoulder. The noise they (football rumble strips) make in a car is about the same. I feel they (rumble strips) are essential to help keep drivers alert as they speed down the road."*

- *“Rumble strips do not have to be so long to be effective. Short ones would work for cars and bikes.”*
- *“I definitely like rumble strips as long as the strips allow for plenty of cycling space.”*
- *“Make sure strips are placed to leave most of the shoulder for biking. Colorado has good laws on rumble strips.”*
- *“(Football rumble strips) gives more room on shoulder to ride.”*
- *“Football rumble strips are definitely better; they give more room for cyclists.”*
- *“Rumble strips are necessary, but the football strips make it easier to ride on.”*
- *“I have ridden the rumbles west of Maize, KS on K-96. Footballs are great! And, they separate bicyclists and traffic.”*
- *“Just don’t place them across the entire shoulder.”*
- *“Please use football shaped rumble strips so that cyclists may ride to one side of the strips. Riding over rumble strips is very uncomfortable, thus encouraging a rider to ride in a prime auto lane rather than the shoulder.”*
- *“Please use the football rumble strips, allow at least three feet of space for bicycles.”*
- *“Whatever the shape of rumble strips, please leave enough room for cyclists to pass them safely.”*
- *“Rumble strips serve a good purpose to alert drivers who run off the road, but they need to allow room for bicyclists to also ride on the shoulder. They do not need to be the entire width of the shoulder.”*

5.1.3 Discussion

Based on questions 1, 2, and 3 of the survey, the bicyclists responded that they did not like the rectangular rumble strips, but they definitely preferred the football shaped rumble strips. The bicyclists were also pleased with the placement, size and depth of the football shaped rumble strips. However based on questions 7 and 8, the bicyclists like rumble strips when talking about the safety of drivers, but remain neutral or dislike rumble strips overall. Bicyclists prefer rumble strips that do not cross the entire shoulder and the allowance of at least two to three feet for riding. This is brought out by the additional comments made by the surveyed bicyclists. Overall it can be concluded that the surveyed bicyclists preferred the football shaped rumble strips, but they put more emphasis on having enough room on the shoulder to ride, no matter what the shape of the rumble strips.

5.2 Resident Survey

In January of 2006, surveys were sent out to residents along the section of US Highway 40 where the football shaped centerline rumble strips were installed. The centerline rumble strips were installed in May, 2005. It was assumed that seven months was enough time for residents to familiarize themselves with the centerline rumble strips. The survey consisted of nine questions designed to gage the residents like, dislike, concern or ambivalence to the external noise produced from cars driving over the rumble strips. Most of the questions were in yes/no form; two were multiple choice, and one fill in the blank. A copy of the survey can be found in Appendix D. Responses were sent back to the K-State Rumble Strip Research Team and the data was analyzed

to determine if there is a concern about the external noise of rumble strips in residential areas.

5.2.1 Data Analysis

Fifty-eight surveys were distributed through the mail to residents between Lawrence and Topeka, KS on the stretch of US 40 where the football shaped centerline rumble strips are installed. A total of 32 surveys were returned completed, giving a response rate of 55%. Each question and answers received will be discussed in detail. Also, any comments made by the residents are included.

Question 1: Have you driven over (come in contact with) the centerline rumble strips along US 40?

Respondents were asked to answer yes or no for the first question. If they answered yes, they were asked to continue to question two. If they answered no they were asked to continue to question four. The distribution of answers can be seen in Figure 5.9.

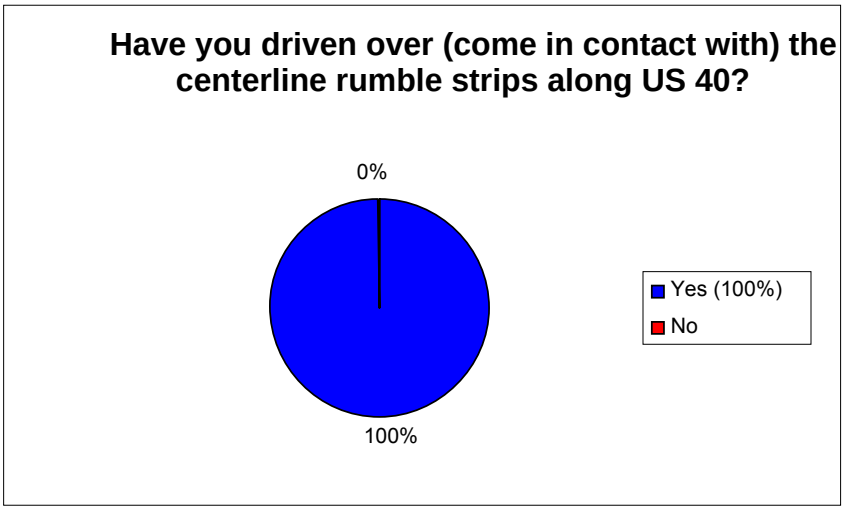

Figure 5.9: Response Distribution for Question 1, resident survey

As seen in figure 1, all 100% (n = 32) of the respondents answered yes that they had come in contact with centerline rumble strips. This was a positive, because all of the returned surveys could be used for data analysis. No surveys had to be discarded for respondents having no prior contact with the rumble strips.

Question 2: Do you think the centerline rumble strips provide a proper auditory alert to alert a driver?

The respondents were asked their opinion on the interior vehicle noise level of the rumble strips and if the noise was a proper level to alert a driver. Again, they were asked to answer either yes or no. The distribution of the responses can be found in Figure 5.10.

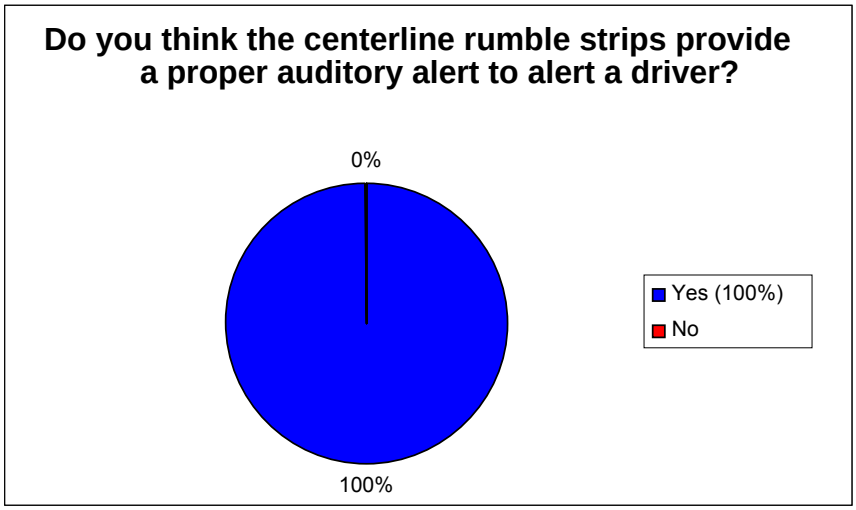

Figure 5.10: Response Distribution of Question 2, resident survey

All 32 respondents replied that the centerline rumble strips give off the proper noise level to alert a driver.

Question 3: Do you think the centerline rumble strips provide a proper vibratory level to alert a driver?

Similar to question two, respondents were asked their opinion of the vibration produced by driving over rumble strips and the vibration was enough to alert a driver. The respondents were asked to answer either yes or no. The distribution of responses can be seen in Figure 5.11.

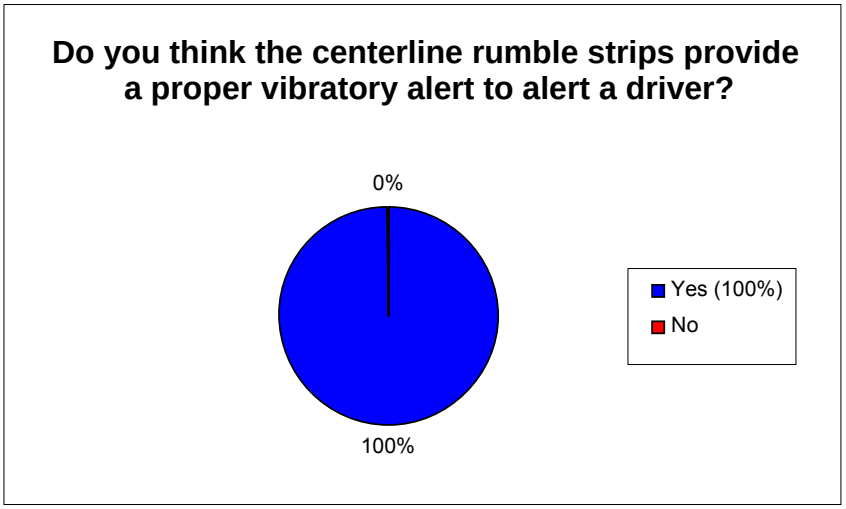

Figure 5.11: Response Distribution of Question 3, resident survey

All 32 respondents replied that the centerline rumble strips give off the proper vibration level to alert a driver.

Question 4: Can you hear from your residence when a driver crosses over (comes in contact with) the centerline rumble strips?

This was a setup question for questions five and six to make sure that they can hear the exterior noise from the rumble strips in their residence. The respondents were asked to answer either yes or no. If they answered yes, they were instructed to continue to question five. If they answered no, they were instructed to continue to question seven. The distribution of responses can seen in Figure 5.12.

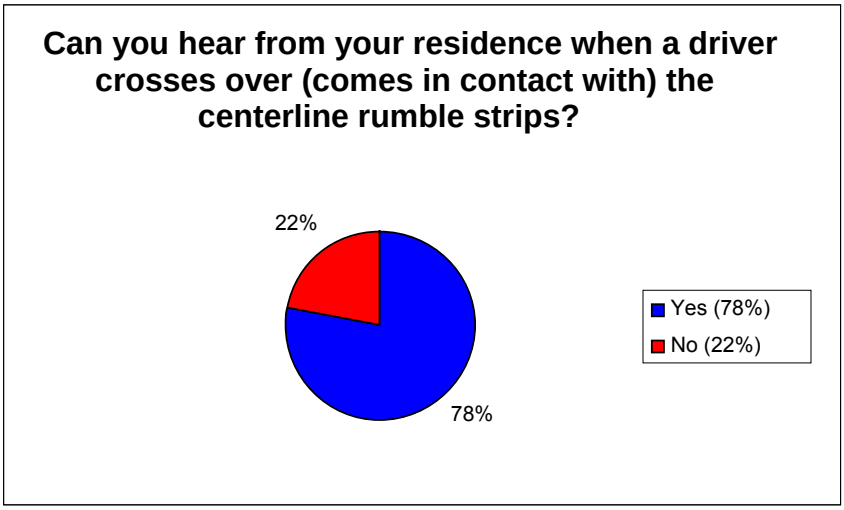

Figure 5.12: Response Distribution of Question 4, resident survey

Seventy-eight percent (n = 25) of the respondents answered yes that they can hear from their residence when a driver crosses the centerline rumble strips. Twenty-two percent (n = 7) answered that they cannot hear any noise from their home when a driver crosses the centerline rumble strips. The seven people that answered no to question four and were excluded from any analysis on questions five and six.

Question 5: Choose one of the following and please comment below.

Respondents were given three choices to rate the external noise produced from the centerline rumble strips as heard from their residence. Respondents were asked to choose one of the following answer choices: “The noise produced is loud enough to cause a problem or a distraction”, “The noise is only inconvenient and annoying”, or “The noise is unnoticeable and not a concern”. The distribution of responses can be seen in Figure 5.13.

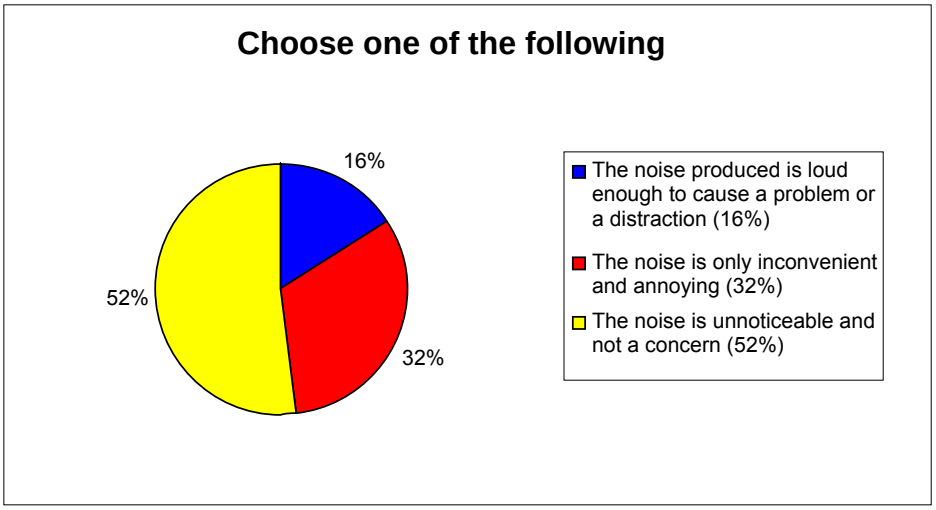

Figure 5.13: Response Distribution of Question 5, resident survey

25 of the 32 total respondents answer yes to question four, therefore only the 25 surveys were analyzed for question 5. Of those 25 surveys, 52% (n = 13) answered that the noise produced by the rumble strips is unnoticeable and not a concern. Thirty-two percent (n = 8) of the used surveys replied that the noise is only inconvenient and annoying. The final 16% (n = 4) of the included surveys replied that the noise produced is loud enough to cause a problem or a distraction.

Question 6: If you answered yes to question 4, how often can you hear the noise produced from a driver crossing the centerline rumble strips?

If the respondents can hear the noise, they were asked how often to they hear the external noise from the centerline rumble strips. They were given four choices and asked to pick one from the following: “less than once a day”, “1-5 times a day”, “5-10 times a day”, or “more than 10 times a day”. The distribution of responses can be seen in Figure 5.14.

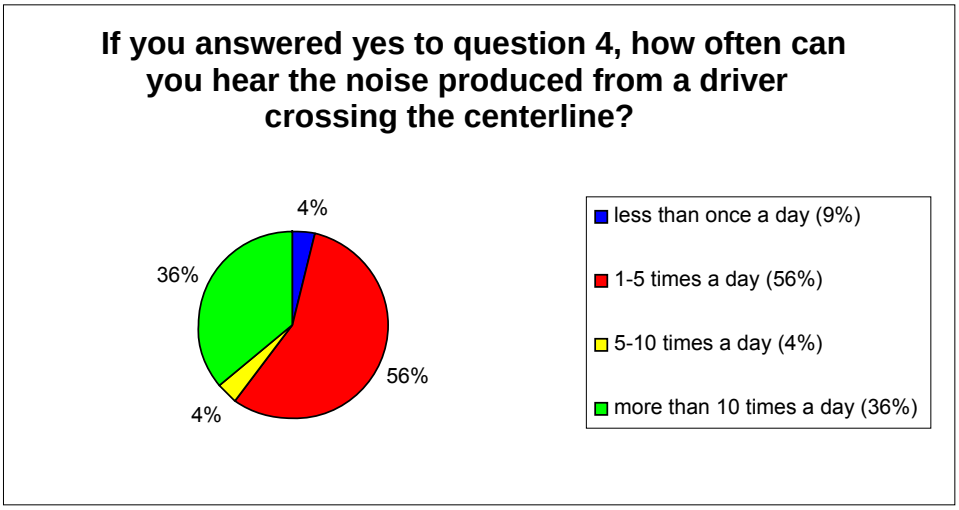

Figure 5.14: Response Distribution of Question 6, resident survey

Again, only the 25 of the total 32 surveys that answered yes to question four were included in the analysis of question six. Of the 25 surveys, 4% (n = 1) replied that they can hear the noise produced by the centerline rumble strips less than once a day. Fifty-six percent (n = 14) of the included surveys responded they hear the noise at least one to five times a day. Another 4% (n = 1) of the included surveys answered they can hear the noise between five to ten times a day. Finally, 28% (n = 7) of the included surveys responded they could hear the noise more than ten times a day.

Question 7: What is the approximate distance from your house to US 40?

Respondents were asked to fill in the blank on the survey with the approximate distance from the highway to their house. The distribution of responses can be seen in Figure 5.15.

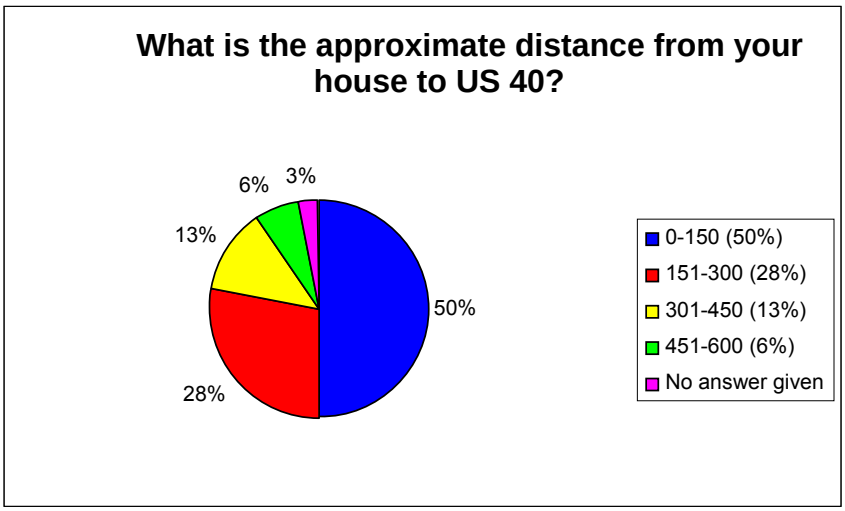

Figure 5.15: Response Distribution of Question 7, resident survey

Once the responses were collected they were grouped into ranges for analysis purposes. The overall range of the responses went from zero to six hundred feet. So, the answers were divided into four groups of 150 feet increments. All 32 collected surveys were analyzed. Fifty percent (n = 16) of the respondents residences are between zero and one hundred fifty feet from US Highway 40. Twenty-eight percent (n = 9) are between 151 and 300 feet from the highway. Thirteen percent (n = 4) are between 301 and 450 feet from the highway. Finally, only six percent (n = 2) are between 451 and 600 feet from the highway. There was one person, or three percent of respondents, that did not give an answer to the question. The responses to this question were then tested for correlation to the responses from question five to determine if the distance from the highway had anything to do with the respondents'

opinions of the noise. A Pearson correlation coefficient of -0.40 was calculated with a p-value of 0.852. This shows that there is almost no correlation between the distance from Highway 40 to the respondents' residences and the respondents' opinions of the noise produced from the centerline rumble strips.

Question 8: Do you believe the centerline rumble strips on US 40 contribute to your driving safety?

Respondents were asked to answer yes, no, or no opinion to question eight. The response distribution can be seen in Figure 5.16.

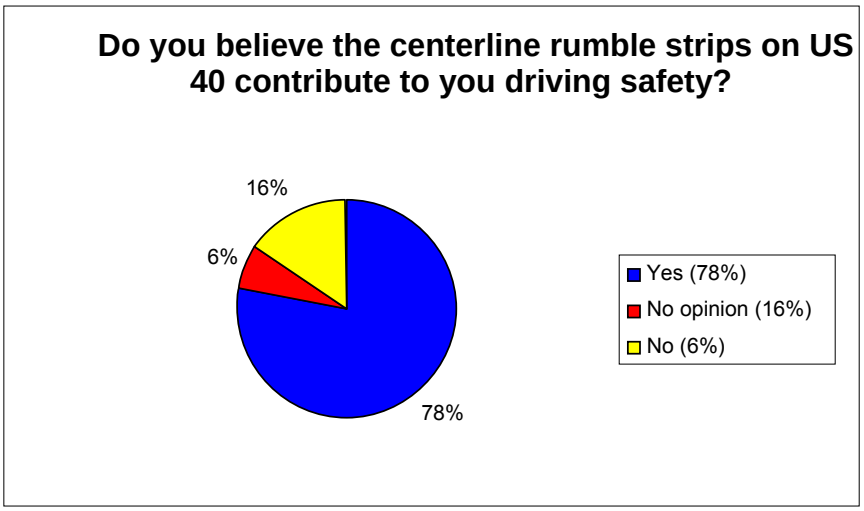

Figure 5.16: Response Distribution of Question 8, resident survey

Seventy-eight percent (n = 25) responded that the centerline rumble strips do contribute to their driving safety along US 40. Six percent (n = 2) had no opinion on the question. Sixteen percent (n = 5) believed that the centerline rumble strips do not contribute to their driving safety.

Question 9: Do you believe the potential safety effect is worth some level of annoying noise?

Again, respondents were asked to answer yes, no, or no opinion to question eight. The response distribution can be seen in Figure 5.17.

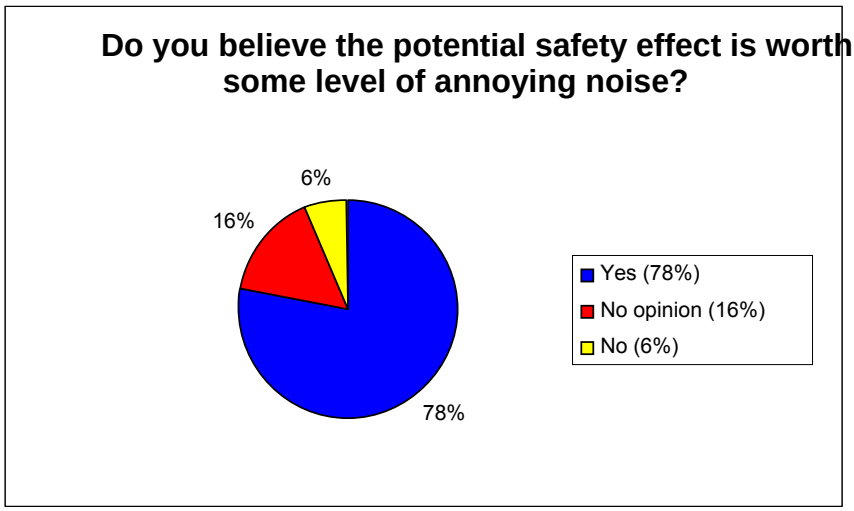

Figure 5.17: Response Distribution of Question 9, resident survey

Again, 78% (n = 25) responded that the safety effect from the centerline rumble strips outweighed some level of annoying exterior noise. Sixteen percent (n = 5) had no opinion on the question. Six percent (n = 2) believed the safety effects of the centerline rumble strips do not outweigh some level of annoying noise.

5.2.2 Additional Comments

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

- *"Some drivers run on strips for long periods for no reason only to hear and feel or for fun."*

- *"It was a real concern to me as a driver how the traffic in the other lane would come into my lane when they went to fast around the corners. The rumble strips have helped this a great deal."*
- *"I think the rumble strips help to keep cars and trucks out of the center of the road."*
- *"Much of the noise is caused by speeders passing where they should not pass."*
- *It (the noise) does not cause a problem, you get used to it in a couple of days. I think it (rumble strips) is a good thing."*
- *"I think it (rumble strips) is a good idea. My boys always know when someone 'crossed the line'."*
- *"Love them! I think more highways need them. Plus 'horizontal' (rumble strips) before really bad locations – like before toll booths – would be great too."*
- *"They are a great addition to the highway."*
- *"I think that it (rumble strips) is the best alert system ever used."*
- *"I think that whoever thought this up should have to live on Hwy 40 and be awakened by the noise every night!"*
- *"I hear/feel most big trucks day and night."*
- *"We're in a passing zone and the rumble is constant and gets my attention every time."*

5.2.3 Discussion

According to questions two and three, all 100% (n = 32) of those surveyed believed that the centerline rumble strips give the proper auditory and vibratory levels to alert a driver who comes in contact with the rumble strips. Also, 78% (n = 25) of the

respondents answered yes to question eight when asked if the centerline rumble strips contribute to their driving safety. The same 78% (n = 25) answered yes to question nine when asked if the potential safety effects outweighed some level of annoying noise heard in their residences. Of the 78% (n = 25) of people who can hear the noise from their residences, only 16% (n = 4) answered that the noise is loud enough to cause a concern or a distraction. Therefore it can be concluded that the majority of residents are satisfied with the centerline rumble strips on US Highway 40 because there is more potential for driver safety than the effects of the external noise produced from coming in contact with the rumble strips.

Future research should measure the actual external noise level at several distances to determine decibel ranges for residential areas where centerline rumble strips might be installed. Also, there was a variation in responses for question six when asked how many times a day the respondents hear noise from the centerline rumble strips. Future research should study to find which areas have more instances of drivers coming in contact with the centerline rumble strips whether from passing a vehicle or from drifting into the other lane.

Chapter 6: Conclusions and Future Work

6.1 Conclusions

Based on the literature review, the limited tests performed (Water and Debris Removal, Noise, and Vibration), and the surveys conducted (Bicyclists on K-96 and residents along US 40), it can be concluded that no significant difference was found between the two types of rumble strips.

The literature review in Chapter 2 documented that shoulder rumble strips are widely used in the United States (U.S.) to mitigate run-off-the-road accidents. Since there are no federal standards, there are many different dimensions and patterns used. One of the biggest design considerations for shoulder rumble strips is bicyclists. Bicyclists are concerned that shoulder rumble strips increase motor vehicle safety while decreasing bicyclist safety. U. S. States have attempted to accommodate bicyclists through design and placement of shoulder rumble strips. Similarly, centerline rumble strips are used in many U. S. States and several studies have concluded that they are effective in preventing crossover accidents.

The experiments in Chapter 4 showed that the football shaped rumble strips are as effective as the rectangular rumble strips. There was no significant difference in either type of rumble strip based on water and debris removal. Both types of rumble strips produced a significant amount of noise for the vehicles tested; however, there was no significant difference in the noise levels between the two types of rumble strips. Both types of rumble strips produced a significant vibratory response level; however, there was no statistical difference in the vibratory level for five of the six vehicles tested.

Also, there was not enough data to determine if either type of rumble strip reduced accidents more than the other.

The bicyclist survey in Chapter 5 was used to determine the opinions of a group of bicyclists towards the football shaped rumble strips as compared to the rectangular rumble strips. The results showed that the bicyclists surveyed preferred the football shaped rumble strips but were more concerned with the amount of shoulder room on which to ride.

The resident survey in Chapter 5 was used to determine the opinions of residents in areas where centerline rumble strips had been placed. The results showed that the majority of residents find the external noise produced from the centerline rumble strips acceptable or tolerable. The majority of residents responding believed that the potential driver's safety outweighed the effect of the external noise.

It can be concluded based on the limited number of tests and surveys that no significant difference was found between the two types of rumble strips. The Kansas State Rumble Strip Research team concludes that the football shaped rumble strips can be considered an equally effective alternative to the rectangular rumble strips

6.2 Future Research

For future work there are several areas that could be researched. With proper time and resources, a quantifiable measure of the exact time for water and debris removal for each type of rumble strip could be collected. Possible correlation with wind speed and direction should also be calculated. Next, a longer accident analysis period should be used to determine if either type of rumble strips on K-96 and US 40 has given a significant change in the number of accidents in those areas. Future research should

conduct a more detailed study for measuring and analyzing the external noise produced by either type of rumble strip at several distances away from the rumble strips. From this, a model could be developed to determine if the noise is loud enough to be heard in residences based on the distance of the residence from the rumble strips. Based on US 40 residents' comments, future research should study the areas along US 40 where vehicles come in contact with the centerline rumble strips more often and determine reasons for the increase of contact. Finally, a survey should be conducted of driver's along US 40 to determine opinions of the noise, vibration, and potential safety effects of the centerline rumble strips.

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APPENDIX A

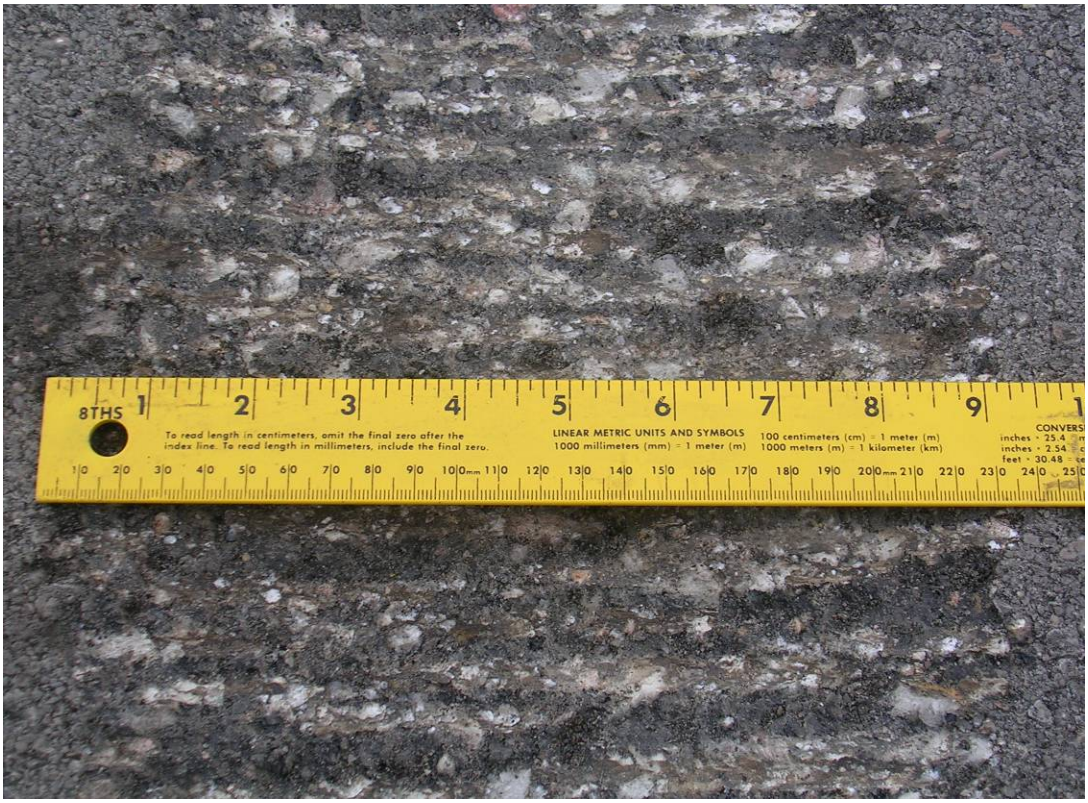

Figure A1: Width of single football shaped rumble strip (9 in.)

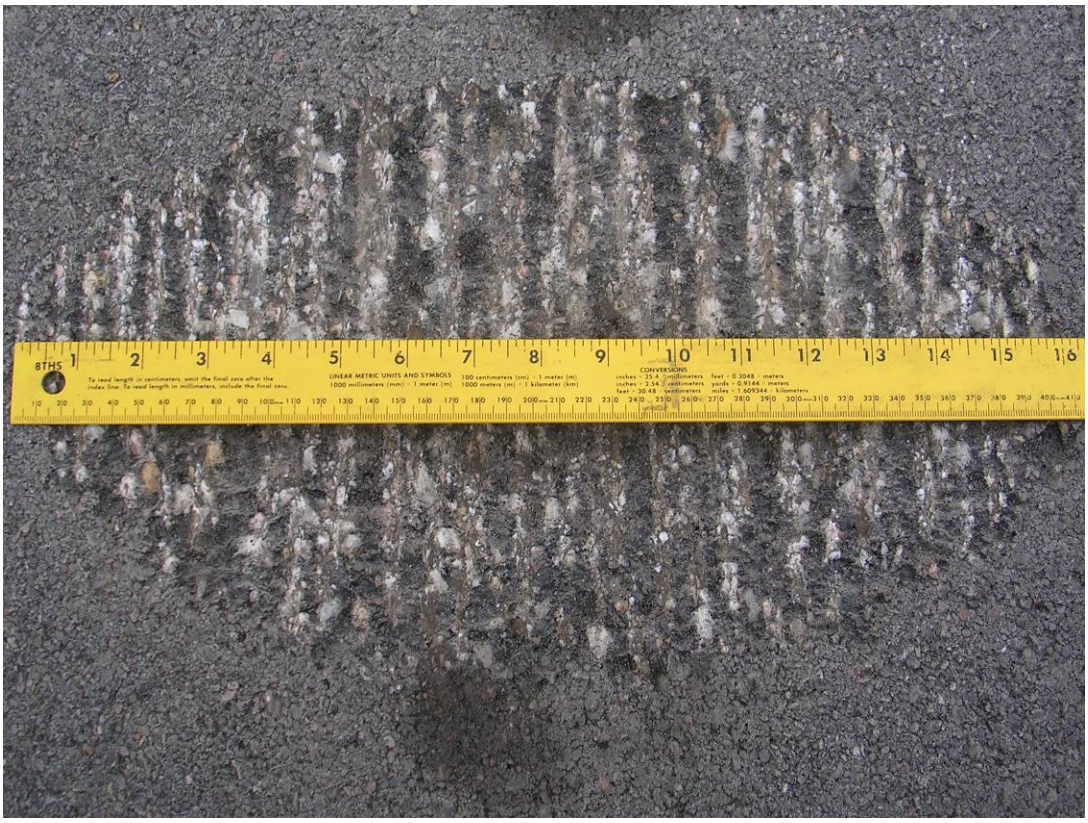

Figure A2: Length of single football shaped rumble strip (16 in.)

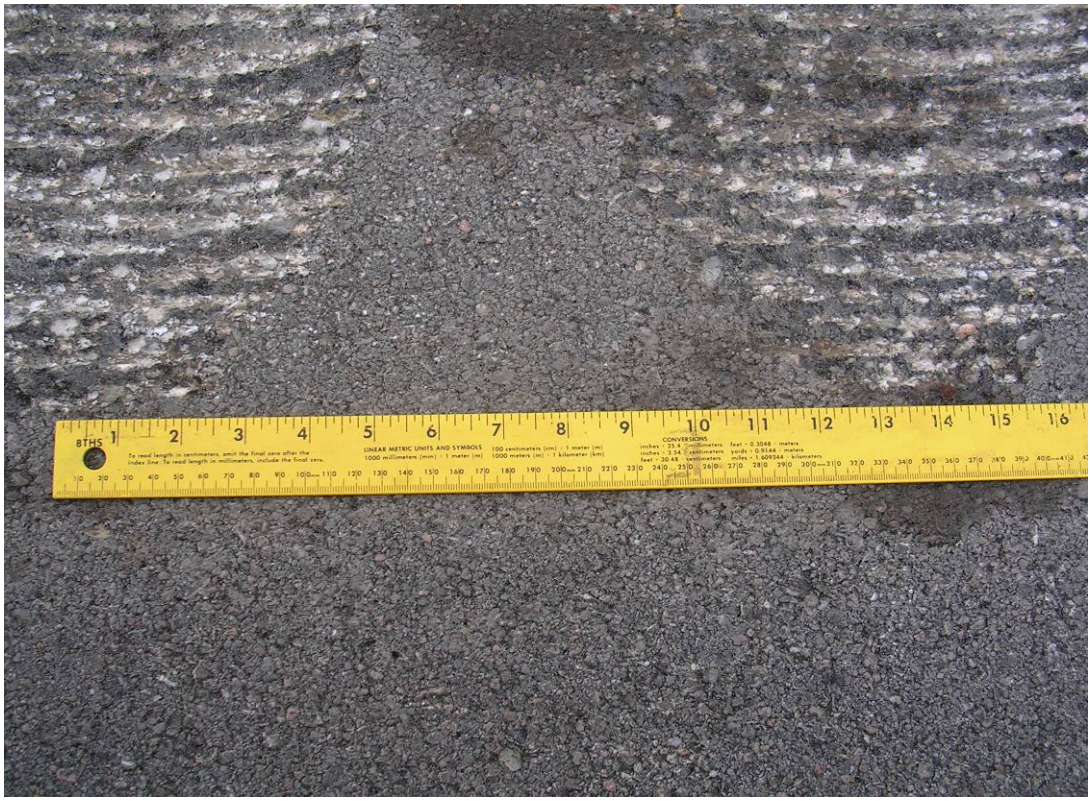

Figure A3: Distance between football rumble strips center-to-center (approx. 14 in.)

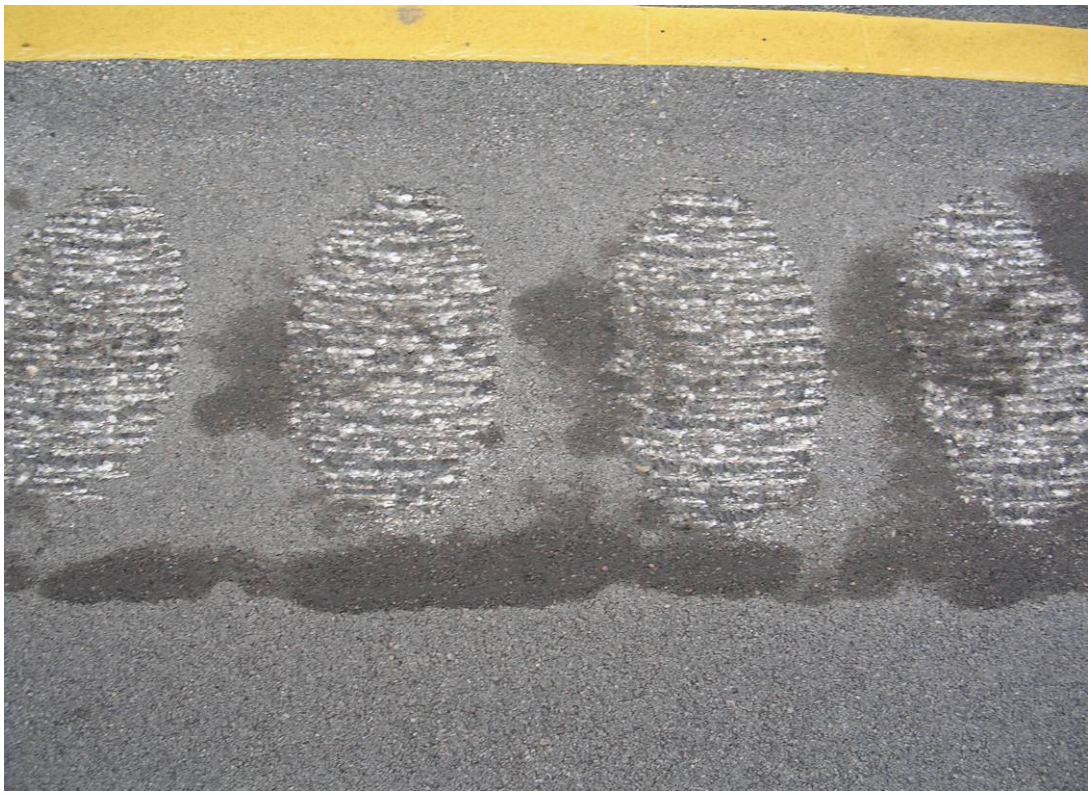

Figure A4: Football rumble strips located along K-96 between Maize and Wichita, KS

Figure A5: Milling apparatus for cutting football shaped rumble strips (Dustrol, Inc.)

Figure A6: Cleaning apparatus following milling apparatus (Dustrol, Inc.)

Figure A7: Football shaped rumble strips after clearing of milled debris

Figure A8: Work convoy cutting football shaped rumble strips and clearing debris

Figure A9: 2000 Ford Ranger XLT Pickup Truck

Figure A10: 1996 International 4900 DT466 Dump Truck

Figure A11: 1999 Chevrolet 2500 Diesel Pickup Truck

Figure A12: 2005 Lexus RX330 SUV (left) and 2002 Dodge Caravan minivan (right)

Figure A13: Summit Instruments accelerometer attached to steering wheel, vibration test setup

Figure A14: Vibration test setup

APPENDIX B

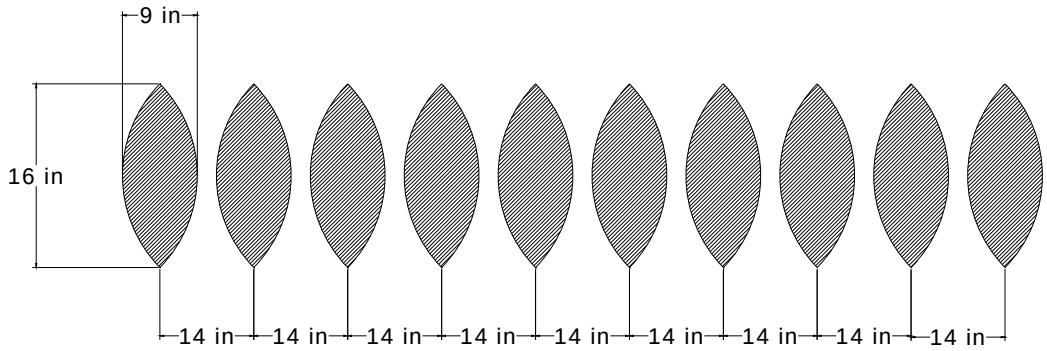

Figure B1: Layout of football rumble strips with dimensions

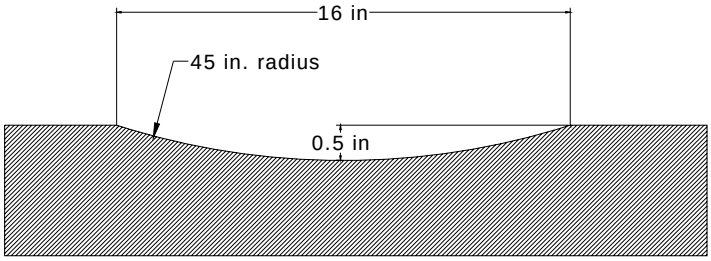

Figure B2: Cross-section layout of football rumble strip

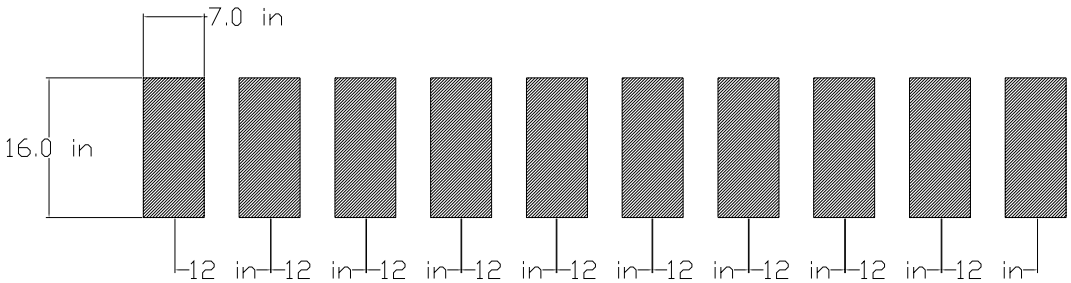

Figure B3: Layout of rectangular rumble strips with dimensions

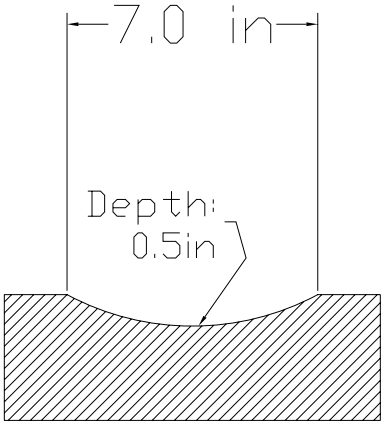

Figure B4: Cross-section layout of rectangular rumble strip

APPENDIX C

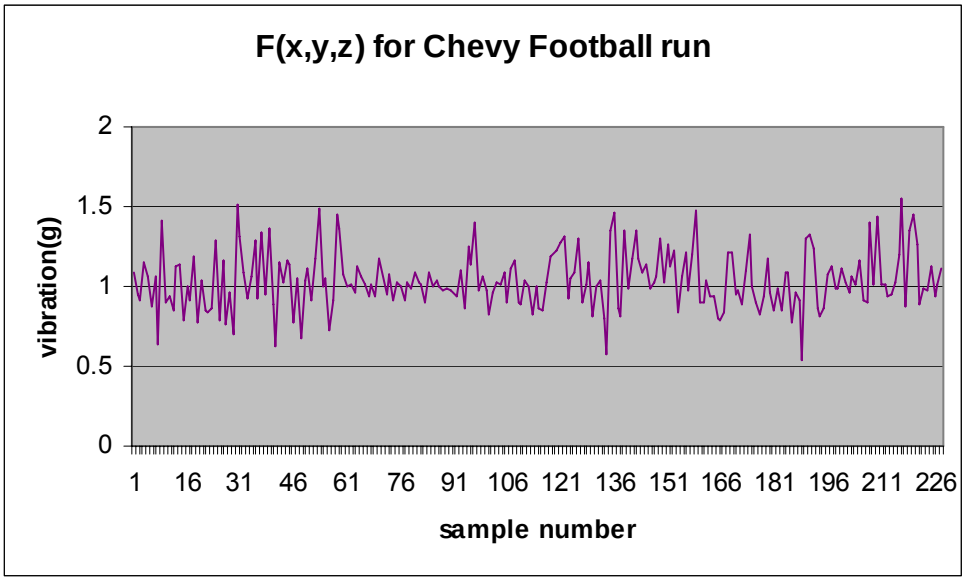

Figure C1: Resultant plot for Chevy Truck football shaped rumble strip trial on K-96

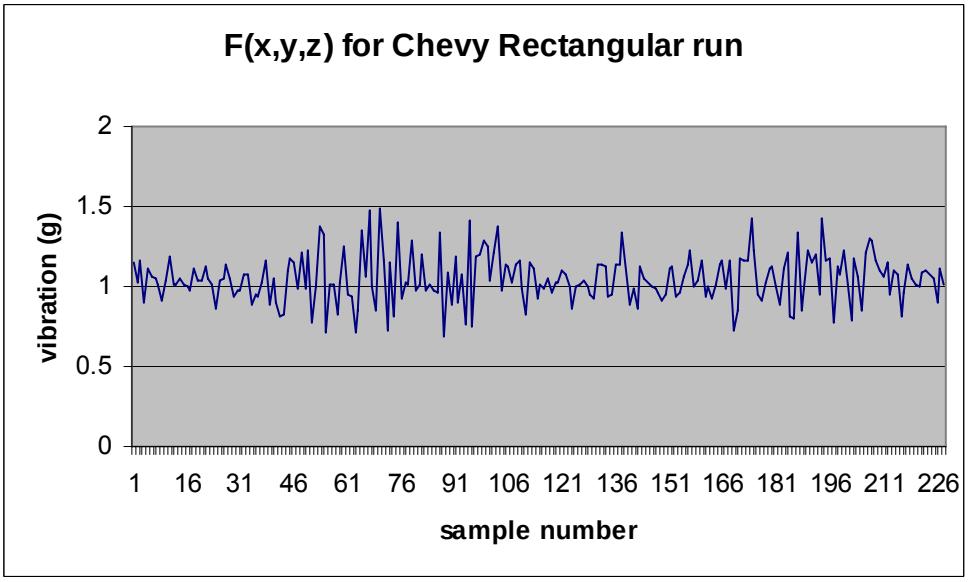

Figure C2: Resultant plot for Chevy Truck rectangular shaped rumble strip trial on K-96

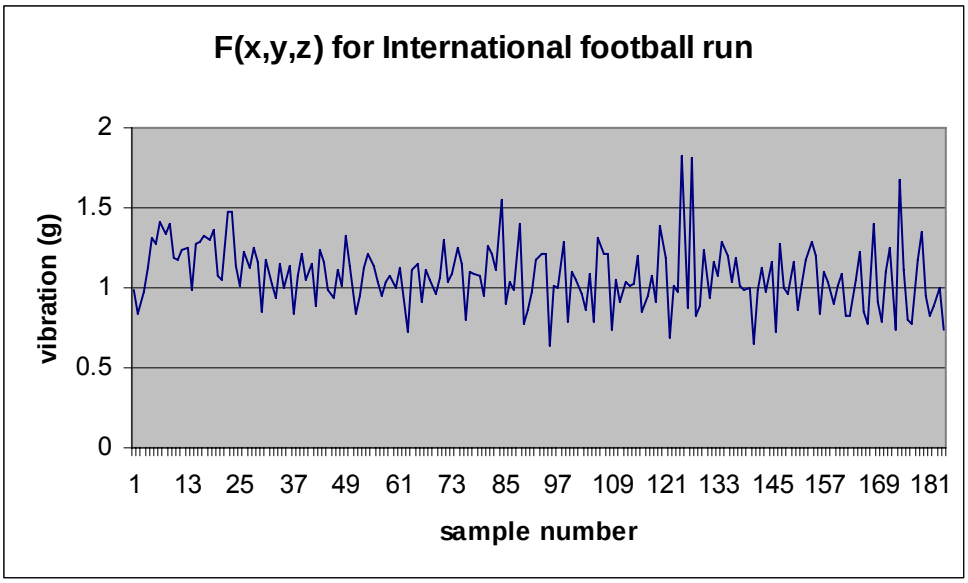

Figure C3: Resultant plot for International Truck football shaped rumble strip trial on K-96

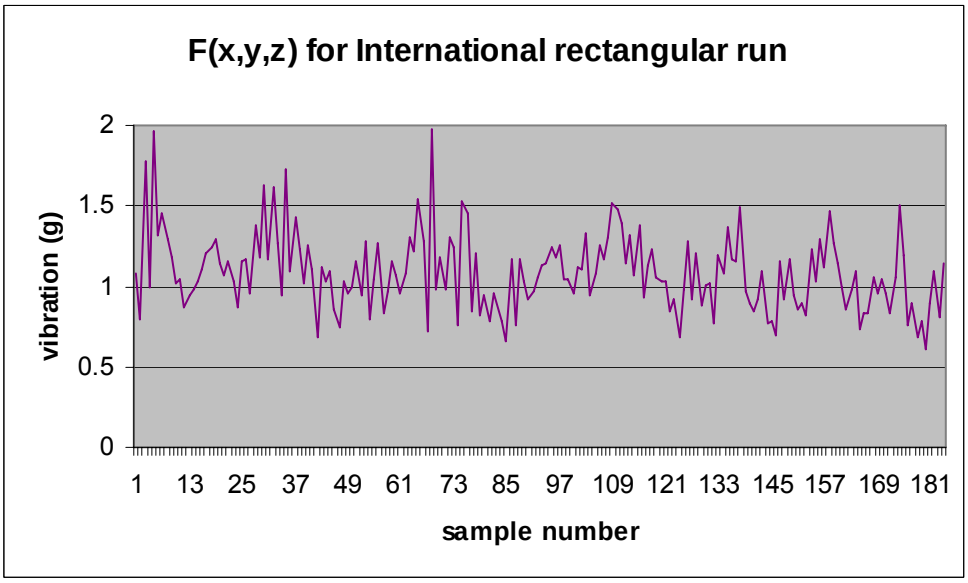

Figure C4: Resultant plot for International Truck rectangular shaped rumble strip trial on K-96

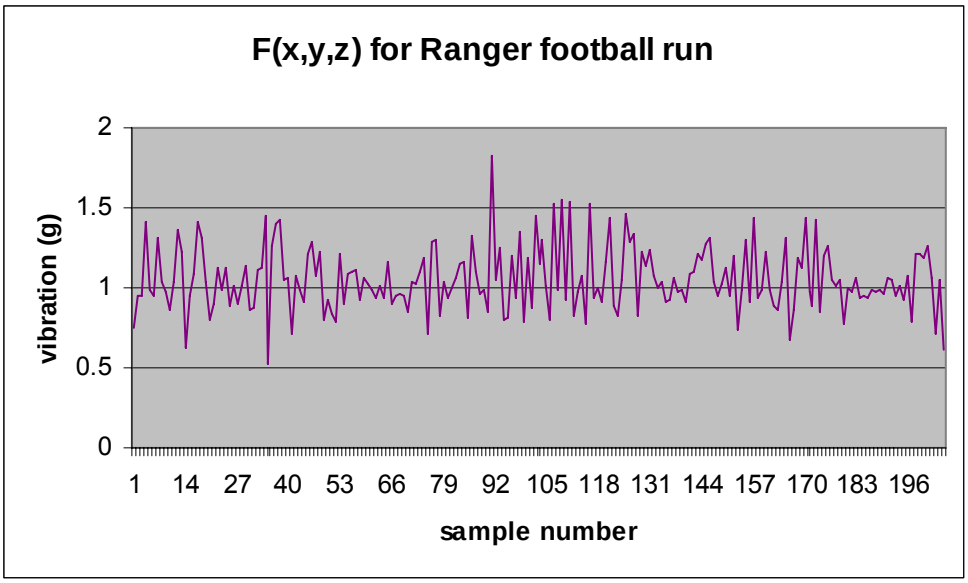

Figure C5: Resultant plot for Ford Ranger football shaped rumble strip trial on K-96

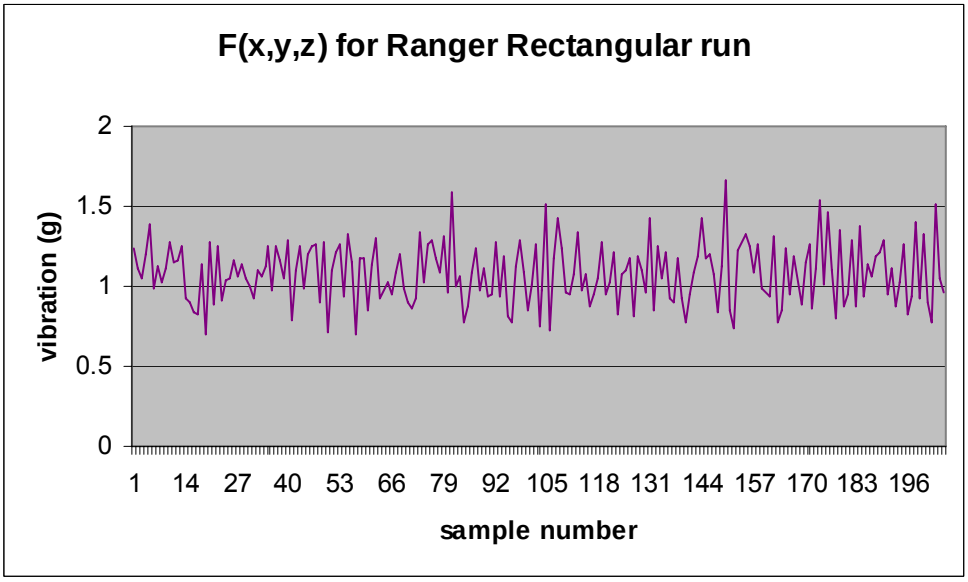

Figure C6: Resultant plot for Ford Ranger rectangular shaped rumble strip trial on K-96

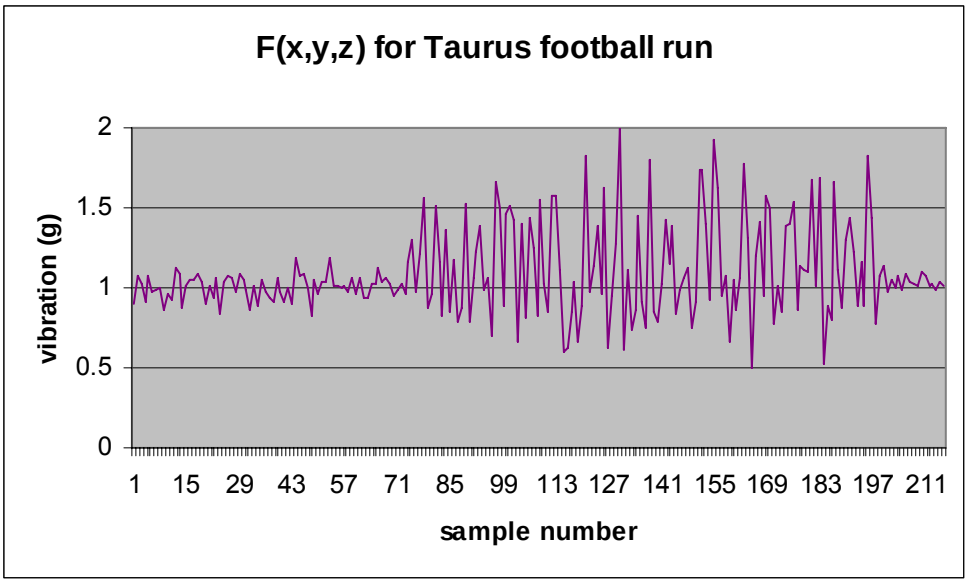

Figure C7: Resultant plot for Ford Taurus football shaped rumble strip trial on K-96

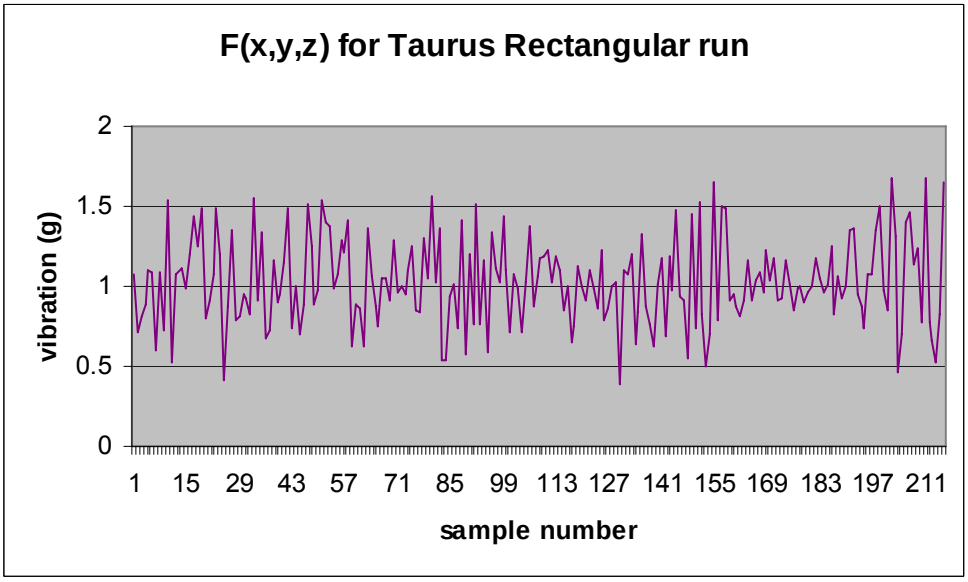

Figure C8: Resultant plot for Ford Taurus rectangular shaped rumble strip trial on K-96

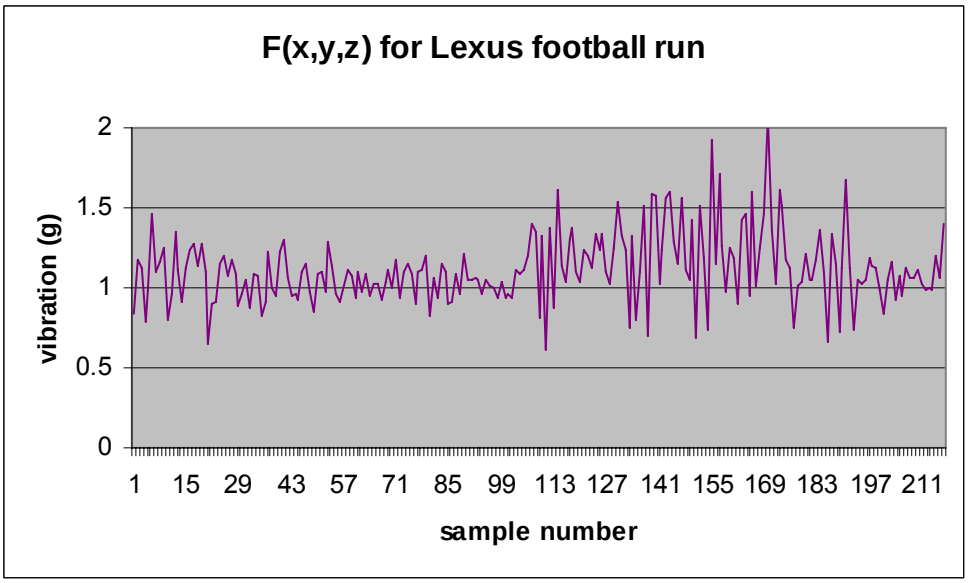

Figure C9: Resultant plot for Lexus RX330 football shaped rumble strip trial on K-96

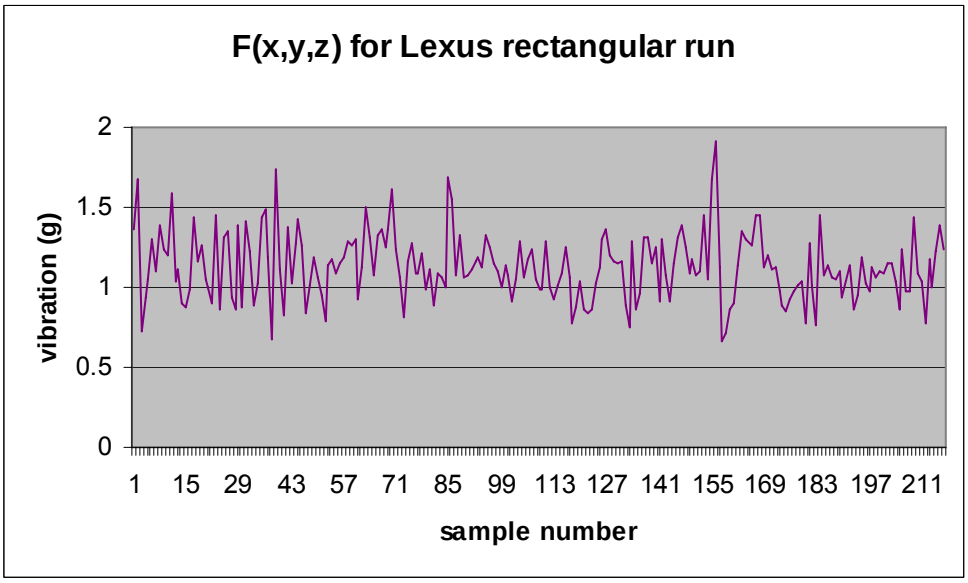

Figure C10: Resultant plot for Lexus RX330 rectangular shaped rumble strip trial on K-96

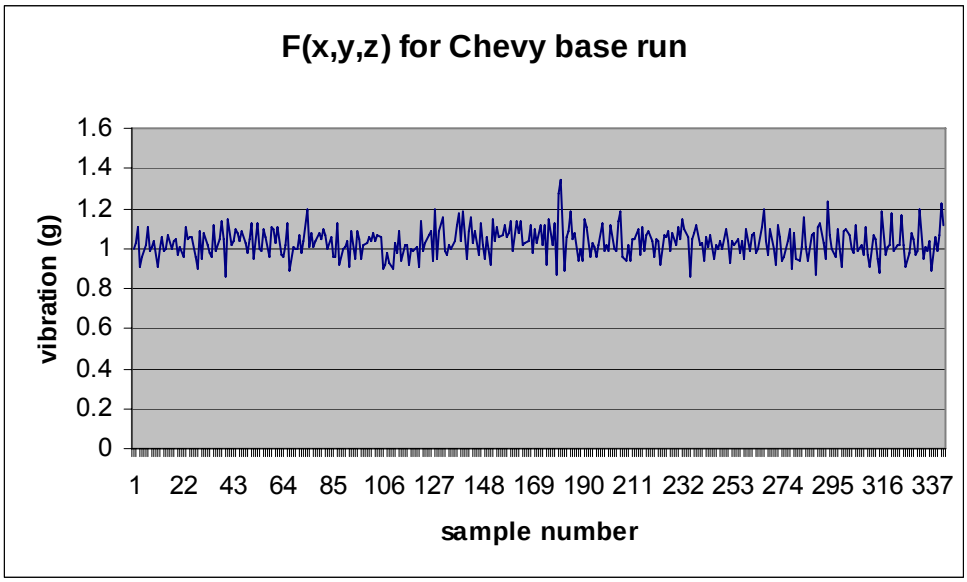

Figure C11: Resultant Plot for Chevrolet pickup truck base trial on US 40

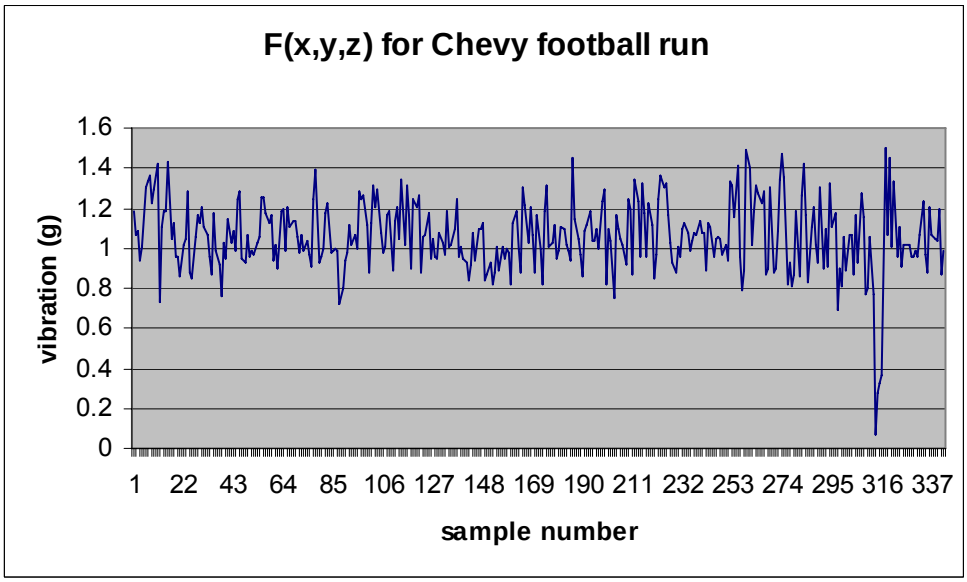

Figure C12: Resultant plot for Chevrolet pickup truck football shaped rumble strip trial on US 40

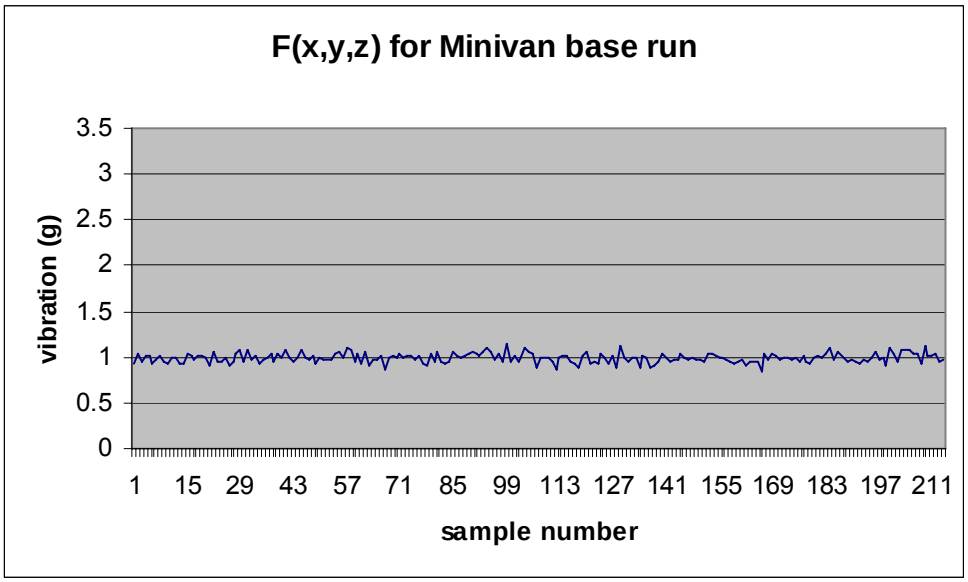

Figure C13: Resultant plot for Dodge Minivan base trial on US 40

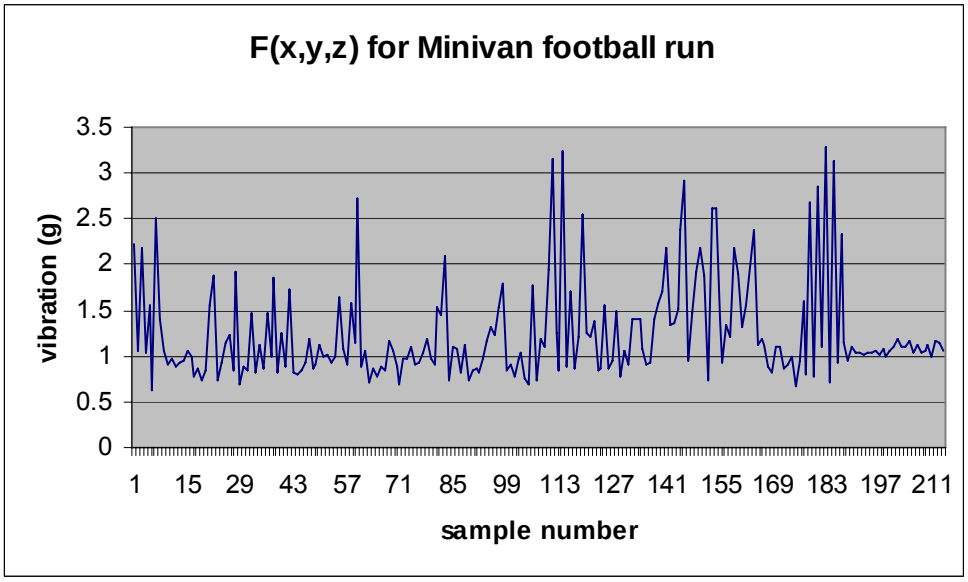

Figure C14 Resultant plot for Dodge Minivan football shaped rumble strip trial on US 40

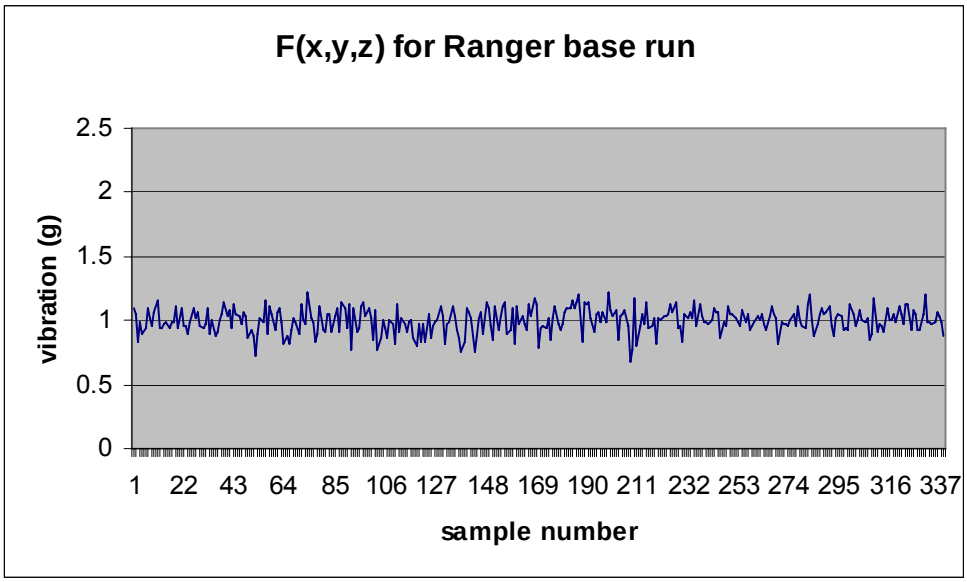

Figure C15: Resultant plot for Ford Ranger pickup truck base trial on US 40

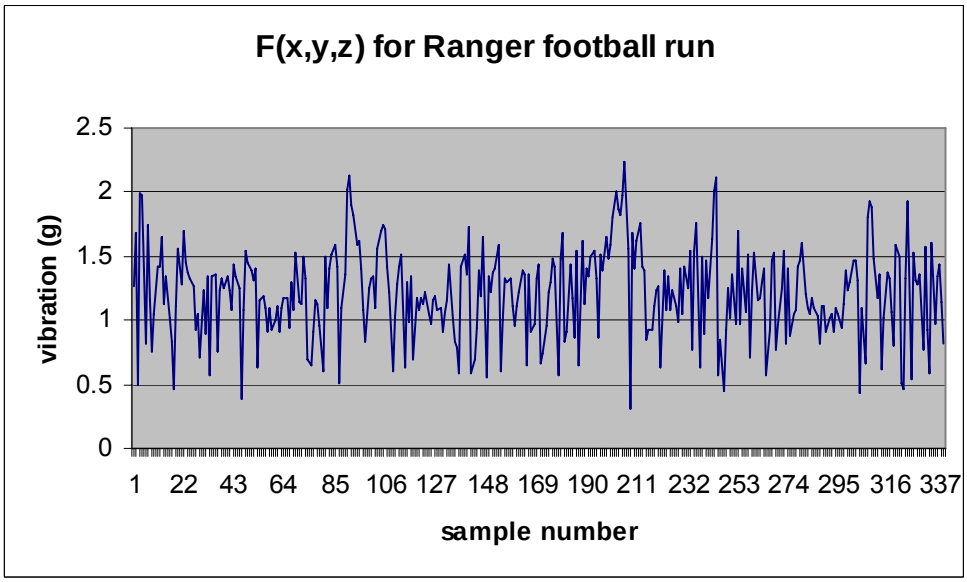

Figure C16: Resultant plot for Ford Ranger pickup truck football shaped rumble strips on US 40

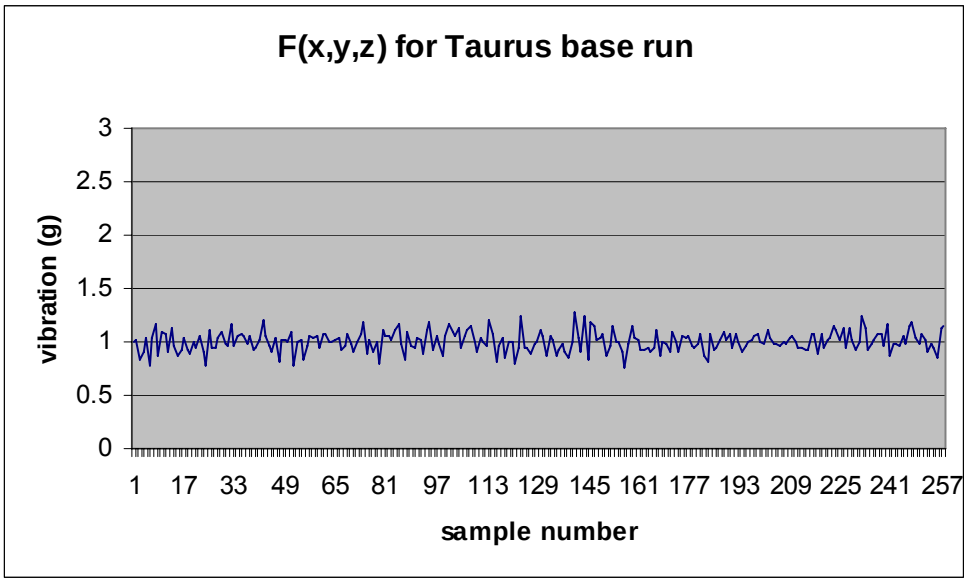

Figure C17: Resultant plot for Ford Taurus base trial on US 40

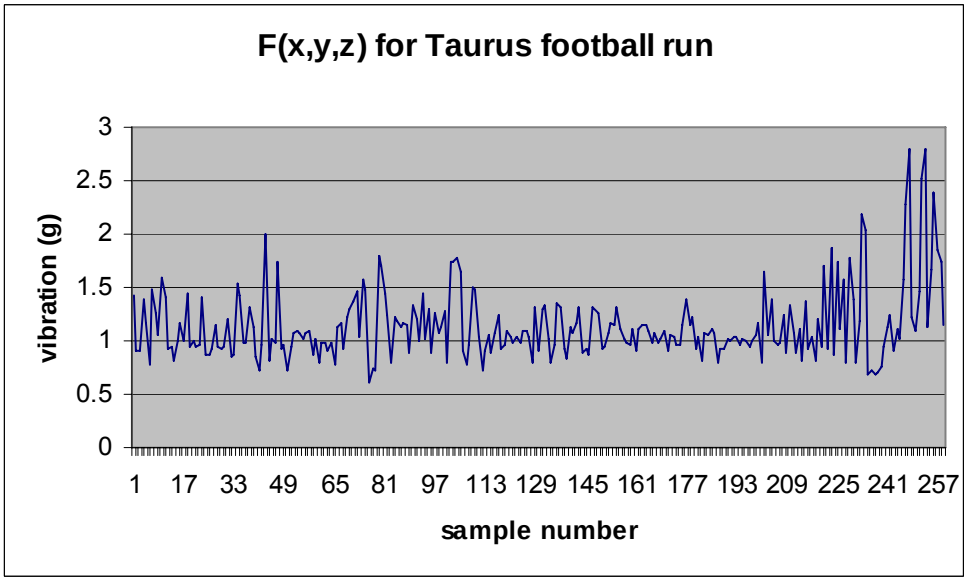

Figure C18: Resultant plot for Ford Taurus football shaped rumble strips trial on US 40

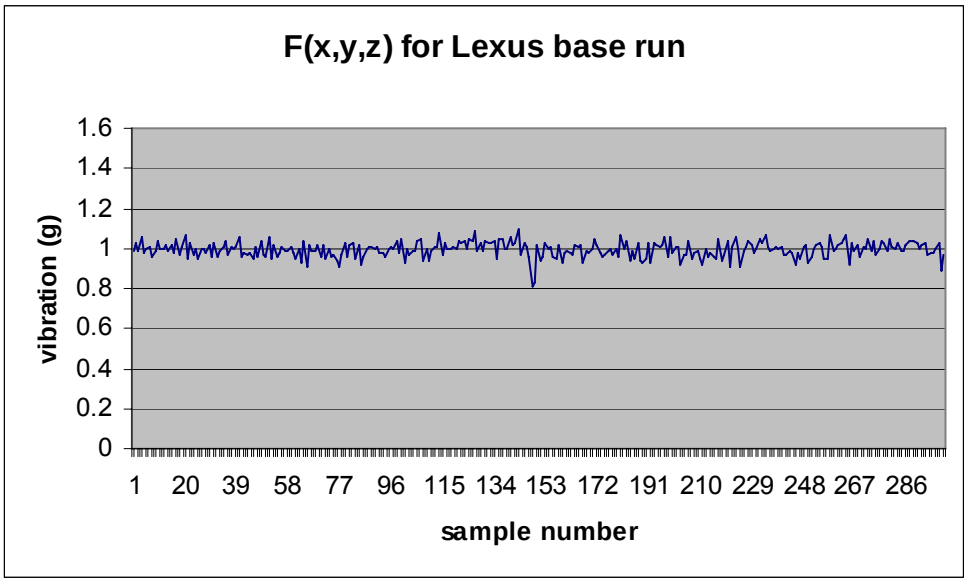

Figure C19: Resultant plot for Lexus SUV base trial on US 40

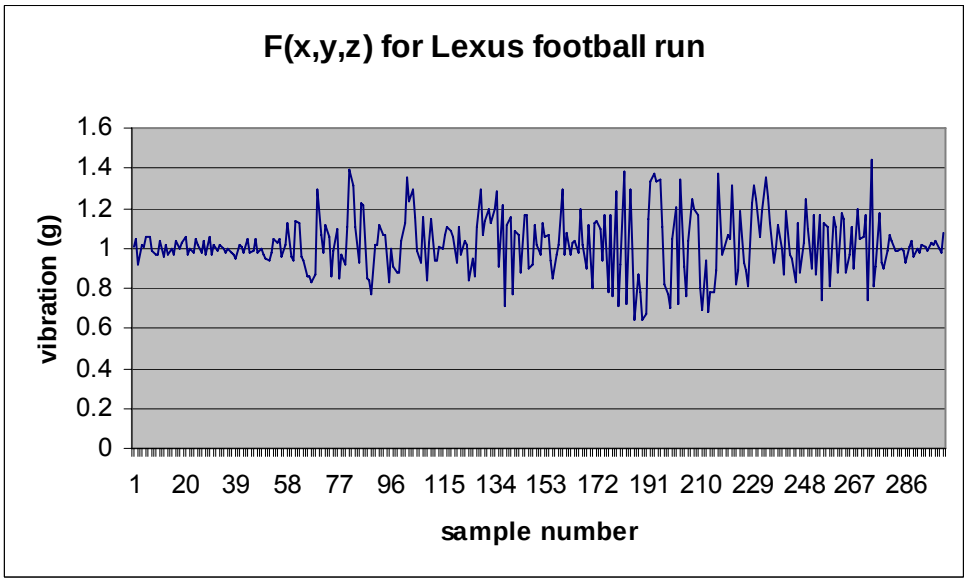

Figure C20: Resultant plot for Lexus SUV football shaped rumble strip trial on US 40

APPENDIX D

Kansas State University Football Rumble Strip Research Questionnaire

A team from Kansas State University is researching the new football shaped rumble strips along the eastbound lanes K-96 between Maize and Wichita. The opinions of bicyclists in regard to the new football rumble strips are very important to the team's research. After observing the rumble strips, please fill out the following questionnaire. Return completed questionnaires to Helen Wait at the next Oz Bicycle Club meeting on April 4thor mail to the address on the back. Thank you for your participation.

1. What do you think of the rectangular shaped rumble strip?

1	2	3	4	5
Definitely Dislike		**Neutral**		**Definitely Like**

2. What do you think of the football shaped rumble strip?

1	2	3	4	5
Definitely Dislike		**Neutral**		**Definitely Like**

3. How do the football shaped rumble strips compare to the rectangular rumble strips?

1	2	3	4	5
Definitely Worse		**Neutral**		**Definitely Better**

4. The placement of the football rumble strips gave me plenty of room to ride on the shoulder.

1	2	3	4	5
Definitely Disagree		**Neutral**		**Definitely Agree**

5. The size of the football rumble strip did not distract from the safety of my riding.

1	2	3	4	5
Definitely Disagree		**Neutral**		**Definitely Agree**

6. The depth of the football rumble strips (1/2"-5/8") would not be a problem for me if I rode over them on my bike.

1	2	3	4	5
Definitely Disagree		**Neutral**		**Definitely Agree**

7. What is your opinion of rumble strips as pertaining to the safety of vehicle drivers from running off the road?

1	2	3	4	5
Definitely Dislike		**Neutral**		**Definitely Like**

8. What is your overall opinion of rumble strips?

1	2	3	4	5
Definitely Dislike		**Neutral**		**Definitely Like**

Comments and/or Recommendations:

EVALUATION OF CENTERLINE RUMBLE STRIPS
KANSAS DEPARTMENT OF TRANSPORTATION

Your comments concerning the centerline rumble strips are important.

Please complete, detach, and mail the lower portion of this pre-addressed questionnaire at your earliest convenience. The information you provide will be kept confidential and only a summary of the results will be available for review.

In appreciation for completing and returning this survey, we would like to send you a free State of Kansas Highway map. To receive your map, please provide your mailing address where indicated.

PLEASE ANSWER ALL QUESTIONS AND DROP IN MAIL
NO POSTAGE REQUIRED

---

1. Have you driven over (come in contact with) the centerline rumble strips?
   ☐ Yes (continue to question 2) ☐ No (continue to question 4)
2. Do you think the centerline rumble strips provide a proper auditory alert to alert a driver?
   ☐ Yes ☐ No
3. Do you think the centerline rumble strips provide a proper vibratory level to alert a driver?
   ☐ Yes ☐ No
4. Can you hear from your residence when a driver crosses over (comes in contact with) the centerline rumble strips?
   ☐ Yes (continue to question 5) ☐ No (continue to question 7)
5. Choose one of the following and please comment below:
   The noise produced is loud enough to cause a concern or a distraction. ☐
   The noise is only inconvenient and annoying. ☐
   The noise is unnoticeable and not a concern. ☐
6. If you answered yes to question 4, 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
7. What is the approximate distance from your house to US 40?_____
8. Do you believe the centerline rumble strips on US 40 contribute to your driving safety?
   ☐ Yes ☐No opinion ☐ No
9. Do you believe the potential safety effect is worth some level of annoying noise?
   ☐ Yes ☐No opinion ☐ No

Comments: _____

_____

Name/Address: _____

EVALUATION OF CENTERLINE RUMBLE STRIPS
KANSAS DEPARTMENT OF TRANSPORTATION

Dear Resident:

The Kansas Department of Transportation (KDOT) needs your help in a special study of the centerline rumble strips along US 40 highway between Lawrence and Topeka. US 40 highway has had a number of serious crashes from vehicles crossing over the centerline (cross over crashes). KDOT is concerned with your driving safety and has installed centerline rumble strips in an effort to reduce cross over crashes. When driving over the centerline rumble strips, noise and vibration are created in the cab of the vehicle. This gives an alerting signal to the driver that they are nearing the opposing lane. Noise is also created that can be heard outside the vehicle. The purpose of this survey is to determine the level and severity of the external noise created by rumble strips placed near residential areas. To identify problems and/or better solutions in the rumble strip design and placement, we need to know how residents near rumble strips feel. KDOT wishes to get your opinion as to the acceptability of the noise level, i.e., are the safety benefits worth the inconvenience of some noise. Your answers to the attached survey will help provide this valuable information.

K - TRAN

KANSAS TRANSPORTATION RESEARCH AND NEW - DEVELOPMENTS PROGRAM

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

KANSAS DEPARTMENT OF TRANSPORTATION

THE UNIVERSITY OF KANSAS

KANSAS STATE UNIVERSITY