EVALUATION OF DIFFERENT SAFETY ASPECTS OF CENTERLINE RUMBLE STRIPS

by

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Abstract

In this thesis, various safety aspects of centerline rumble strips were evaluated. Based on the literature review centerline rumble strips (CLRS) are considered to be effective safety countermeasure for reducing crossover accidents on two-lane, two-way roadways. CLRS are indentations milled into the centerline of undivided two-lane, two-way roadways to warn driver of drifting into upcoming traffic. Researchers at Kansas State University (KSU) have conducted studies on CLRS and retroreflective pavement markings (RRPM) installed over them. Based on the literature review and the survey conducted on motorcycle riders it can be concluded that majority of riders believe in the effectiveness of CLRS and they recommend the KDOT to implement CLRS in more locations. From the survey conducted on residents of US 40 it can be concluded that RRPM help them in providing visual guidance. They also noticed that there is considerable deterioration of RRPM over CLRS on US 40. From the studies conducted on US 24, US 50 and US 40 it can be concluded that wet retroreflectivity of pavement markings installed over CLRS is considerably lower than dry retroreflectivity. In locations without CLRS wet retroreflectivity of RRPM is higher than dry retroreflectivity. Also, the analysis performed on retroreflectivity measurements from US 24, US 50 and US 40 show that retroreflectivity follows a linear reduction in performance over time. In addition, a new methodology was developed for evaluating RRPM over CLRS. Various tests and analysis were performed and the new method seems effective.

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Dedication

This thesis is dedicated to my parents – Chandrika and VijayaKumar.

CHAPTER 1 - Introduction

Since August 1999, researchers at Kansas State University (KSU) have been conducting studies on centerline rumble strips (CLRS) installed on two-lane, two-way roadways in the United States (U.S.). The rumble strips alter the flat surface which drivers are familiar with by providing a distinct sound and vibration alert to the drivers when encountered. This sound and vibration, alert the driver to a potential conflict or crash situation due to lane departure. Several studies were conducted on the operational impact of the CLRS with respect to passing operations, lateral position of vehicle within the travel lane, and the erratic maneuvers associated with the installations of the CLRS. CLRS along with retroreflective pavement markings (RRPM) provide proper guidance to drivers and riders in keeping their lane positions. The overall objective of this research project conducted by KSU research team was to evaluate different safety aspects of CLRS affecting motorcycle riders and drivers.

Through the research, it was learned that many states have conducted studies on CLRS and RRPM. Initial stage of this research focused on reviewing current and past studies on safety effects of CLRS, retroreflective pavement markings and the CLRS impact on motorcycle riders' safety.

The primary objective of this study was to develop a standardized method for evaluating visibility of RRPM placed over CLRS and studying the various factors affecting RRPM deterioration. For accomplishing this objective a methodology was developed for inspecting various factors affecting retroreflectivity of RRPM and field data measurements were taken from US 24, US 50, US 40 and they were analyzed. In addition, a prediction model was developed to predict trend in retroreflectivity deterioration. Secondary objective was to evaluate concerns of RRPM over CLRS. Here a questionnaire survey was conducted on the residents of US 40 where RRPM over the CLRS were installed in May 2005. A last objective was to understand the impact of the CLRS on motorcycle riders' safety. This was achieved by conducting a questionnaire based study on motorcycle riders travelling on undivided highways having the CLRS.

CHAPTER 2 - Literature Review

Rumble strips are a series of bumps or indentations installed along roadways and are used to alert drivers or aid them in their lateral positioning. Rumble strips alter the flat surface which the drivers are familiar with, by providing a distinct sound and vibration when encountered. This sound and vibration alert the driver to a potential conflict or crash situation due to lane departure (Gardner, 2006). Moreover, rumble strips along with the retroreflective pavement markings, can act as a roadway guide for drivers in areas where rain, fog and snow can obscure the pavement lane separation markings and edges.

Current literature reviewed are categorized into three parts,

- Part I – Studies on safety effects of Centerline Rumble Strips (CLRS) on drivers.
- Part II – Studies on Retroreflective Pavement Marking (RRPM).
- Part III – Studies on CLRS impact on Motorcycle rider's safety.

2.1. Part I - Studies on safety effects of Centerline Rumble Strips (CLRS).

Research at the University of Massachusetts, Amherst and the University of Wisconsin, Madison conducted a study for evaluating drivers' behavior when encountering CLRS (Dulaski et al., 2006). They conducted a static evaluation that required the drivers to correct when they were going to run-off the road to the right toward a shoulder or to the left when crossing over the centerline. The static evaluation was given to 100 drivers. The evaluation consisted of a series of images that were automatically presented to the drivers on a computer monitor. The images presented to the drivers consisted of two consecutive images taken from the driver's perspective on a two-lane, undivided rural roadway. The first image presented the scenario of the driver being properly located (i.e., centrally or laterally) in the lane. The second image placed the left edge of the vehicle on the centerline or the right edge of the vehicle on the edge line. Two consecutive image groups were presented to the driver. One was a "clear" group and the other a "foggy" one. In the clear group, the roadway, the pavement markings and the current lateral positioning were easily decipherable by the driver. In the foggy group, the first image was slightly overexposed providing a foggy or hazy view. Pavement markings were barely visible. The second image in the foggy group was completely overexposed, in which the driver could not discern their lateral position by the visual clues alone. Each set of images was automatically and randomly presented to each driver on the computer monitor. Speakers were positioned next to the monitor, and a sub woofer near the driver's feet to broadcast the sound and the vibration of the rumble strip.

Prior to the beginning of the survey, each driver was presented with a short slide show illustrating that he will be seeing a number of images in groups of two. In the first image the vehicle was properly located in the lane. In the second one, the driver would be drifting toward the shoulder or centerline. To correct his position the driver was instructed to press a button on the keyboard. There were two portions for this evaluation - one uninformed and the other informed. The driver took the uninformed session without any explanation, other than what to do in the evaluation. Once the uninformed portion was completed, a brief slide show was presented on the computer screen which provided information to the driver on rumble strips and the patterns of rumble strips they will be encountering. For the two scenarios presented (clear and foggy conditions), the drivers corrected 85% of the time before a pre-information session and 91 % after the information intermission, under clear visibility conditions. The ratings were 40% and 66%, respectively, under foggy conditions. Thus, the result indicates that there is significant improvement in the driver's reaction when he is made aware of the scenario.

The Virginia Department of Transportation conducted a study for developing guidelines for the use of centerline rumbles in Virginia (Chen et al., 2005). In this study, the research team conducted a literature review on existing practices. This study gives information about rumble stripes. Rumble stripes are pavement marking materials installed over rumble strips. The purpose of rumble stripes is to provide improved visibility of pavement markings especially under wet night conditions. The audible warning provided when the stripes are crossed is equally important or secondary to the visibility of the pavement marking, depending on the application. In the case of CLRS, rumble stripes provide an enhanced wet night visibility which is an added benefit.

Several states are demonstrating the use of rumble stripes, including Mississippi and Texas (Wills et al. 2004) & (Stanford, 2004). The Mississippi DOT has experimented with rumble stripes on the edge line at several sites and concluded that in addition to the excellent audible warning, rumble stripes provide increased retroreflectivity of the pavement markings. Furthermore, in a survey of motorists, it was concluded that the rumble stripes provide improved visibility of the markings under wet night conditions (Wills et al., 2004).

The Texas Transportation Institute (TTI) conducted a study on the operational impacts of the installation of Centerline and Edgeline Rumble Strips (Pratt et al., 2006 (a)). In this study, the CLRS were evaluated with respect to passing operations and lateral positioning of the vehicle within the travel lane. The evaluation of the operational impacts of CLRS was broken down into two separate tasks: 1. study of passing operations, and 2. study of vehicle lateral positioning. The study was conducted on a 15-mile segment of US 67 in Comanche County, west of Waco. An innovative mobile video data collection system was developed by the researchers to collect video data without alerting drivers. This video system aided researchers in evaluating any change in passing opportunity, which is a measure of the amount of time a driver wishing to pass has clear and legal opportunities to do so, divided by the amount of time the driver spends queued behind the vehicle and percentage of passing which is the total number of drivers who conducted a single pass divided by the total number of drivers in a position to do so. The study that evaluated the change in lateral positioning was conducted using a stationary video data collection system. Before and after study analysis was conducted on the data for both the tasks. Results of this study showed that implementation of CLRS generally improve lateral positioning by increasing vehicle separation between opposing traffic streams on rural highways.

TTI also studied the erratic maneuvers associated with the installation of rumble strips (Pratt et al., 2006(b)). Rumble strips provide drivers with sound and vibratory warnings when tires contact the strips. For inattentive drivers who inadvertently contact the stripes, these warnings will surprise them. Drivers may react to these clues either by correcting their navigational errors or by making further mistakes due to the surprise warnings. This response to surprise warnings may include both erratic and avoiding maneuvers.

The study was conducted on a 15-mile section. The highway average daily traffic (ADT) was approximately 4000 vehicles/day, with a 50/50 directional split. Study data was collected during the day time using a mobile data collection vehicle (DCV) which is equipped with special recording cameras. After observing 479 vehicle passes for a period of 50 hours, they didn’t observe any erratic maneuvers before and after the installation of CLRS. Thus this study concluded that the installation of CLRS caused no erratic maneuvers on this section.

The Michigan Department of Transport (MDOT) and Michigan State University (MSU) tested the effectiveness of placing shoulder rumble strips close to the edge of the travel lanes and installed the painted edge line in the rumble strips to improve the retroreflective properties of the pavement marking. MSU conducted research on the effects of continuous shoulder rumble strips and pavement markings on lateral placement of vehicles (Taylor et al., 2006). This study shows that moving the painted edge line onto the rumble strips resulted in the vehicles moving slightly closer to the edge of the travel lane. However, maintaining the current edge line and adding an additional paint line over rumble strips (outside the current edge line) resulted in the vehicles moving away from the edge of the pavement, thus reducing noise and potential damage to the pavement. This study showed that the lateral placement of the vehicle is influenced by the painted edge line.

2.2. Part II – Studies on Retroreflective Pavement Marking (RRPM).

This TTI study focused on evaluation of the visibility of pavement marking in wet-night rainy conditions and the appropriateness of associated measurement techniques (Pike et al., 2007).In this study, the researchers tested the performance of eighteen pavement marking types in wet-night conditions. They measured the wet-night detection distance of a wide range of pavement markings under typical rainfall rates. They also measured the retroreflectivity of the pavement markings under a wide range of continuous wetting rates. Additionally, they measured the luminance of the marking at a fixed 30-meter distance under the same rainfall rate of the detection distance measurements. Retroreflectivity was measured using a portable 30-meter pavement marking reflectometer and continuous wetting spray apparatus. This study results showed that the rate of continuous wetting influenced the measured retroreflectivity of the markings. The higher the rate of continuous wetting, the lower the retroreflectivity.

The research team also measured detection distances of pavement markings under simulated rainfall conditions. The measurements were conducted at night with the research participants driving an instrumented vehicle at a constant speed of 30 mph. The vehicle was equipped with a calibrated distance measuring instrument (DMI). Detection distance study results showed that the detection distance is influenced by the intensity of rainfall. Detection distance is reduced with the increase in intensity of rainfall. This study also focused on measuring the luminance of pavement markings. Luminance of the pavement marking was measured using a Radiant Imaging CCD (Charge Coupled Device) photometer. The photometer records a digital picture of the scene for analysis. The photometer was mounted on a tripod in the test vehicle at driver eye height. The measurements were taken with the test vehicle positioned 30 meters (98.43 feet) from the pavement markings. Results of this study showed that the luminance intensity of the pavement marking decreases with the increase in intensity of rainfall. Another important finding is this paper is that luminance measurement maintains significantly high correlation with retroreflectivity.

Concordia University, Montreal, Quebec, created a synthesis on practices of sustainable pavement markings in Canada (Shahata et al., 2008). The objective of this study was to summarize the best practices of managing pavement marking systems in Canada. This study collected data from Canadian provinces, including current management strategies, material types and re-striping criteria. Pavement marking maintenance practices in five provinces (Alberta, British Colombia, Ontario, Quebec, and Saskatchewan) were summarized in this study. This study results are summarized in Table 2.1.

Table 2.1 Current Practices for Managing Pavement marking System in Canadian Provinces. (Source: Shahata et al. , 2008)

Activity / Province	Highway/ Roadway System Pavement Markings	Urban/Lateral System Pavement Marking	Re-stripe Practice (Service Life)
Alberta	- Waterborne base paint - Alkyd base paint	- MMA - Epoxy - Thermoplastics	- Service Life (1-5) years for durable markings - Roadway lane lines are painted once per year. - On lower volume highways painted one edge line and centerline. The edge lines are alternated yearly and the centerline is painted every year. - On higher volume roadways painted several times a year (up to 3 times)
British Colombia	- Alkyd base paint	- Waterborne base paint - Thermoplastics	- Paint renewed every 1-2 years on the average. - Centerline is typically re-striped on a yearly basis. Try to get two year out of Edge Line, but in high snowfall areas where there is lots of salting and sanding may have to repaint yearly. - Thermoplastic renewed every 3 years while some need touching up annually.
Ontario	- Waterborne base paint - Alkyd base paint	- Waterborne base paint - Thermoplastics	- Paint all longitudinal lines once per year. - Main arterial roads, twice per year.
Quebec	- Waterborne base paint - Alkyd base paint - Resins Epoxy	- Resins Epoxy - Marking tape - Thermoplastic - Methyl Methacrylate (MMA)	- Alkyd base paint and Waterborne base paint: 6-8 months - Resin Epoxy: 2-4 years - Methyl Methacrylate (MMA): 6 months to 6-years *New application:* - Yellow lines 140 *mcd/m²/lux.* - White lines 200 *mcd/m²/lux.* - If the retroreflectivity drops below 60(white)/50 (yellow) *mcd/m²/lux,* re-stripe.
Saskatchewan	- Waterborne base paint - Alkyd base paint	- Waterborne base paint - Alkyd base paint	- Service life for applied pavement marking: 10 – 12 months *New application:* - Yellow lines 200/250 *mcd/m²/lux.* - White lines 290/350 *mcd/m²/lux.* - If the reflectivity drops below 100 *mcd/m²/lux, re-stripe*

A Civil engineering research team for cold regions in Hiragishi, Japan conducted a study on development of recessed pavement markings that incorporates rumble strips (Hirasawa et al., 2008). In this study the research team proposed a new design of pavement markings whose recessed design prevents scraping damage from snowplows. This design also incorporates rumble strips which increases driving safety. This new design of pavement markings was designed with the intention of improving durability and reducing costs by eliminating the cost for annual repainting of pavement markings. In this design, the markings were installed by milling a shallow longitudinal recess into the pavement while simultaneously milling recessed transverse grooves (the rumble strips) more deeply, and then applying paint. In this study to determine the optimum design for recessed pavement markings, two trial installations were made using two intervals or spacing between grooves. A questionnaire survey was conducted on test drivers to determine the difference in noise and vibration generated by the two patterns. The survey results did not reveal any difference between the two intervals. Field studies were also conducted to determine the sound and vibration from trial installation with different spacing. Field study results showed that recessed markings with long spacing generate more noise and vibration than recessed markings with short spacing, making the former more noticeable than the latter. Therefore, recessed markings with long spacing were selected for installation on roads in service. This study also found that waterborne paints are not durable enough to be used on recessed pavement markings and suggests that thermoplastic paint should be used.

Iowa State University conducted a study on safety effectiveness of pavement marking retroreflectivity. This study focused on analyzing the correlation between longitudinal pavement marking retroreflectivity and safety performance. In this study, when data records with low retroreflectivity were analyzed ($\leq$200 mcd/m^2/lux), a negative correlation was found to be statistically significant. This study showed that as retroreflectivity decreases crash probability increases. This study helped the concerned agencies to develop a better pavement marking management program to reduce nighttime crashes, where low pavement marking retroreflective values are a contributing factor.

The Kansas Department of Transportation (KDOT) adapted a new replacement policy in 2000 (Migletz et al., 2002), which includes the following conditions in replacing the pavement marking:

"Average reading of retroreflectivity falls below 150mcd/m^2/lux for white and 100mcd/m^2/lux for yellow, marker detached from the roadway due to adhesive failure, and ineffective daytime lane delineation due to loss of pigment."

Federal Aviation Administration (FAA) conducted a study on evaluating airport pavement marking effectiveness (Cyrus 2003). This study was conducted for replacement of ineffective subjective method of pavement marking evaluation. In the subjective method paint performance was evaluated by visual inspection of segments of marking. The subjective method lacked confidence in the validity of evaluation and it lacked the consistency an objective method would provide. Thus they developed an objective method measuring three important factors of pavement marking: 1) retroreflectivity, 2) chromaticity & 3) coverage of paint material. For measuring retroreflectivity they developed a manual and automated method using a hand held and vehicle mounted retro reflectometers. For Chromaticity measurement a hand held point detection spectrometer was used. This measured the spectral coverage of the paint material. For measuring the coverage of paint material they used a glass grid. This objective method was found to be really effective and it was adopted by FAA as a standard method.

McGinnis collected data from various highway agencies on minimum initial and minimum accepted retroreflectivity for different pavement marking materials (McGinnis, 2001). Initial and minimum accepted retroreflectivity data is shown in Table 2.2 & 2.3 respectively. Initial retroreflectivity reading is the retroreflectivity reading taken from pavement markings from 0-14 days of installation. Minimum accepted retroreflectivity reading is the reading from pavement marking within 180 days of installation.

Table 2.2 Summary of minimum initial retroreflectivity values for selected highway agencies, (Source McGinnis, 2001)

Type of Material	Marking Color	Minimum Retroreflectivity (mcd/m²/lux)									
		KS		KY		MD		NC		PA	
		Initial		Initial		Initial		Initial		Initial	
		Min. RR	Period of Days	Min. RR	Period of Days	Min. RR	Period of Days	Min. RR	Period of Days	Min. RR	Period of Days
Waterborne Paint	White					250	0				
	Yellow					150	0				
Epoxy	White	300	0-14			275	0	375	0-30	300	0-60
	Yellow	225	0-14			200	0	250	0-30	250	0-60
Thermoplastic	White	300	0-14			250	0	375	0-30	300	0-60
	Yellow	225	0-14			150	0	250	0-30	250	0-60
Preformed Thermoplastic	White	300	0-14	700	0	250	0				
	Yellow	225	0-14	500	0	150	0				
Spray Thermoplastic	White	300	0-14								
	Yellow	225	0-14								
Cold Plastic	White	250	0-14								
	Yellow	175	0-14								
Patterned Cold Plastic	White	475	0-14			350	0-30			300	0-60
	Yellow	375	0-14			250	0-30			250	0-60
High Durability Tape	White	225	0-14							300	0-60
	Yellow	175	0-14							250	0-60
Modified Urethane	White	300	0-14								
	Yellow	225	0-14								
Polymer-Modified Cementitious	White	300	0-14								
	Yellow	225	0-14								

Table 2.3 Summary of minimum acceptance retroreflectivity values for selected highway agencies (Source McGinnis, 2001)

Type of Material	Marking Color	Minimum Retroreflectivity (mcd/m²/lux)									
		KS		KY		MD		NC		PA	
		Acceptable		Acceptable		Acceptable		Acceptable		Acceptable	
		Min. RR	Period of Days	Min. RR	Period of Days	Min. RR	Period of Days	Min. RR	Period of Days	Min. RR	Period of Days
Waterborne Paint	White			175	30-60						
	Yellow			150	30-60						
Epoxy	White	250	180					325	150-180	125	1095
	Yellow	175	180					200	150-180	100	1095
Thermoplastic	White	250	180	300	150-210			325	150-180	125	1095
	Yellow	175	180	175	150-210			200	150-180	100	1095
Preformed Thermoplastic	White	250	180	200	1440	300	180				
	Yellow	175	180	150	1440	220	180				
Spray Thermoplastic	White	250	180								
	Yellow	175	180								
Cold Plastic	White	200	180								
	Yellow	125	180								
Patterned Cold Plastic	White	425	180			300	180			125	1095
	Yellow	325	180			220	180			100	1095
High Durability Tape	White	200	180							125	1095
	Yellow	150	180							100	1095
Modified Urethane	White	250	180								
	Yellow	175	180								
Polymer-Modified Cementitious	White	250	180								
	Yellow	175	180								

From Table 2.2 it can be seen that minimum initial retroreflectivity for thermoplastic paint in Kansas is 225 mcd/m^2/lux (for yellow) and 300 mcd/m^2/lux (for white). From Table 2.3

it can be seen that minimum accepted retroreflectivity of thermoplastic paint in Kansas is 175 mcd/m^2/lux (for yellow) and 250 mcd/m^2/lux (for white)

2.3. Part III – Studies on CLRS impact on Motorcycle rider's safety.

Minnesota Department of Transportation (MNDOT) conducted a study on evaluating effect of CLRS on non-conventional vehicles (Miller 2008). In this study, motorcycle riders were asked to ride through a one-mile closed circuit having two lane changes over CLRS. There were 32 participants in this study and a full range of motorcycles including touring, cruising and sports bikes. Included with those vehicles were two three wheeled cycles and a scooter. Video observation on riders showed no adjustment to steering, brakes, or throttle while crossing CLRS. Post ride interview was conducted and it was observed that none of the riders expressed any difficulty or concern while crossing CLRS. Also about half of the riders noticed CLRS before crossing them but did not express any concerns while crossing them. Eight riders considered them to be nuisance while crossing. Also the study results reveal that CLRS pose no hazard to motorcycles.

Civil engineering research institute of Hokkaido, Japan conducted a study on development and practical use of rumble strip as a new measure for highway safety (Hirasawa at al., 2005). In this study 62 participants travelled three times over a test section with CLRS. The vehicles used by participants were passenger cars, motorcycles and bicycles. Vehicles driven by participants were videotaped and after driving/riding, each participant filled out a questionnaire. Here the study results revealed that participants felt danger when riding on deep grooves than on shallow grooves.

California Department of Transportation (CDOT) evaluated milled-in rumble strips; rolled-in rumble strips and audible edge stripe (Bucko et al., 2001). In this study a group of California Highway Patrol (CHP) riders travelled over a section treated with rumble strips. After riding each CPH rider filled out a questionnaire. Study results are shown in Table 2.4.

Table 2.4 Results from CPH rider's questionnaire. (Source Bucko et al., 2001)

Subjective motorcycle rider comfort and control questionnaire results		
		Average riders rating on a scale of 5
1	Milled-In Section B (16in*5in*.2in (Length*Breadth*Depth)	
	Wrist/Fingers/Elbows	5
	Shoulder/Neck	5
	Back	5
	Seat area	5
	Knee/Ankle/Foot	5
	Overall	5
	Control Level	5
2	Milled-In Section C (16in*6in*.35in (Length*Breadth*Depth)	
	Wrist/Fingers/Elbows	4.5
	Shoulder/Neck	4.5
	Back	4.5
	Seat area	4.5
	Knee/Ankle/Foot	4.5
	Overall	4.5
	Control Level	4.75
3	Milled-In Section D (16in*7in*.5in (Length*Breadth*Depth)	
	Wrist/Fingers/Elbows	3.75
	Shoulder/Neck	3.75
	Back	3.75
	Seat area	3.75
	Knee/Ankle/Foot	3.75
	Overall	3.75
	Control Level	4.5
4	Milled-In Section D (16in*8in*.6in (Length*Breadth*Depth)	
	Wrist/Fingers/Elbows	3.5
	Shoulder/Neck	3.5
	Back	3.5
	Seat area	3.5
	Knee/Ankle/Foot	3.5
	Overall	3.5
	Control Level	4.5

From Table 2.4 it can be observed that riders' comfort and control level decreased as the depth of rumble trips increased.

After reviewing the current and past literature it was concluded that there were no studies conducted that focused on:

1. **The impact of CLRS on Motorcycle Riders travelling on undivided two lane and four lane highways.**
2. **The evaluation of concerns on visibility of retroreflective pavement markings over CLRS.**
3. **Developing a methodology for evaluating pavement marking over CLRS and developing models for predicting the trend of retroreflectivity.**

The next three sections of this report present studies conducted by the K-State research team that focuses on the above concerns.

CHAPTER 3 - Impact of Centerline Rumble Strips on Motorcycle Riders' Safety

3.1. Introduction

Kansas State University research team conducted a questionnaire survey on motorcycle riders travelling on undivided highways with CLRS. In this study 44 motorcycle riders were evaluated. The participant group consisted of a diversified group of motorcyclists riding both sports and cruise motorcycles. Participants consisted of different age groups. Six riders were in the age group of 18-24, thirty in the group of 25-45, seven in the 45 – 65 age group and one rider was above 65 years. Eighty six percent of participants were males and fourteen percent females. Two percent of the participants had less than 1 year of riding experience, thirty four percent had 1-5 years and sixty four percent had above 5 years of motorcycle riding experience. Sizeable share of the participants were employees of Harley-Davidson's Vehicle and Power train operations plant in Kansas City, Missouri. This questionnaire was also distributed on 7th of June 2008, among members of Harley-Davidson Employee Riders' meeting at the Peets Inn located in Missouri. Subjects were individually approached for survey purposes. A brief description and objective of survey was included at the beginning of the questionnaire. The actual questionnaire can be found in Appendix A.

2.2. Methodology of Study

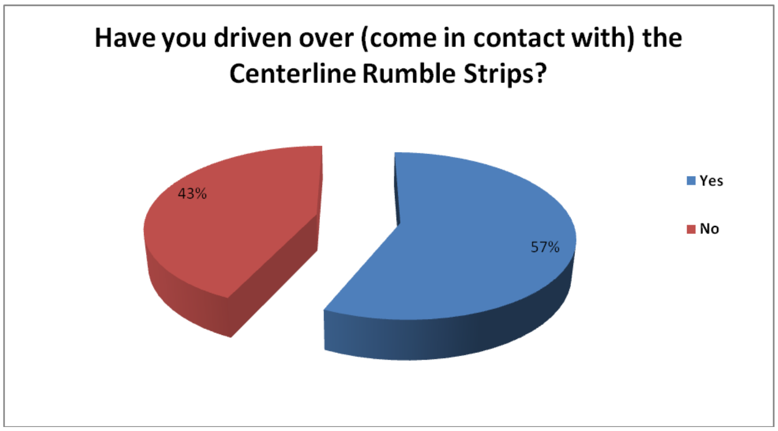
A paper based questionnaire survey was developed by Kansas State University research team. The questions were designed to determine the key safety factors impacting motorcycle riders when traversing over CLRS. This study focused on the following factors: CLRS effect on motorcyclist in reducing heads on collisions in undivided two-lane and four-lane highways, effects of sound and vibratory warnings in correcting the lane position, rider's initial reaction when encountering CLRS, erratic maneuvers encountered while traversing CLRS, intensity of difficulty encountered in motorcycle handling, motorcycle rider's opinion on rumble effect, and difficulty and safety concerns while making legal passing maneuvers. The period of study was between April and June, 2008.

3.3. Results

Question 1: *Have you driven over (come in contact with) the Centerline Rumble Strips (CLRS)?*

Respondents were asked to answer "yes" or "no" to 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 thirteen. The distribution of answers can be seen in Figure 3.1.

Figure 3.1 Response Distribution for Question 1, Motorcycle Survey



As seen in Figure 3.1 57% (n = 25) of the respondents answered yes that they have encountered CLRS. Forty three percent (n = 19) respondents answered that they have not encountered CLRS. All respondents, including the participants who have not encountered CLRS answered questions 14 through 18.

Question 2*: Do you remember the location where you encountered Centerline Rumble Strips? If so please write down the location.*

Locations where riders came across CLRS are shown in Table 3.1.

Table 3.1 Response Distribution for Question 2, Motorcycle Survey

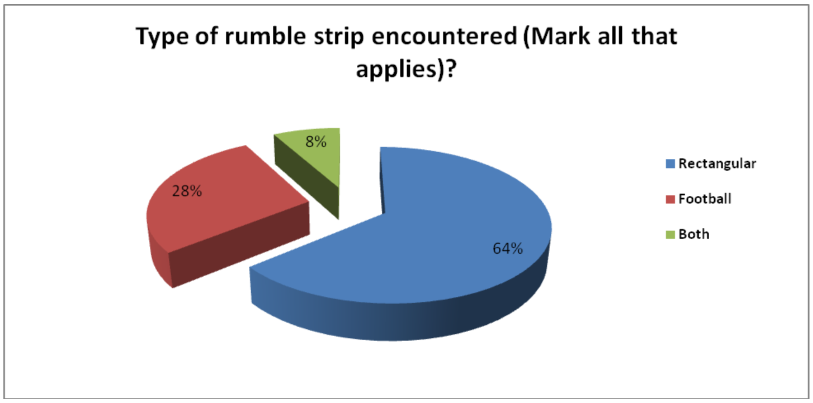
	Location
1	US-40 Topeka, Kansas.
2	Highway 169 North of Smithville, Missouri
3	South Missouri & Arkansas
4	210 from North Kansas City to Orrick, Missouri.
5	Highway 13 south of Warrensburg to Clinton, Missouri.
6	Highway 59 between ST-Joseph, Missouri & Atchison, Kansas.
7	Warsaw, Missouri.
8	Highway 92 between Kearney & Springs, Missouri.

From Table 3.1 it can be seen that the locations where CLRS were encountered by riders in the survey were all in Kansas and Missouri.

Question 3*:* *Type of rumble strip encountered (Mark all that applies)?*

In this question respondents were asked the types of CLRS encountered. For this question three answering options were given, a. Rectangular CLRS, b. Football CLRS and c. Both.
The distribution of answers can be seen in Figure 3.2.

Figure 3.2 Response Distribution for Question 3, Motorcycle Survey

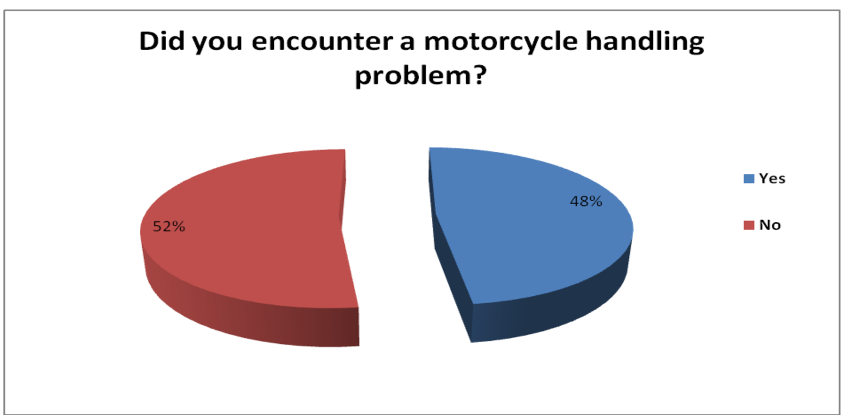


From the results it can be seen that 64% (n = 16) have encountered rectangular rumble strips, 28% (n = 7) football shaped and 8% (n = 2) have encountered both. Hence, most of the respondents have encountered rectangular shaped CLRS.

Question 4*:* *Did you encounter a motorcycle handling problem?*

In this question respondents were asked about the difficulty encountered in motorcycle handling when they traversed CLRS. Here the respondents were asked to answer either “yes” or “no”. The distribution of the responses can be found in Figure 3.3.

Figure 3.3 Response Distribution for Question 4, Motorcycle Survey

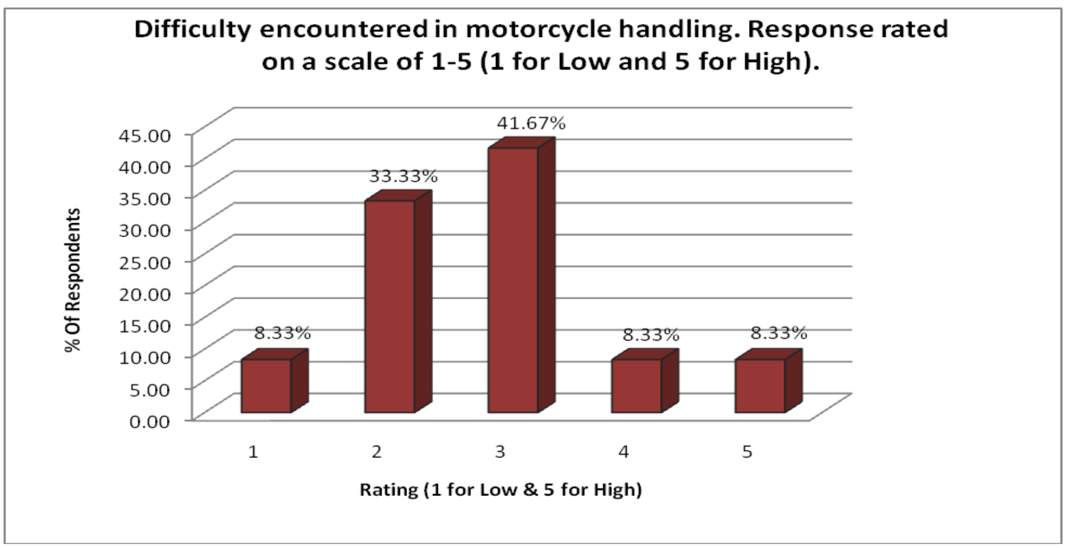


From the results it can be seen that 52% (n = 13) answered yes that they have encountered motorcycle handling trouble and 48% (n = 12) answered no. Hence we can see that only about half of the respondents feel that they have encountered problems in motorcycle handling when they encountered CLRS.

Question 5: *If your answer is 'Yes' to Question # 4, please rate the level of difficulty encountered on a scale of 1-5 (1 for Low and 5 for High). If your answer is 'No' to Question # 4, please continue to Question # 6.*

This question was only for respondents who answered "yes" to Question # 4. In this question respondents were asked to rate their difficulty encountered in motorcycle handling on a scale of 1-5 (1 for Low and 5 for High). For those who answered "no" to Question # 4 were asked to continue to Question # 6. Response ratings are shown in the following Figure 3.4.

Figure 3.4 Response Rating Distribution for Question 5, Motorcycle Survey

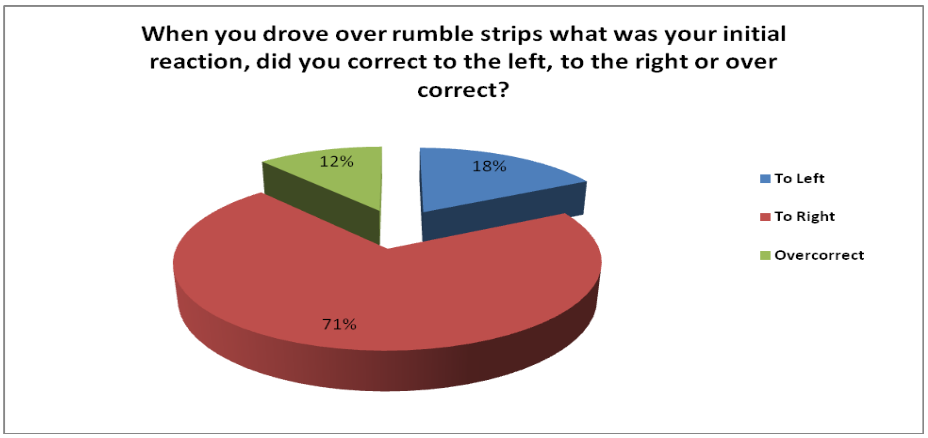


Above distribution shows that 8.33% (n = 1) of respondents faced level 5, 4 & 1 difficulty, 41.67% (n = 5) faced level 3 difficulties and 33.33% (n = 4) faced level 2 difficulties. From this response rating it can be concluded that little difficulty in motorcycle handling is faced when riders ride over CLRS.

Question 6: *When you drove over centerline rumble strips what was your initial reaction, did you correct to the left, to the right or overcorrect?*

This question was meant to determine riders' initials reaction when they rode over CLRS. Response to this question determined what erratic maneuvers riders encountered when they rode over CLRS. There were three answering options for the question. If the answer was anything other than those three answering options they were asked to write that down that in the form of a comment. The distribution of the responses can be found in Figure 3.5.

Figure 3.5 Response Distribution for Question 6, Motorcycle Survey

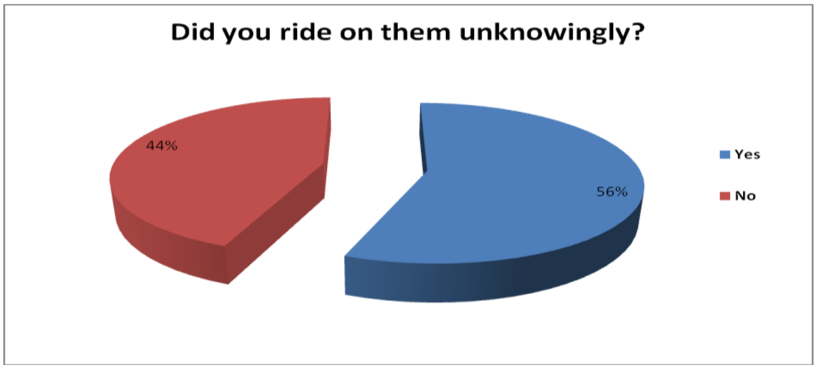


From the response distribution it can be seen that 71% (n = 12) of rider's initial reaction was to turn right for correcting their lane position, 18% (n = 3) turned left and 12% (n = 2) overcorrected their lane position. Also some of the respondents gave interesting comments which are quoted at the end of this chapter. From this distribution it can be seen that the majority of respondents reacted properly to the corrective stimuli given by CLRS.

Question 7: *Did you ride on them unknowingly?*

In this question respondents were asked to answer either "yes" or "no". Response distribution is shown in Figure 3.6.

Figure 3.6 Response Distribution for Question 7, Motorcycle Survey



Response distribution shows that 56% (n = 14) of riders rode over CLRS unknowingly.

Question 8: *What is your initial impression on Centerline Rumble Strips?*

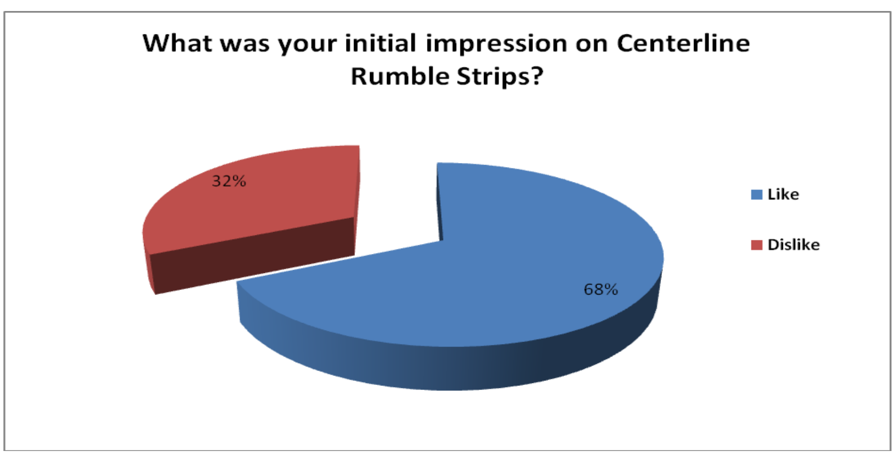
☐ Like, please rate your opinion on a scale of 1-5 (1 for Low and 5 for High) on how strongly you like _____

Or

☐ Dislike, please rate your opinion on a scale of 1-5 (1 for Low and 5 for High) on how strongly you dislike _____

As shown below this question had two answering options, either "Like" or "Dislike". Their "Like" and "Dislike" answers were further asked to be rated on a scale of 1-5 (1 for Low and 5 for High). Respondent's "Like" and "Dislike" response distribution is shown in Figure 3.7.

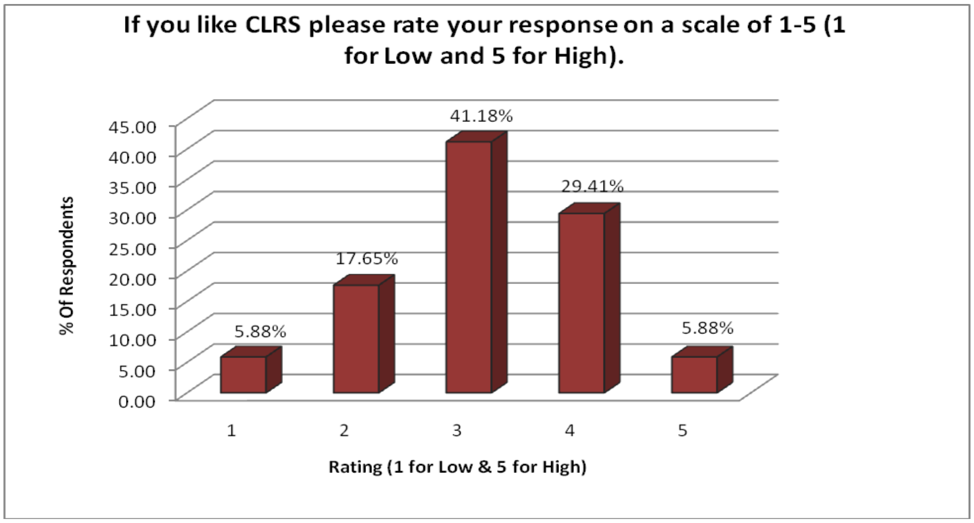
Figure 3.7 Response Distribution for Question 8, Motorcycle Survey



From the response distribution it can be seen that 68% (n = 17) of respondents say that they like CLRS and 32% (n = 8) of them dislike CLRS.

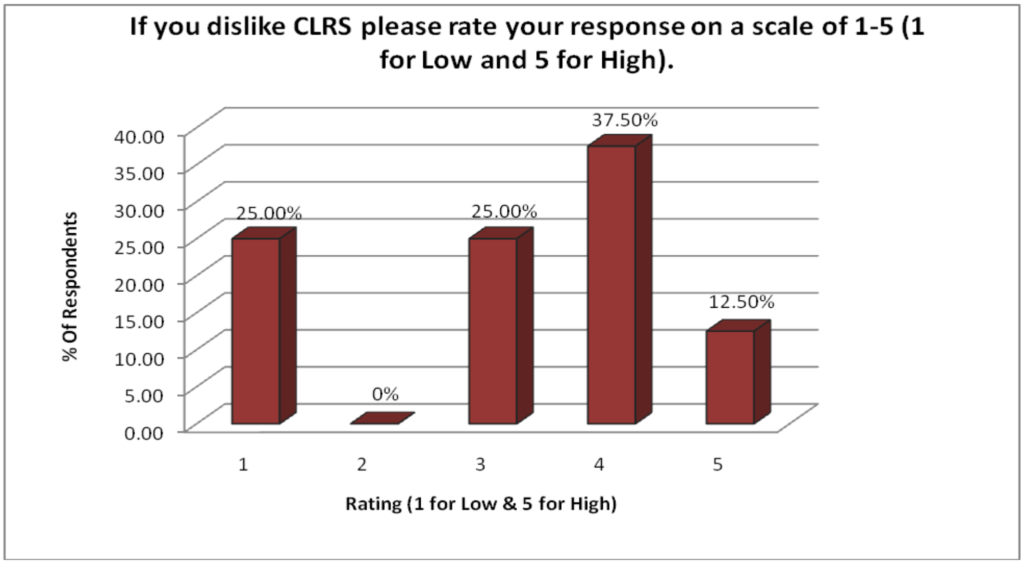
Respondents "Like" and "Dislike "distributions are shown in Figures 3.8 & 3.9 respectively.

Figure 3.8 "Like" Response Distribution for Question 8, Motorcycle Survey



From the likeness distribution it can be seen that 5.88 % (n = 1) of respondents gave a likeness rating of 1 and 5, 17.65 % (n = 3) gave a rating of 3, 41.18% (n = 7) and 29.41% (n = 5) gave a rating of 4. Therefore, of respondents who like the CLRS, they strongly like them.

Figure 3.9 " Dislike" Response Distribution for Question 8, Motorcycle Survey

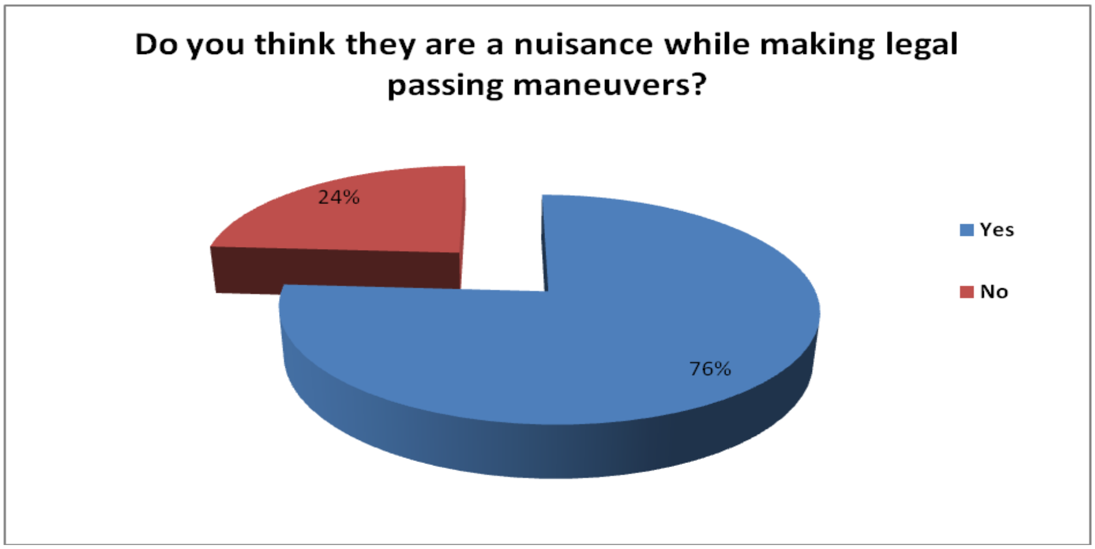


From the “Dislike” distribution it can be seen that 25 % (n = 2) of respondents gave a dislike rating of 1 and 3. 37.5% (n = 3) gave a rating of 4 and 12.5% (n = 1) gave a rating of 5. Therefore respondents’ who dislike the CLRS, strongly dislike them.

Question 9*:* *Do you think they are a nuisance while making legal passing maneuvers?*

This question asks respondents whether they think CLRS are a nuisance while they make legal passing maneuvers. Here respondents were asked to answer either “yes” or “no”. Response distribution is shown in Figure 3.10.

Figure 3.10 Response Distribution for Question 9, Motorcycle Survey



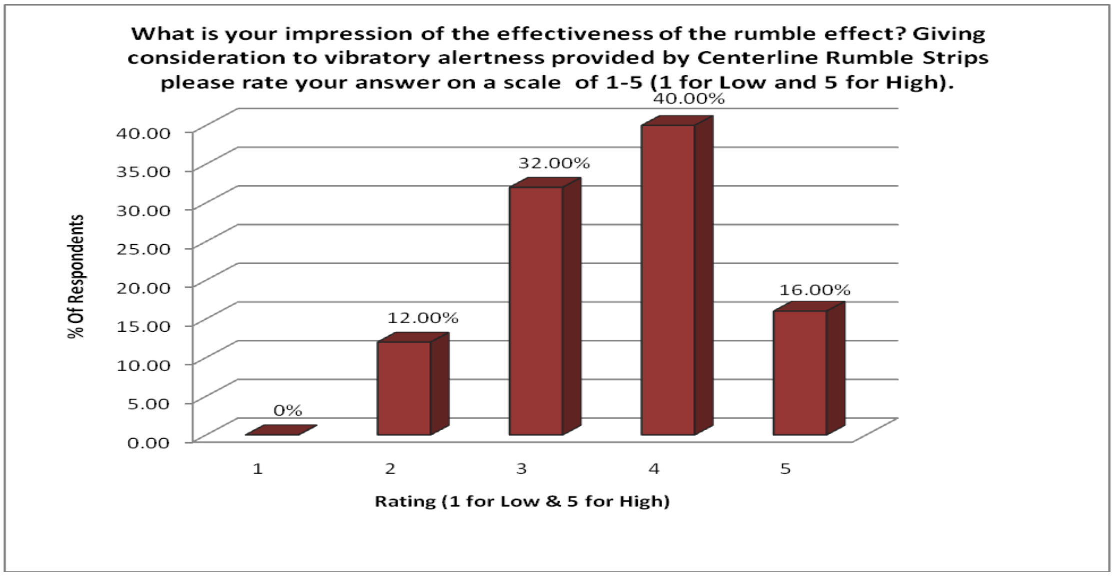
From the distribution it can be seen that 76 % (n = 19) believe that CLRS are a nuisance while making legal passing maneuvers.

Considering Question 8 (Fig 3.7) it can be seen that 68% of respondents like CLRS, from Question 6 (Fig 3.5) it can be seen that 71% corrected properly and Question 5 (Fig 3.4) it can be seen that only little difficulty was encountered by most. Also from Question 10 (Fig 3.11) respondents rated CLRS effectiveness as high and Question 11 (Fig 3.12) shows that CLRS provide safety improvement in reducing heads on collision. Hence we can see that only 24% of the respondents consider CLRS as nuisance.

Question 10: *What is your impression of the effectiveness of the rumble effect? Giving consideration to vibratory alertness provided by Centerline Rumble Strips please rate your answer on a scale of 1-5 (1 for Low and 5 for High).*

This question asks respondents about their impression on the effectiveness of the rumble effect, giving consideration to vibratory alertness provided by CLRS. Their response is rated on a scale of 1-5 (1 for Low and 5 for High). Response rating distribution is shown in Figure 3.11.

Figure 3.11 Effectiveness of Response Distribution for Question 11, Motorcycle Survey

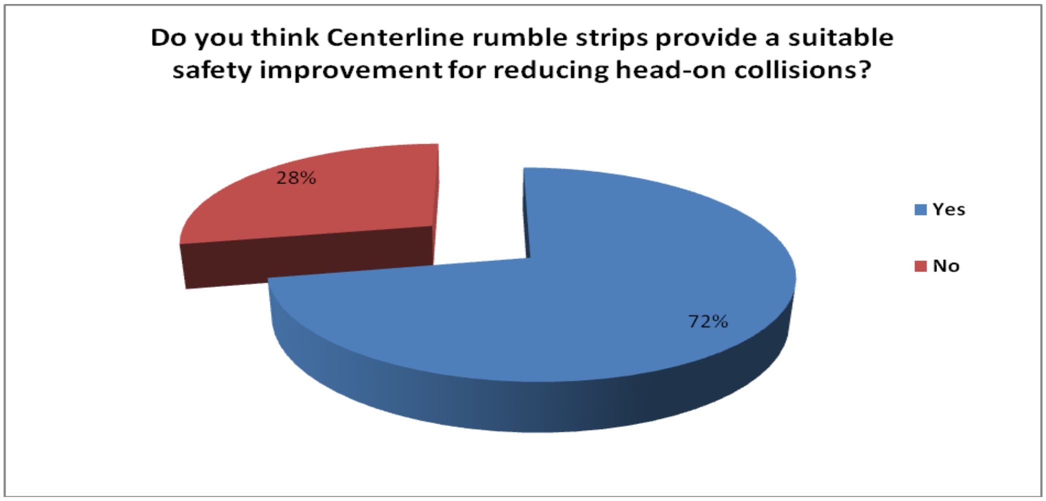


Response distribution shows that 16% (n = 4) of respondents have rated effectiveness level-5, 40% (n = 10) have rated effectiveness level-4, 32% (n = 8) have rated effectiveness level-3 and 12% (n = 3) have rated effectiveness level-2. Therefore from the distribution it can be seen that most of the respondents rate the overall effectiveness of CLRS as high.

Question 11: *Do you think Centerline Rumble Strips provide a suitable safety improvement for reducing head-on collisions?*

This question asks respondents whether they think CLRS provide a suitable safety improvement for reducing head-on collision. Here respondents were asked to answer either "yes" or "no". The response distribution is shown in Figure 3.12.

Figure 3.12 Response Distribution for Question 11, Motorcycle Survey

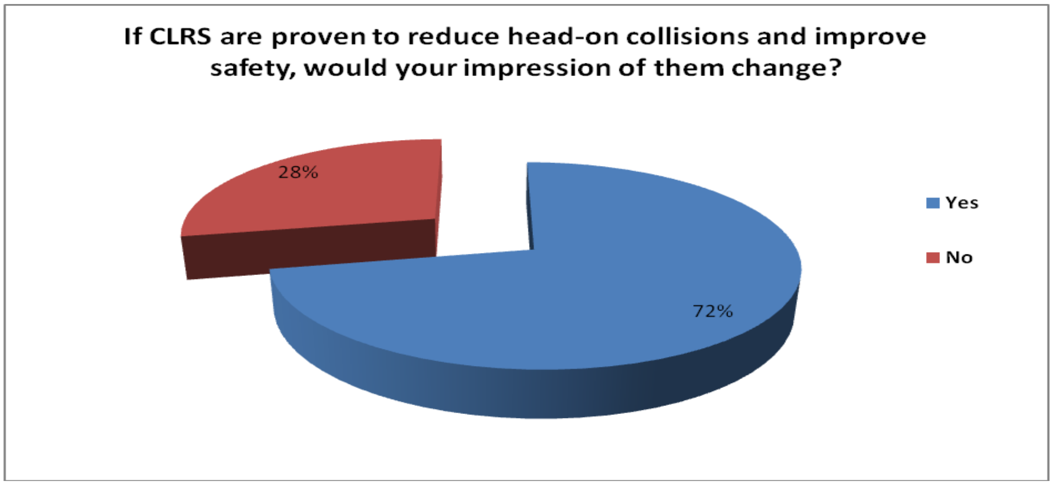


From the distribution it can be seen that 72 % (n = 18) believe that CLRS provide a suitable safety improvement for reducing head-on collision.

Question 12: *If CLRS are proven to reduce head-on collisions and improve safety, would your impression of them change?*

This question was designed under the assumption that majority of responders would not have a good initial impression on CLRS, but results were contradictory and it was seen from Question 8 that majority (68%) liked CLRS and Question 10 (Fig 3.11) rating shows CLRS is highly effective. Here respondents were asked to answer either "yes" or "no". Response distribution is shown in Figure 3.13.

Figure 3.13 Response Distribution for Question 12, Motorcycle Survey

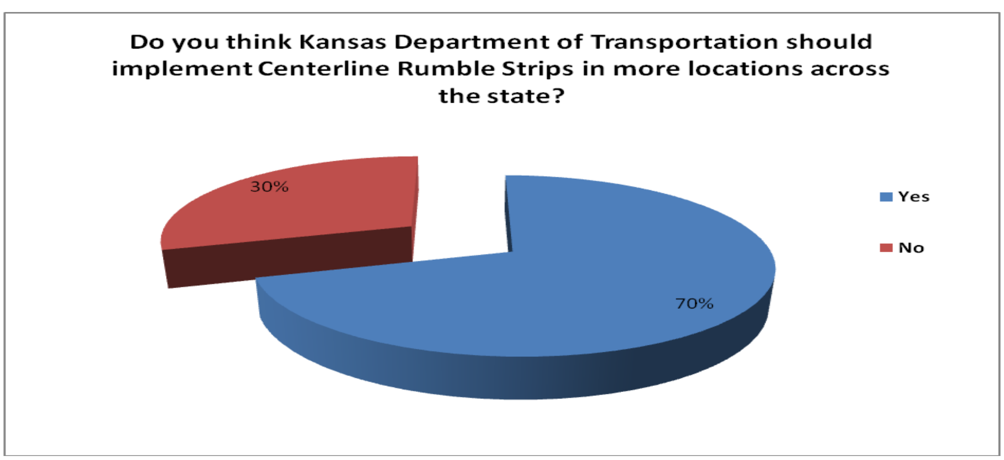


From the distribution it can be seen that 72% (n = 18) of respondents say that their initial impression on CLRS would change if CLRS is proven to reduce head-on collision and improve safety. Due to the misassumption while designing the study this response has low validity.

Question 13*: Do you think Kansas Department of Transportation should implement Centerline Rumble Strips in more locations across the state?*

This question asks respondents whether they think KDOT should install CLRS in more locations. Here also respondents were asked to answer either "yes" or "no". Response distribution is shown in Figure 3.14.

Figure 3.14 Response Distribution for Question 13, Motorcycle Survey



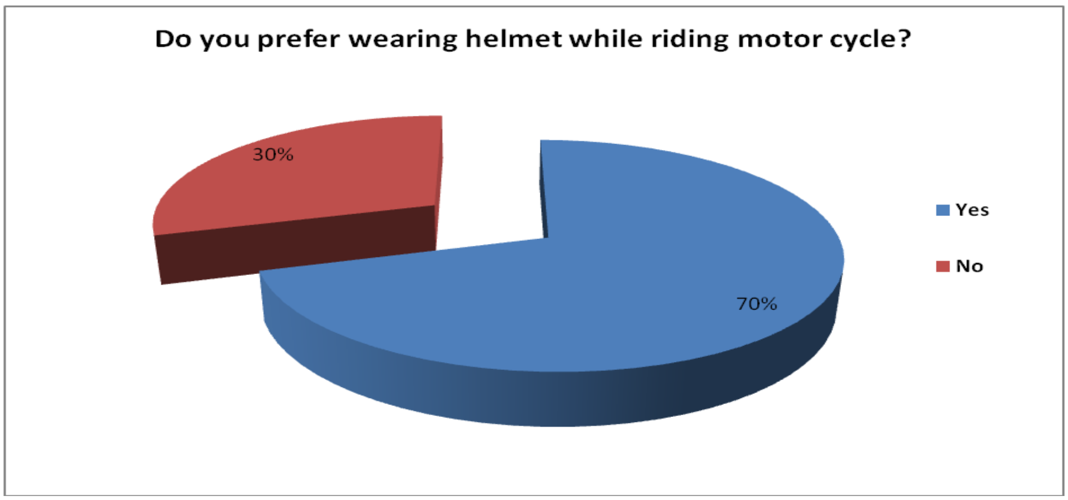
From the distribution it can be seen that 70% (n = 31) of respondents suggest that KDOT should install CLRS on more locations across the state.

Many respondents requested that their response to this question should be also shared with Missouri DOT.

Question 14: *Do you prefer wearing a helmet while riding motorcycle?*

This question asked respondents about their preference in wearing a helmet while riding motorcycle. Here also respondents were asked to answer either "yes" or "no". Response distribution is shown in Figure 3.15.

Figure 3.15 Response Distribution for Question 14, Motorcycle Survey



From the distribution it can be seen that 70% (n = 31) of respondents prefer wearing a helmet while riding.

3.4. Comments:

Respondents were requested to provide additional comments concerning centerline rumble strips. They are as follows,

- *"Rumble strips are very effective on the outside of lane, so they probably would be in the middle also. I have ridden on shoulder rumble strips with no loss of control."*
- *"Potentially widening the rumble strips and gradually taper from their depth would provide a subtle warning before being on centerline."*
- *"Centerline Rumble Strips is a good idea. I have never encountered one but based on my experience with other types of road conditions, a motorcycle rider could safely negotiate a lane change over centerline rumble strips without incident impacting safety."*
- *"I'll be in favor of implementing centerline rumble strips. I would also be very selective of the locations where they are added. i.e. very high head-on collision only areas."*
- *"Judging from my experience I don't feel that these strips would affect handling of motorcycle. They would definitely reduce the number of head on collisions on two-lane roads."*
- *"Make drivers aware that centerline rumble strips are installed ahead. Then they won't come across any erratic maneuver which affects safety."*
- *"This is a good way to deal with the already uneducated driving public."*
- *"Its better to have them to reduce head on collision and suggest to have more of them on undivided highways."*
- *"I was aware of centerline rumble strips - No surprise. My response might have been different if I was unaware of the situation."*

3.5. Conclusion and Future Work

From the results of this survey it is seen that 57% of motorcycle riders have traversed over CLRS and about half of them encountered motorcycle handling problems while traversing CLRS. However, it can be seen from the difficulty response distribution that the level of difficulty encountered is not high. Also 68% of respondents like the rumble effect and 72% believe in their effectiveness in reducing head-on-collisions. In addition, 70% of respondents have strongly recommended that Kansas Department of Transportation should implement CLRS in more locations across the state. Therefore, it can be concluded that the majority of riders believe in the effectiveness of centerline rumble strips. Riders say that when they were aware of the situation they didn't encounter much difficulty in motorcycle handling.

Future research should be focused in conducting field studies on undivided highways with CLRS for evaluating the erratic maneuvers which riders may face when they traverse CLRS. Also studies should be conducted on the need for providing warning signs before riders approach highways having centerline rumble strips. Warning signs like "Centerline Rumble Strips Ahead" (see Figure 3.16) would warn the rider of the upcoming situation. This should reduce any unexpected reactions when they encounter centerline rumble strips.

Figure 3.16 Possible Warning Signs

Source :(www.trianglesigns.org/center-rumble)

Possible Warning Signs

CHAPTER 4 - Evaluation of Concerns on Visibility of Retroreflective Pavement Markings (RRPM) over CLRS

4.1. Introduction

Inadequate and poorly maintained pavement markings are often cited as a contributing factor for fatal crashes (Shantana et al., 2008). After reviewing the current and past studies on pavement markings' safety impacts, it can be concluded that no studies were focused on evaluating visibility of retroreflective pavement markings over centerline rumble strips. Centerline rumble strips, along with pavement markings provide guidance for drivers in keeping their lane position. Deteriorated or poorly visible pavement markings will fail to serve their purpose. Hence this study is conducted to evaluate drivers' concerns regarding pavement markings over centerline rumble strips on a section of US-40, in Kansas between Topeka and Lawrence.

4.2. Methodology of Study

The Kansas State University research team conducted a questionnaire survey of the residents along the section of US-40 (48 residents along the sections of US-40 were surveyed) to determine their visibility concerns regarding reflectivity of retro-reflective pavement markings over rumble strips under various conditions i.e. dry day-night, wet day-night and snowy day-night conditions. The questionnaire survey evaluated the drivers' perception of the level of warning provided by retroreflective pavement marking under these conditions. This study also identified the problems concerning the deterioration in brightness of paint material and visibility of paint material under dry day-night, wet day-night and snowy day-night conditions.

In March, 2008, retro-reflective pavement marking visibility concern surveys were sent out to residents along the section of US Highway 40 where the football shaped centerline rumble strips had been installed. The centerline rumble strips were installed in May, 2005.

Responses were sent back to the K-State Industrial Engineering Department Rumble Strip Research Team, where the data was analyzed to determine resident drivers' concern regarding visibility of pavement marking material on centerline rumble strips.

The survey consisted of nine questions designed to determine the resident's concerns regarding pavement markings on centerline rumble strips. A copy of the survey can be found in Appendix B.

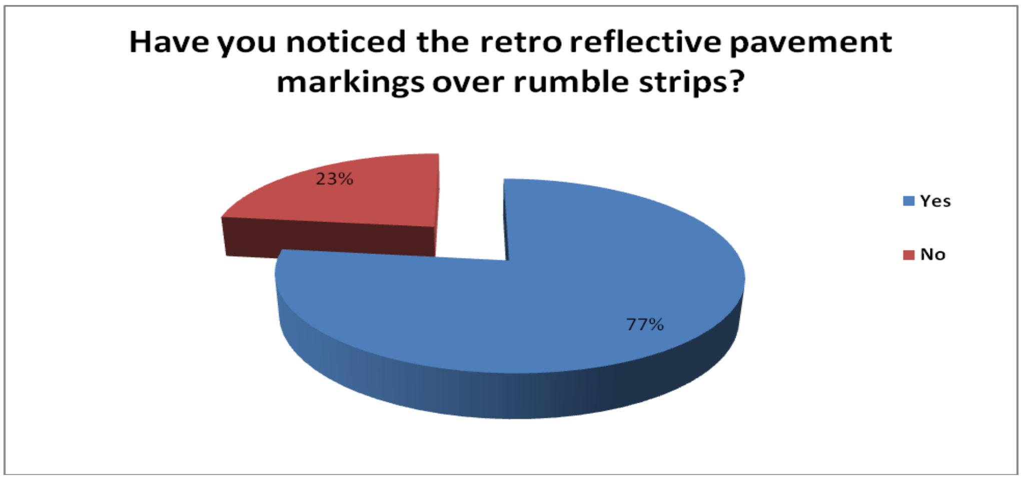
Forty-eight surveys were distributed through the mail to residents between Lawrence and Topeka, KS on the section of US 40 where football shaped centerline rumble strips are located. A total of 13 completed surveys were returned, giving a response rate of 27%. Each question and the answers received are discussed in detail below. Also, any comments made by the residents are included in section 4.4.

4.3. Results

Question 1: *Have you noticed the retroreflective pavement markings over rumble strips?*

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 eight. The distribution of answers can be seen in Figure 4.1.

Figure 4.1 Response Distribution for Question 1, US-40 Resident Survey

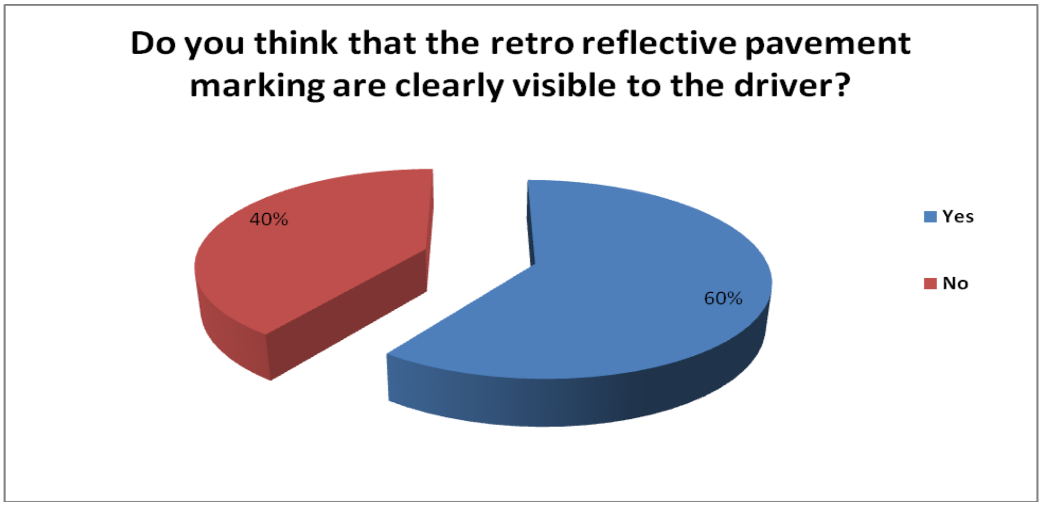


As seen in Figure 4.1, 77% of the respondents answered yes that they have noticed retroreflective pavement markings over the rumble strips. Twenty three percent of respondents answered that they had not noticed the retroreflective pavement markings over rumble strips. Even though this 23% didn't answer the entire survey, some of them provided interesting comments which are included in section 4.4.

Question 2*: Do you think that the retroreflective pavement markings are clearly visible to the driver?*

The respondents who answered "yes" to question one were asked about their opinion of whether retroreflective pavement markings over rumble strips are clearly visible to the driver. In this question they were also asked to answer “yes” or “no”. The distribution of the responses can be found in Figure 4.2.

Figure 4.2 Response Distribution for Question 2, US-40 Resident Survey

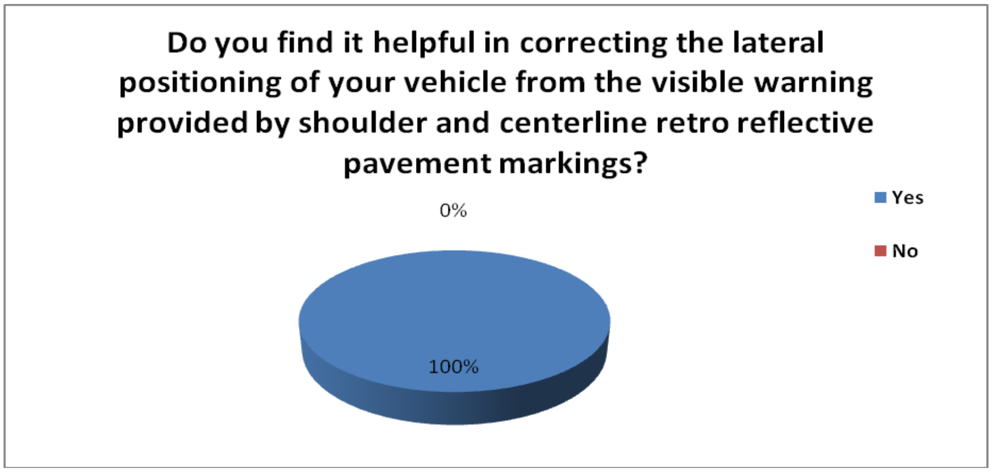


Sixty percent of the respondents answered that RRPM are clearly visible to driver. Forty percent of respondents answered that RRPM are not clearly visible to the driver.

Question 3: *Do you find it helpful in correcting the lateral positioning of your vehicle from the visible warning provided by shoulder and centerline retroreflective pavement markings?*

Similar to question two, respondents were asked their opinion on the usefulness of the visible warning provided by retroreflective pavement markings over rumble strips in correcting the lateral positioning of their vehicle. The respondents were asked to answer either “yes” or “no”. The distribution of the responses can be found in Figure 4.3.

Figure 4.3 Response Distribution for Question 3, US-40 Resident Survey



From the response distribution it can be seen that 100% of the respondents agreed that retroreflective pavement markings on the shoulder and the centerline are one of the main guiding factor in maintaining their correct lane position.

Question 4: *On a scale of 1-5 (1 for Low and 5 for High) where do you rate the visibility of the retroreflective pavement markings under the following conditions?*

a) Dry day light _____
b) Rainy day light_____
c) Dry night _____
d) Rainy night _____
e) Foggy day _____
f) Foggy night _____
g) Snowy day ______
h) Snowy night______

In this question respondents were asked to rate their answer on a scale of 1-5 (1 for Low and 5 for High) under eight different visibility condition. These questions were designed to determine the pavement markings' visibility problems as perceived by drivers under different weather conditions. This question had eight sub-questions and the response ratings are shown in Table 4.1.

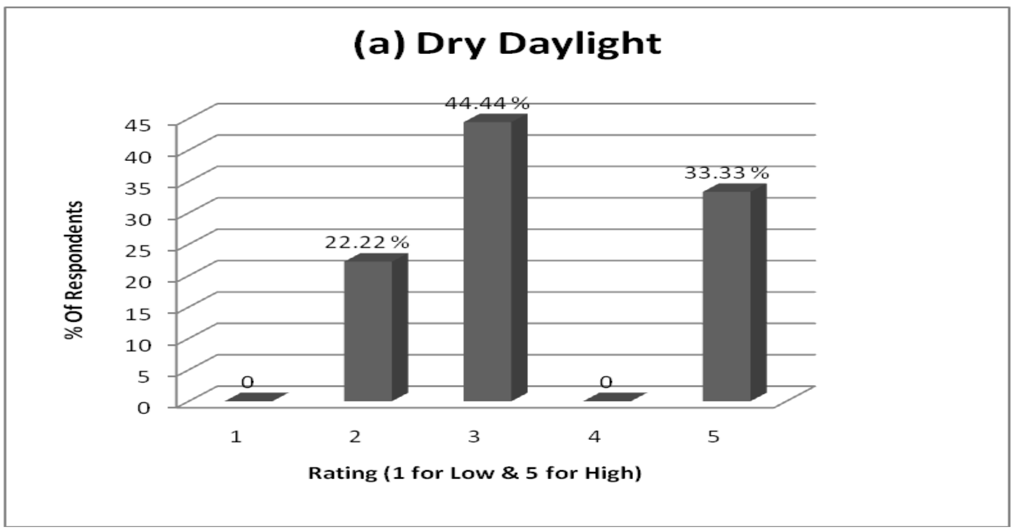
Table 4.1 Results rating for Question 4

		Rating %				
Sub section	**Condition**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
(a)	**Dry day light**	0.00	22.22	44.44	0.00	33.33
(b)	**Rainy Day light**	0.00	55.56	11.11	33.33	0.00
(c)	**Dry night**	0.00	33.33	22.22	33.33	11.11
(d)	**Rainy night**	22.22	33.33	11.11	11.11	11.11
(e)	**Foggy day**	55.56	22.22	11.11	11.11	0.00
(f)	**Foggy night**	55.56	22.22	11.11	0.00	11.11
(g)	**Snowy day**	88.89	11.11	0.00	0.00	0.00
(h)	**Snowy night**	88.89	0.00	0.00	11.11	0.00

Each sub-question is individually analyzed as follows.

Question 4 (a): *Visibility rating under Dry Daylight.*

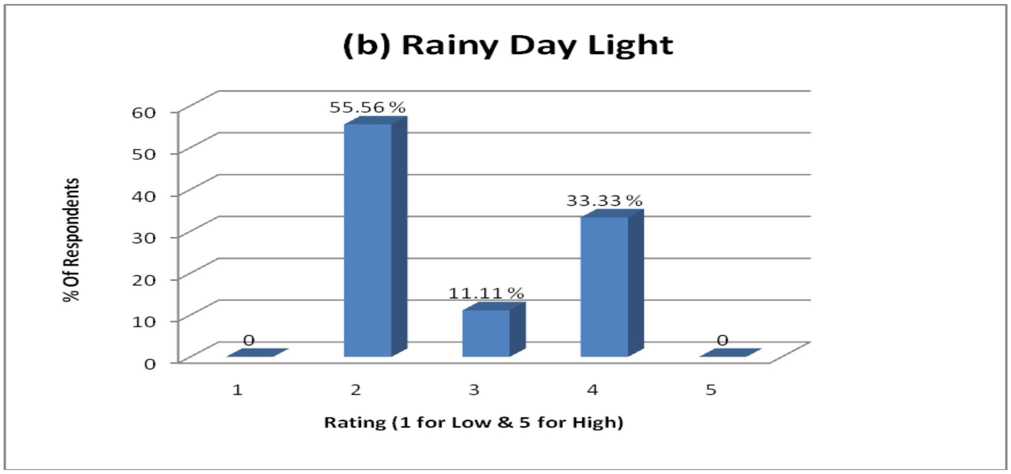
Figure 4.4 Response Distribution for Question 4, US-40 Resident Survey



The dry daylight rating distribution shows that 22.2% of the respondents have given a rating of two, 44.4% of respondents have given a rating of three and 33.3 % of respondents haven given a rating of five. From this rating distribution it can be concluded that retroreflective pavement markings over rumble strips are rated to have good visibility under dry daylight condition by the majority of respondents.

Question 4 (b): *Visibility rating under Wet Daylight.*

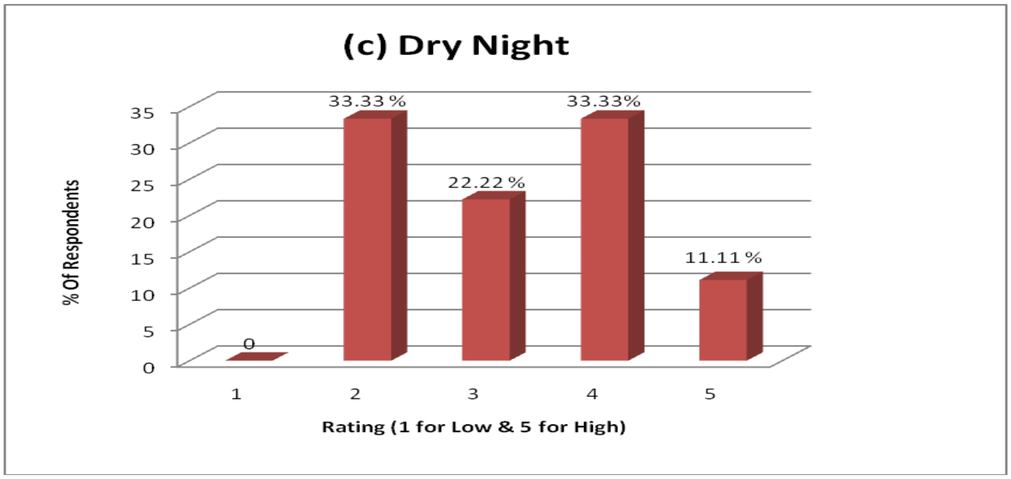
Figure 4.5 Response Distribution for Question 4, US-40 Resident Survey



The wet daylight rating distribution shows that 55.6% of the respondents have given a rating of two, 11.1% of respondents have given a rating of one and 33.3 % of respondents haven given a rating of four. From this distribution rating it can be seen that majority of respondents rate visibility low and it can be concluded that the retroreflective pavement markings over rumble strips are less visible under the rainy, daylight condition when compared to the dry, daylight condition.

Question 4 (c): *Visibility rating under Dry Night.*

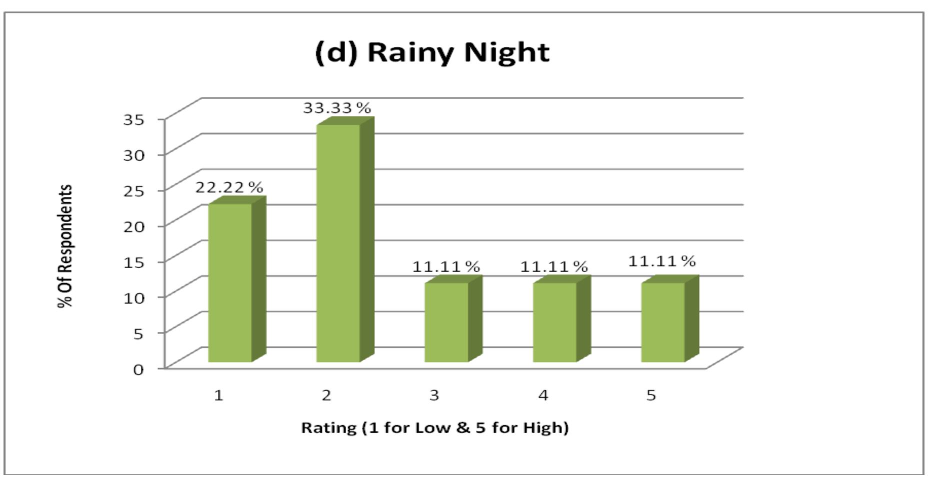
Figure 4.6 Response Distribution for Question 4, US-40 Resident Survey



The dry night rating distribution shows that 33.3% of the respondents have given a rating of two, 22.2% of respondents have given a rating of three, 33.3 % of respondents' have given a rating of four and 11.1% of distribution has given a rating of five. From this ratings distribution it can be seen that the retroreflective pavement markings over rumble strips under dry night conditions resulted in a wide range, with a slight indication towards good visibility.

Question 4 (d): *Visibility rating under Wet Night.*

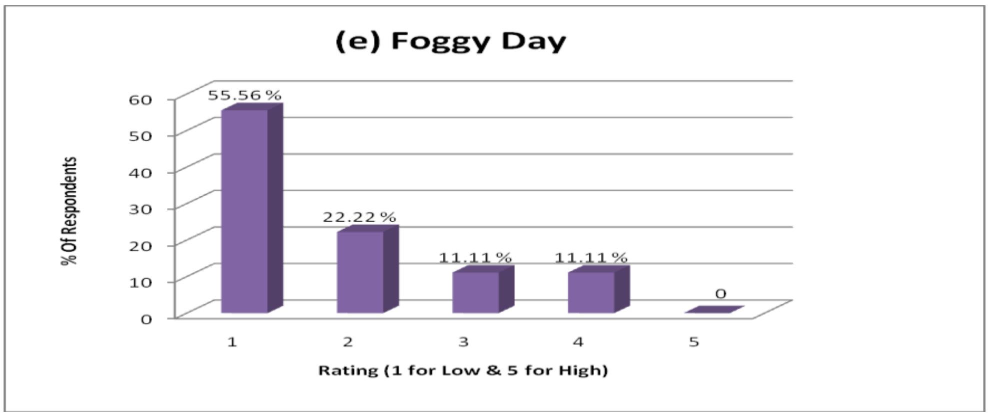
Figure 4.7 Response Distribution for Question 4, US-40 Resident Survey



The rainy night rating distribution shows 22.2% of the respondents have given a rating of one, 33.3% of respondents have given a rating of two and 11.1 % of respondents have given a rating of three four & five. From this distribution rating it can be seen that retroreflective pavement markings over rumble strips are perceived by the majority of respondents to have low visibility under rainy night conditions.

Question 4 (e): *Visibility rating under Foggy Daylight*

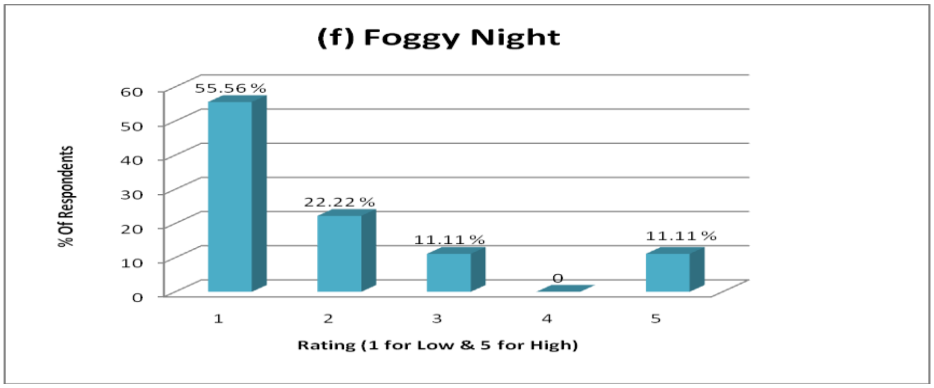
Figure 4.8 Response Distribution for Question 4, US-40 Resident Survey



The foggy day rating distribution shows that 55.6% of the respondents have given a rating of one, 22.2% of respondents have given a rating of two and 11.1 % of respondents have given a rating of three and four. From this distribution rating it can be seen that retroreflective pavement markings over rumble strips are rated fairly low to very low by the majority of respondents under foggy day conditions.

Question 4 (f): *Visibility rating under Foggy Night*

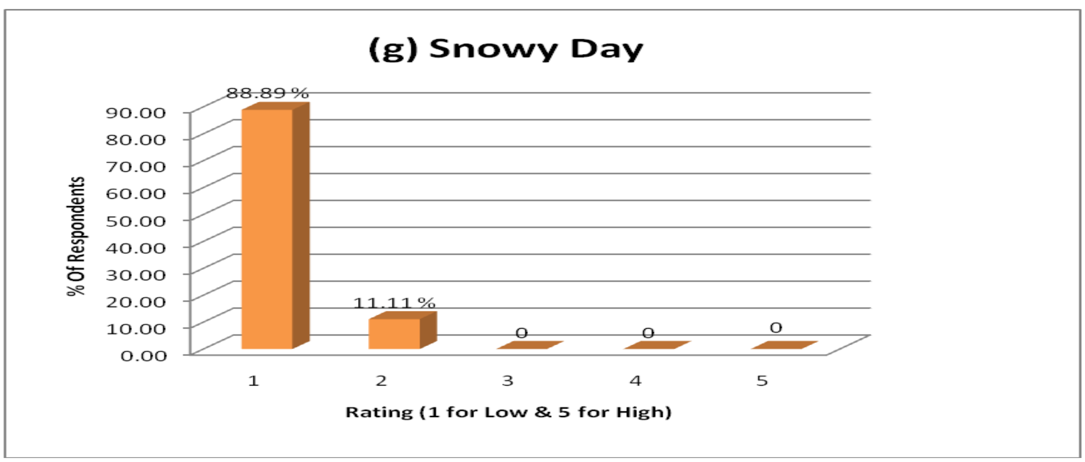
Figure 4.9 Response Distribution for Question 4, US-40 Resident Survey



The foggy night rating distribution shows that 55.6% of the respondents have given a rating of one, 22.2% of respondents have given a rating of two and 11.1 % of respondents have given a rating of three and five. From this distribution rating it can be seen that retroreflective pavement markings over rumble strips are rated low to very low by majority of respondents under foggy night conditions. This is similar to the foggy daylight response.

Question 4 (g): *Visibility rating under Snowy Day*

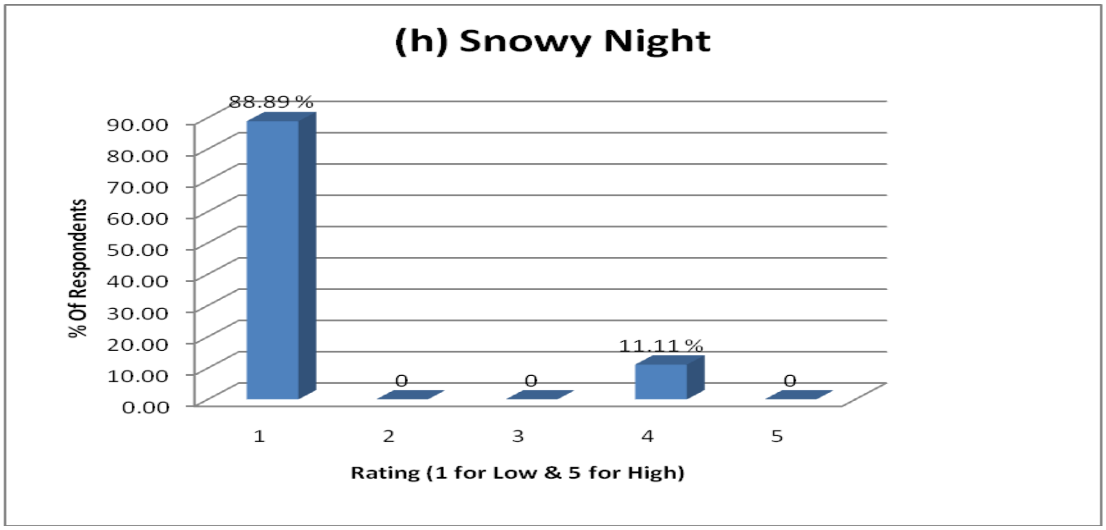
Figure 4.10 Response Distribution for Question 4, US-40 Resident Survey



The snowy day rating distribution shows that 88.9% of the respondents have given a rating of one and 11.1% of respondents have given a rating of two. From this rating distribution it can be seen that retroreflective pavement markings are rated very low by all the respondents under snowy day condition.

Question 4 (g): *Visibility rating under Snowy Night*

Figure 4.11 Response Distribution for Question 4, US-40 Resident Survey



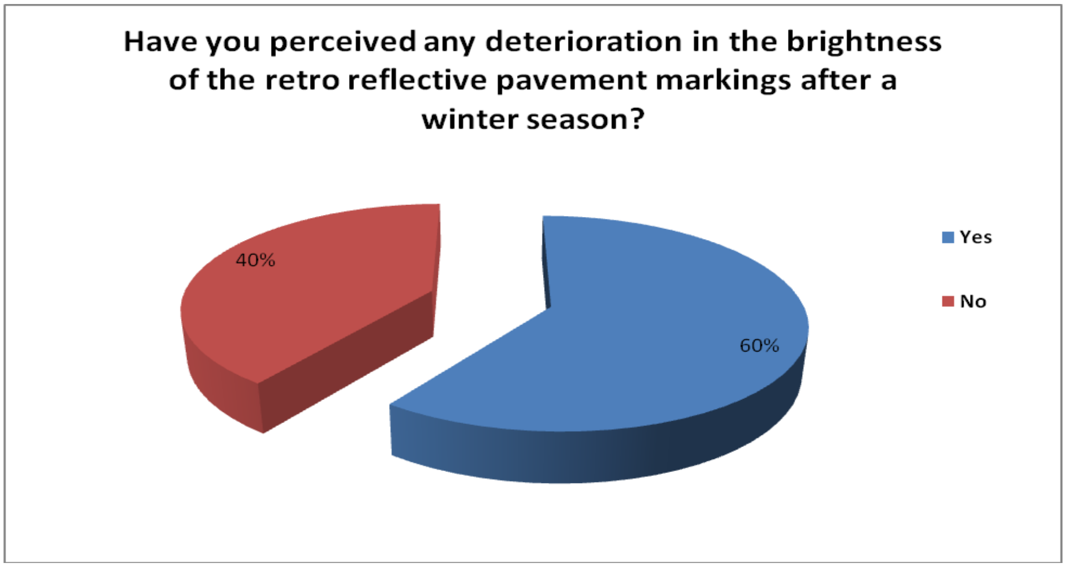
Snowy night rating distribution shows that 88.9% of the respondents have given a rating of one and 11.1% of respondents have given a rating of four. From this distribution rating it can be seen that the retroreflective pavement markings are rated very low by all but one of the respondents under snowy day condition. This is similar to the dry snowy condition.

From the above response distribution it is evident that consideration should be given to improving the pavement markings visibility under night and foggy conditions.

Question 5: *Have you perceived any deterioration in the brightness of the retroreflective pavement markings after a winter season?*

Respondents were asked to answer yes or no to question five. The response distribution can be seen in Figure 4.12.

Figure 4.12 Response Distribution for Question 5, US-40 Resident Survey



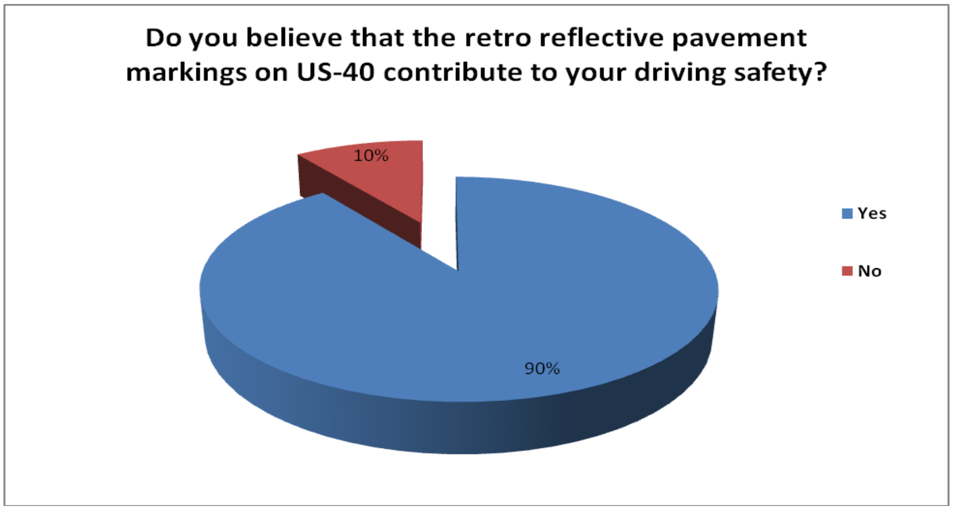
Sixty percent responded that they perceived deterioration in the brightness of retroreflective pavement markings after a winter season.

Due to snow plowing vehicles, the upper surface of the pavement markings will get slowly scraped off. Response to this question shows that this is probably contributing to reducing the brightness of the pavement markings after a winter season. This is generally thought to be directly related to the reduction in retroreflectivity of pavement marking.

Question 6*:* *Do you believe that the retroreflective pavement markings on US-40 contribute to your driving safety?*

In this question also respondents were asked to answer "yes" or "no". The response distribution can be seen in Figure 4.13.

Figure 4.13 Response Distribution for Question 7, US-40 Resident Survey

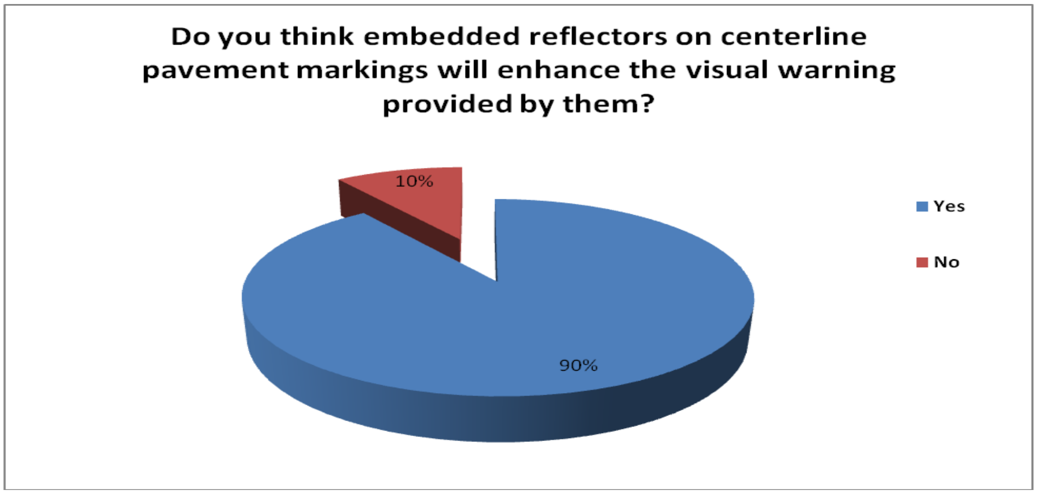


From the response distribution it can be seen that ninety percent of the respondents feel that retroreflective pavement markings contribute towards their driving safety. Only ten percent believe that retroreflective pavement markings do not contribute towards their driving safety.

Question 7: *Do you think embedded reflectors on centerline pavement markings will enhance the visual warning provided by them?*

This question was focused on determining the drivers' apinion on a future recommendation for improving the visibility of retro-reflective pavement markings under low visibility conditions. The response distribution can be seen in Figure 4.14.

Figure 4.14 Response Distribution for Question 7, US-40 Resident Survey

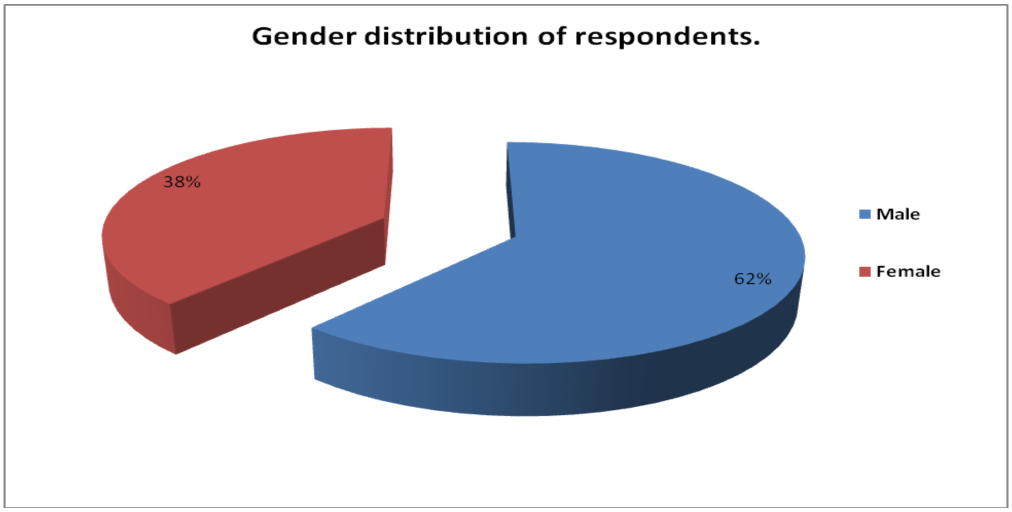


From the response distribution it can be seen that ninety percent respondents feel that embedding reflectors on centerline pavement markings will enhance the visual warning. Ten percent believe that embedding reflectors on centerline pavement markings will not enhance the visual warning.

Question 8*: Gender of respondents?*

Gender distribution is shown in Figure 4.15.

Figure 4.15 Response Distribution for Question 8, US-40 Resident Survey

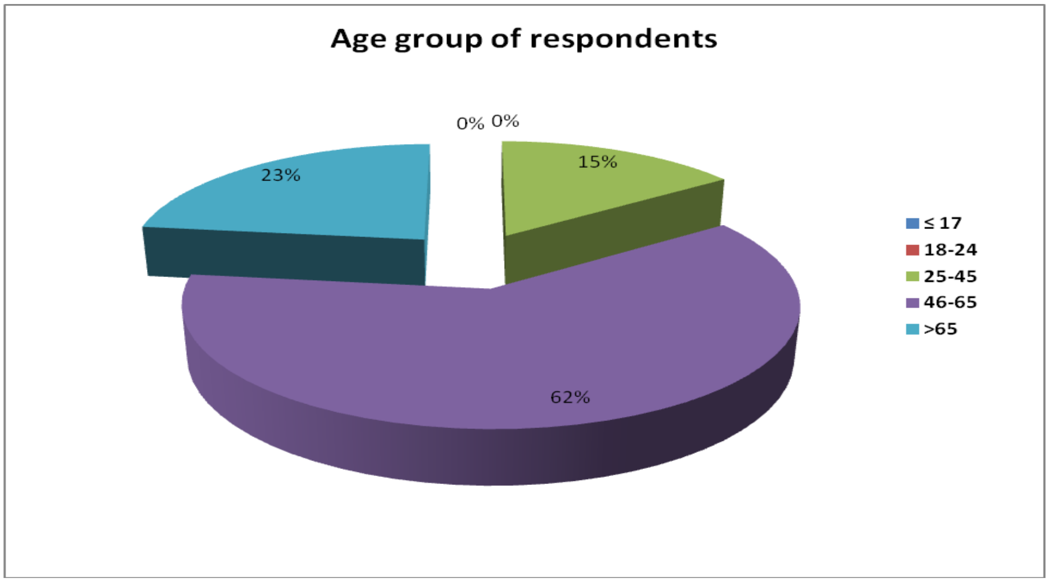


Thirty eight percent of respondents were females and sixty two percent were males.

Question 9*:* *Age group of respondents?*

Age groups of respondents are shown in Figure 4.16.

Figure 4.16 Response Distribution for Question 9, US-40 Resident Survey



Fifteen percent of respondents were between 18-24 years, 62% were between 46-65 years and 23 percent were above 65 years.

4.4. Comments

Respondents were also requested to write in any additional comments about the centerline rumble strips and pavement markings. There comments were as follows.

- *"Retroreflective pavement markings are too old to notice"*
- *"There is lot of highway noise due to the sound from centerline rumble strips"*
- *"Too much noise from road"*

4.5. Conclusions and Future Work

From the results of this questionnaire it can be seen that 100% of respondents believe that the visible warning provided by shoulder and centerline retroreflective pavement markings are extremely helpful in correcting the lateral position of their vehicle. Also 90% of respondents believe that retroreflective pavement markings contribute to their driving safety. The majority (60%) of respondents believe that retroreflectivity of pavement marking have deteriorated after a winter season. Also it's seen that pavement markings have poor visibility under low visibility conditions (Rainy, Foggy and Snowy conditions). Therefore, it can be concluded that the majority of the drivers believe that pavement marking are really important for safe driving but there is deterioration in the retroreflective pavement markings over the rumble strips on US 40. Also, retroreflective pavement markings over rumble strips have low visibility under rainy, foggy and snowy conditions. Respondents also believe that embedding reflectors on pavement marking will enhance their visibility under low visibility conditions.

Further research will focus on conducting field studies for measuring the retroreflectivity of pavement marking on centerline rumble strips. Chapter 5 of this study will be focused on the following factors,

- **Developing a standardized method for evaluating retroreflectivity of pavement marking over CLRS.**
- **Studying visibility of RRPM over CLRS under dry and wet conditions.**
- **Studying the trend of reduction of retroreflectivity of RRPM installed on CLRS over time.**

CHAPTER 5 - KSU Retroreflective Pavement Marking Evaluation Study

5.1: Introduction

Painted, retroreflective pavement markings on the centerline and shoulderline rumble strips play a major role in providing visual warning to drivers. Pavement markings play a major role in preventing centerline and shoulder incursions. This study supplements Study II in Chapter 4, a questionnaire survey sent to the residents of highway US-40 (Evaluation of Concerns on Visibility of Retroreflective Pavement Marking over CLRS). Study II results and field visits conducted during March-April, 2008 helped the research team get a good grasp of current issue related to retroreflective pavement markings over centerline rumble strips. Therefore KSU research team's next effort was focused on developing a standardized method for evaluating the visibility of retroreflective pavement markings (RRPM) placed over CLRS and studying the various factors affecting RRPM deterioration. Next sections will present details on field study locations and the methodology used.

5.2: Field study location details

The Study was conducted on three Kansas State Highways. They are:

1. Kansas Highway US 24 in Jefferson County. Here rectangular CLRS with dimensions of 16in L by 7in W by .6in D (L-Length, W- Width, D-Depth) and RRPM of 5in width were installed on Oct 2nd 2008. AADT (Average Annual Daily Traffic) of the section under study is 5040 vpd (2009 Traffic flow map).

2. Kansas Highway US 50 (Chase County). Here rectangular CLRS with dimensions of 16in L by 7in W by .6in D (L-Length, W- Width, D-Depth) & RRPM of 5in width were installed on June 3rd 2008. AADT (Average Annual Daily Traffic) of section under study is 4085 vpd (2009 Traffic flow map).

3. Kansas Highway US 40 (Douglas county). Here football CLRS with dimensions of 16in L by 9in W by.5in D (L-Length, W- Width, D-Depth), where .5in D is the depth at the center of the depression. Here RRPM of 5in width were installed on May 5th 2005. AADT (Average Annual Daily Traffic) of section under study is 3320 vpd (2009 Traffic flow map).

All three highways had asphalt pavement with retroreflective, bead based, thermoplastic paint. This study was conducted over a period of 7 months in three stages. Field visit dates are shown in Table 5.1,

Table 5.1 Field study visit dates

Location	Visit 1	Visit 2	Visit 3
US 24	**October 31st 2008**	**Mar 12th 2009**	**May 4th 2009**
US 50	**October 24th 2008**	**Mar 12th 2009**	**May 4th 2009**
US 40	**October 31st 2008**	**Mar 12th 2009**	**May 4th 2009**

Maps for each highway study location were prepared using Google maps customization service. Each map shows geographic details including three dimensional location images and data collection points. The following URLs will lead to the specific maps on the Google maps database.

- URL link for US 24 map:

  http://maps.google.com/maps/ms?hl=en&ie=UTF8&om=1&msa=2&vps=3&jsv=151e

- URL link for US 50 map:

  http://maps.google.com/maps/ms?hl=en&ie=UTF8&om=1&msa=2&vps=3&jsv=151e

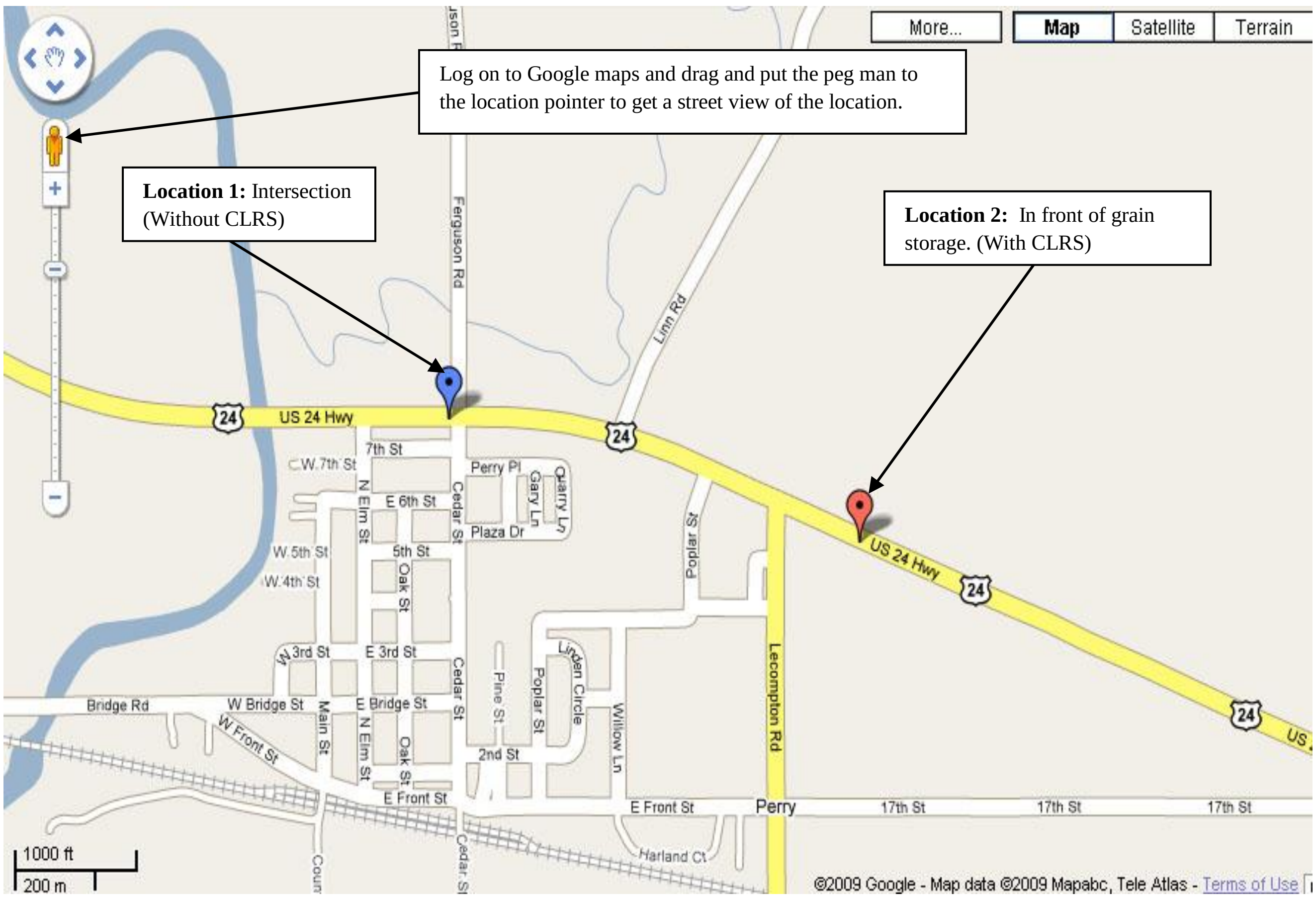
- URL link for US 40 map:

  http://maps.google.com/maps/ms?hl=en&ie=UTF8&om=1&msa=2&vps=3&jsv=151e

5.2.1: Kansas State highway US 24 field study location map and details

On US 24 field data was collected in two locations. Location-1 is an intersection without CLRS where retroreflective readings were taken on plain pavements. Location-2 in front of the grain storage building has retroreflective pavement markings over CLRS. The location map and locations are shown in Figure 5.1.

Figure 5.1 US 24 field study location map.



5.2.2: Kansas State highway US 50 field study location map and details

On US 50, field data was collected in three locations. Location-1 is in front of a concrete drain which is a site with CLRS. Location-2 is in front of a gas pole which is also a site with CLRS. Location-3 is in front of a ramp exit and is a site without CLRS, where retroreflective readings were taken on plain pavements. The location map and exact pin point of locations are shown in Figure 5.2.

Figure 5.2 US 50 field study location map

5.2.3: Kansas State highway US 40 field study location map and details

On US 40, field data was collected in three locations. Location-1 is in front of a park's exit which is a site with CLRS. Location-2 is at an intersection, which is a site without CLRS. Location-3 is another site with CLRS. The location map and exact pin point of locations is shown in Figure 5.3.

Figure 5.3 US 40 field study location map.

5.3: Evaluation

5.3.1 Retroreflectometer Evaluation

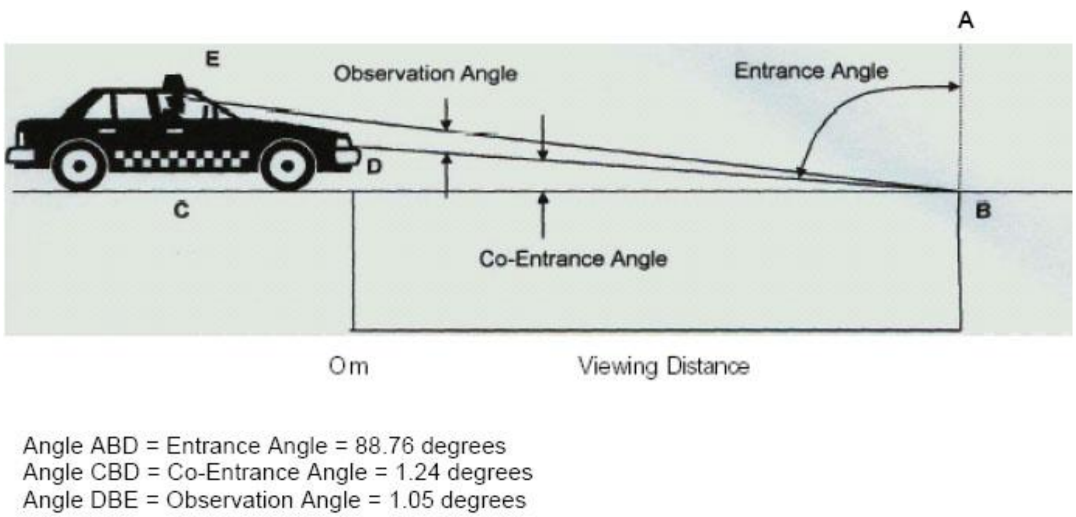
Retroreflectivity is the ability of a surface to return back light to its source. Retroreflective pavement markings bounce light from vehicle headlights back towards the vehicle and the drivers' eyes, making signs and pavement markings visible to the driver at night. Retroreflectivity is measured using retroreflectometer.

Here a 30-meter geometry handheld retroreflectometer (LTL 2000), manufactured by Delta Light & Optics was used for this evaluation. The following URL will lead to the user manual of LTL 2000.

URL link for LTL 2000 user manual -
http://www.delta.dk/C1256ED600446B80/sysOakFil/Roadsensors_LTL2000S-SQman080104SW1%206/$File/LTL2000S-SQman080104SW1%206.pdf

LTL 2000 is a handheld retroreflectometer that is able to measure ability of a RRPM surface to reflect light from car headlight back to the driver. LTL 2000 measures the retroreflectivity of pavement marking as seen in the vehicle headlight illumination. 30-meter geometry retroreflectivity (which is the horizontal viewing distance from headlight to the pavement markings) is the standard used by US highway departments (Figure 5.4).

Figure 5.4 Thirty Meter Geometry Measurement for Retroreflectivity (Cyrus, 2007)



For measuring retroreflectivity of pavement markings on CLRS a hardboard was fabricated with a central rectangular hole. This central rectangular hole was cut on the board to match exactly with the reading head opening of the LTL 2000 retroreflectometer and it prevented other light source from falling on the reflectometer reading head. After each reading the equipment prints out the measured reading in mcd/m^2/lux, which is the standard unit of retroreflectivity. The retroreflectometer is placed on the pavement marking as shown in Figure 5.5 and readings are taken. Six measurements were taken on a stretch of RRPM of a length of 7 feet 7 inches.

Figure 5.5 Retroreflectivity measurement on CLRS using Reflectometer LTL 2000 kept on hardboard.

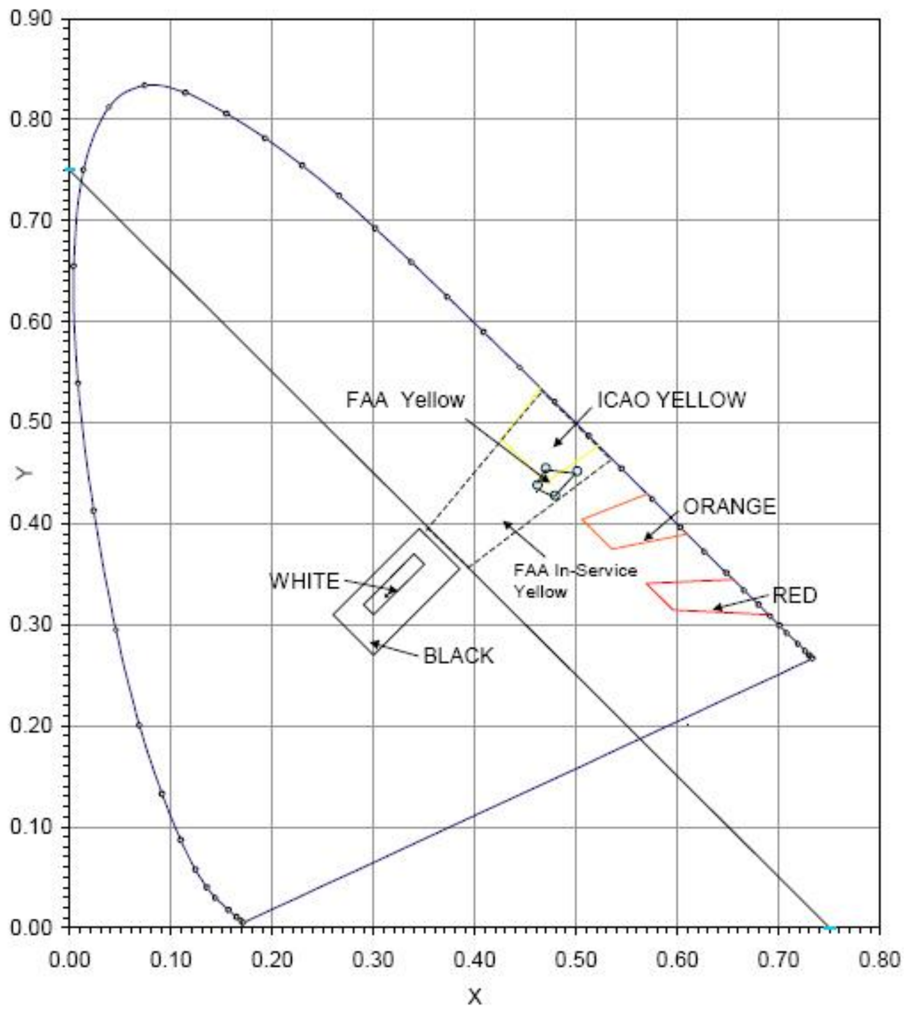
For taking wet RRPM measurements water was poured into the depressiont of rumble strip (See Figure 5.6) in such a way that the depression is filled up to approximately eighty percent. Water is not filled up to the pavement ground level because doing so will interfere with the reading head of reflectometer.

Figure 5.6 Wetting rumble depression up to approximately eighty percent.

5.3.2 Spectrophotometer Evaluation

The international board that sets color standards is the International Commission of Illumination (CIE) (Cyrus 2006 & 2007) developed the methodology for describing the color in a numerical system that is based upon a standard observer. A standard observer is defined as a small group of individuals (about 20-30) that have normal, human color vision. This technique matches color to an equivalent red, green and blue (RBG) tristimulus value. Here chromaticity is expressed in terms of a coordinate system adopted by the CIE. The methodology reduces the spectral emission characteristics of a source to a three letter designation with associated numbers. The CIE units discussed here are CIE Yxy. Where Y is the absolute measure of the visual luminance of the source and x and y are the coordinates. Here chromaticity evaluation was performed by using spectrophotometer. Minolta CL-100 spectrophotometer (shown in Figure 5.8) was used for this study. The data measurement taken is displayed out from Minolta CL-100 spectrophotometer as chromaticity coordinates. The meter was calibrated before each reading is taken. The spectral data was plotted on a chromaticity chart (Shown in figure 5.7).

Figure 5.7 CIE standard illuminant D65 chromaticity chart for beaded retroreflective paint (Cyrus, 2007)



For taking readings, the device is kept at a distance of approximately two inches and aimed at the pavement marking in the rumble strip grove. Chromaticity measurements were taken on all study locations with CLRS. Measurements were taken at the center of all rumble depressions on the entire stretch of RRPM of 7 feet 7 inches length. These reading were plotted on the CIE standard illuminant D_{65} chromaticity chart for beaded retroreflective paint material using MATLAB R2007 software. MATLAB code for plot generation is shown in Appendix C.

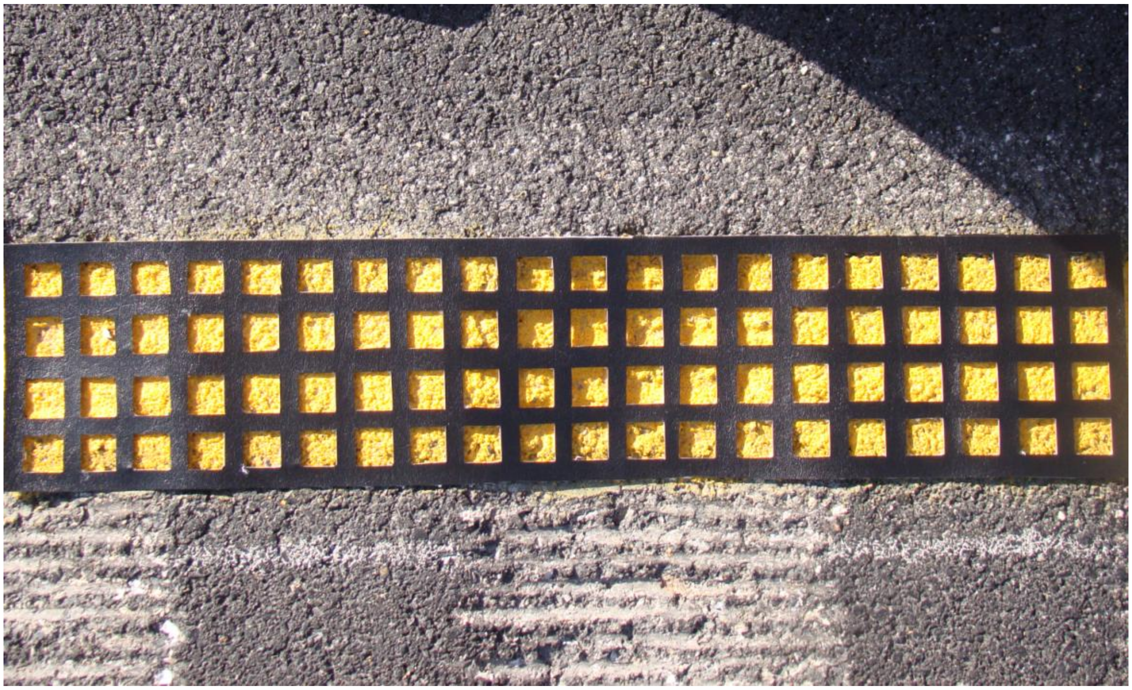
Figure 5.8 Minolta CL 100 spectrophotometer.

5.3.3 Coverage Check

A coverage check evaluation shows the uniformity of coverage of the paint line, such as paint cracking, peeling, and whether or not the marking has adequate coverage or not. Here a flexible grid fabricated from vinyl fabric having 80 equal squares is used as a tool for a quantitative measure of a specified percentage of coverage. The flexible fabric was used as grid material because it fits well in rumble strip groves. This grid concept was adopted by the Air Force who used it for measuring rubber coverage on pavement (www.airtech.tc.faa.gov/safety) (2008).

On Kansas state highways the width of a centerline retroreflective pavement marking is 5 inches, hence here a grid of 4 by 20 equal squares of size 5 by 24inches was used (See Figure 5.9). The grid is placed on the pavement marking and a picture is taken for visual inspection for counting the squares having no paint. For example; 4 out of 80 equal 5% of the paint gone or 95% coverage.

Figure 5.9 Coverage measurement on CLRS using flexible 5 by 24 inch grid.



5.4. Retroreflectivity Data Analysis

5.4.1 Retroreflectivity Measurements on US Highway 24

Retroreflectivity measurements were collected from the US 24 test site using the method explained in section 5.3 of this chapter.

5.4.1.1 Retroreflectivity on RRPMs over CLRS

Retroreflectivity measurements collected from RRPM's over CLRS installed on US 24 at Location 2 (Figure 5.3) are shown in Table 5.2. CLRS and RRPM installation on US 24 was on Oct 2nd 2008.

Table 5.2 Dry and wet retroreflectivity measurements on RRPM's over CLRS from US 24

	Retroreflectivity in mcd/m^2/lux - On CLRS (Dry)			Retroreflectivity in mcd/m^2/lux - On CLRS (Wet)			Percentage reduction
	Location 2 reading			Location 2 reading			
Visit Dates	1 (Left Marking)	2 (Right Marking)	Average	1 (Left Marking)	2 (Right Marking)	Average	
Oct 31st 2008	282	237	260	No data Collected			
Mar 12th 2009	162	119	140	98	65	81.9	41.6 %
May 4th 2009	155	137	146	77	105	91.2	37.5 %

Here two sections called left and right of Location 2 were considered for data collection. Each section is a stretch of RRPM of length 7 feet 7 inches installed over CLRS.

From Table 5.2 it can be seen that the first visit was on Oct 31st 2008, the second visit was on March 12th 2009 and the third visit was on May 4th 2009. These visit dates are 30, 162 and 215 days from the installation date which is June 3rd 2008. Dry retroreflectivity measurements over CLRS were taken during all three visits and wet retroreflectivity measurements of RRPMs over CLRS were collected only during the last two visits.

The minimum acceptable retroreflectivity set by federal highway administration for yellow thermoplastic retroreflective paint material is 175 mcd/m2/lux. (McGinnis, 2001)

From Table 5.2 it can be seen that the dry retroreflectivity measurements taken on Oct 31st 2008 are well above the acceptance level and measurements taken on March 12th 2009 and May 4th 2009 are below the acceptance level. Also from Table 5.2 it can seen that wet retroreflectivity of RRPMs on CLRS are lower than dry retroreflectivity and they are considerably lower than the acceptance level.

5.4.1.2 Retroreflectivity on location without CLRS

Retroreflectivity measurements collected from locations without CLRS installed at US 24 at Location 1 (Figure 5.3) are shown in Table 5.3. CLRS and RRPM installation US 24 was on Oct 2nd 2008.

Table 5.3 Dry and Wet Retroreflectivity measurements on RRPM's without CLRS from US 24

	Retroreflectivity in mcd/m^2/lux - Without CLRS (Dry)				Retroreflectivity in mcd/m^2/lux - Without CLRS (Wet)				Percentage increase
	Location 1 reading				Location 1 reading				
Visit Dates	1	2	3	Average	1	2	3	Average	
Oct 31st 2008	392	412	398	401	No Data Collected				
Mar 12th 2009	117	155	109	127					
May 4th 2009	85	75	93	84	181	230	290	234	63.91 %

Table 5.3 shows the retroreflectivity measurements collected from US 24 Location 1. Three sections at Location 1 were considered for data collection. Here dry retroreflectivity reading were taken during all three visits and wet reading was taken only during the visit on May 4th 2009.

From Table 5.3 it can be seen that retroreflectivity measurement taken during visit on Oct 31st 2008 is well above the acceptance level. Also it can be seen that measurements taken during March 12th 2009 and May 4th 2009 are below the acceptance level. Also from Table 5.3 it can be seen that in locations without CLRS wet retroreflectivity is higher than dry retroreflectivity.

5.4.2 Retroreflectivity Measurements on US Highway 50

Retroreflectivity measurements were collected from the US 50 test site using the method explained in section 5.3 of this chapter.

5.4.2.1 Retroreflectivity on RRPMs over CLRS

Retroreflectivity measurements collected from locations on US 50 (Figure 5.2) over CLRS are shown in Table 5.4.CLRS and RRPM installation on US 50 was on June 3rd 2008.

Table 5.4 Dry and wet retroreflectivity measurement on RRPM's over CLRS from US 50

	Retroreflectivity in mcd/m^2/lux - On CLRS (Dry)			Retroreflectivity in mcd/m^2/lux - On CLRS (Wet)			Percentage reduction
	Location			Location			
Visit Dates	1	2	Average	1	2	Average	
Oct 24th 2008	231	219	225	No data collected			
Mar 12th 2009	193	207	200	83	118	101	49.7 %
May 4th 2009	201	146	174	62	78	70	59.9 %

Table 5.4 shows the retroreflectivity measurements collected from US highway 24, Locations 1 and 2. It can be seen from Table 5.4 that the first visit was on Oct 24th 2008, the second visit on March 12th 2009 and the third visit on May 4th 2009. These visit dates are 144, 283 and 336 days from the installation date which is June 3rd 2008. Dry retroreflectivity measurements over CLRS were taken during all three visits and wet retroreflectivity measurements over CLRS were collected only during the last 2 visits.

In the literature review in Chapter-2, McGinnis (2001) states that the minimum acceptable retroreflectivity set by federal highway administration for yellow thermoplastic retroreflective paint material is 175 mcd/m^2/lux.

From Table 5.4 it can be seen that the retroreflective reading taken on Oct 24th 2008 and March 12th 2009 are well above the acceptance level. Measurements taken on May 4th 2009 shows that the retroreflectivity in Location 2 is lower than the acceptance level and the average reading for location 1 and 2 is 174 mcd/m^2/lux which is near the margin of the acceptance limit. Also from Table 5.4 it is obvious that the wet, measured retroreflectivity of RRPMs on CLRS is lower than the dry retroreflectivity. Also from Table 5.4 it can be seen that the wet retroreflectivity on both locations are considerably lower than the acceptance level.

5.4.2.1 Retroreflectivity on location without CLRS

Retroreflectivity measurements collected from RRPMs without CLRS at Location 3 installed on US 50 (Figure 5.2) are shown in Table 5.5.CLRS and RRPM installation on US 50 was on June 3rd 2008.

Table 5.5 Dry and Wet Retroreflectivity measurements on RRPMs without CLRS from US

Visit Date	Retroreflectivity in mcd/m²/lux - Without CLRS (Dry)						Retroreflectivity in mcd/m²/lux - Without CLRS (Wet)						Percentage increase
	Location 3 reading						Location 3 reading						
	1	2	3	4	5	Average	1	2	3	4	5	Average	
Oct 24th 2008	328	316	247	236	224	270	No data collected						
Mar 12th 2009	232	210	233	192	184	210							
May 4th 2009	219	241	191	179	199	206	236	252	276	307	318	278	35.28 %

Table 5.5 shows the retroreflectivity measurements collected from US highway 24 Location 3. Five sections in Location 3 were considered for data collection. The dry retroreflectivity readings were taken during all three visits and the wet reading was taken only during the visit on May 4th 2009.

From Table 5.5 it can be seen that dry retroreflectivity of RRPM's in location without CLRS were above the acceptance level during all three visits. Also from Table 5.5 it can be seen that in locations without CLRS wet retroreflectivity is higher than dry retroreflectivity.

5.4.3 Retroreflectivity Measurements on US Highway 40

Retroreflectivity measurements are collected from US 40 test location using the method explained in section 5.3 of this chapter.

5.4.3.1 Retroreflectivity on RRPM's over CLRS

Retroreflectivity measurements collected from RRPMs over CLRS installed on US 40 (Figure 5.3) are shown in Table 5.6. CLRS and RRPM installation on US 40 was on May 5th 2005.

Table 5.6 Dry and wet retroreflectivity measurements on RRPM's over CLRS from US 40

	Retroreflectivity in mcd/m^2/lux - On CLRS (Dry)			Retroreflectivity in mcd/m^2/lux - On CLRS (Wet)			Percentage reduction
	Location			Location			
Visit Dates	1	3	Average	1	3	Average	
Oct 31st 2008	125	142	133	No Data Collected			
Mar 12th 2009	107	197	152	16	28	22	85.8 %
May 4th 2009	93	129	111	14	25	20	82.4 %

Table 5.6 shows the retroreflectivity measurements collected from US 40, Location 1 and 2. It can be seen from Table 5.6 that the first visit was on Oct 24th 2008, the second visit on March 12th 2009 and the third visit on May 4th 2009. These visit dates are 1269, 1408 and 1461 days from the installation date which is May 5th 2005. Dry retroreflectivity measurements over CLRS were taken during all three visits and wet retroreflectivity measurements over CLRS were collected only during the last 2 visits.

In the literature review section in Chapter 2, McGinnis (2001) states that the minimum acceptable retroreflectivity set by federal highway administration for yellow thermoplastic retroreflective paint material is 175 mcd/m^2/lux.

From Table 5.6 it can be seen that all measurements except one taken in location 3 on March 12th, 2009, are lower than the acceptance level. Also it can be seen that the average retroreflectivity measurements for all three visits are less than the acceptance level.

Table 5.6 demonstrates that wet retroreflectivity of RRPMs on CLRS is lower than dry retroreflectivity. From Table 5.6 it can be seen that the wet retroreflectivity at both locations are far lower than the acceptance level.

5.4.3.2 Retroreflectivity on location without CLRS

Retroreflectivity measurements collected from locations without CLRS on US 40 (Figure 5.3) are shown in Table 5.7.CLRS and RRPM installation on US 40 was on May 5th 2005.

Table 5.7 Dry and Wet Retroreflectivity measurements on RRPM's without CLRS from

	Retroreflectivity in mcd/m^2/lux - Without CLRS (Dry)						Retroreflectivity in mcd/m^2/lux - Without CLRS (Wet)						Percentage increase
	Location 2 readings						Location 2 readings						
Visit Dates	1	2	3	4	5	Average	1	2	3	4	5	Average	
Oct 31st 2008	52	51	50	52	63	54	No Data Collected						
Mar 12th 2009	46	43	36	34	27	37							
May 4th 2009	32	33	38	39	3	29	196	253	195	149	114	181	84 %

Table 5.7 shows the retroreflectivity measurements collected from US 40 Location 2. Five sections in Location 2 were used for data collection. The dry retroreflectivity readings were taken during all three visits and wet readings were taken only during the visit on May 4th, 2009.

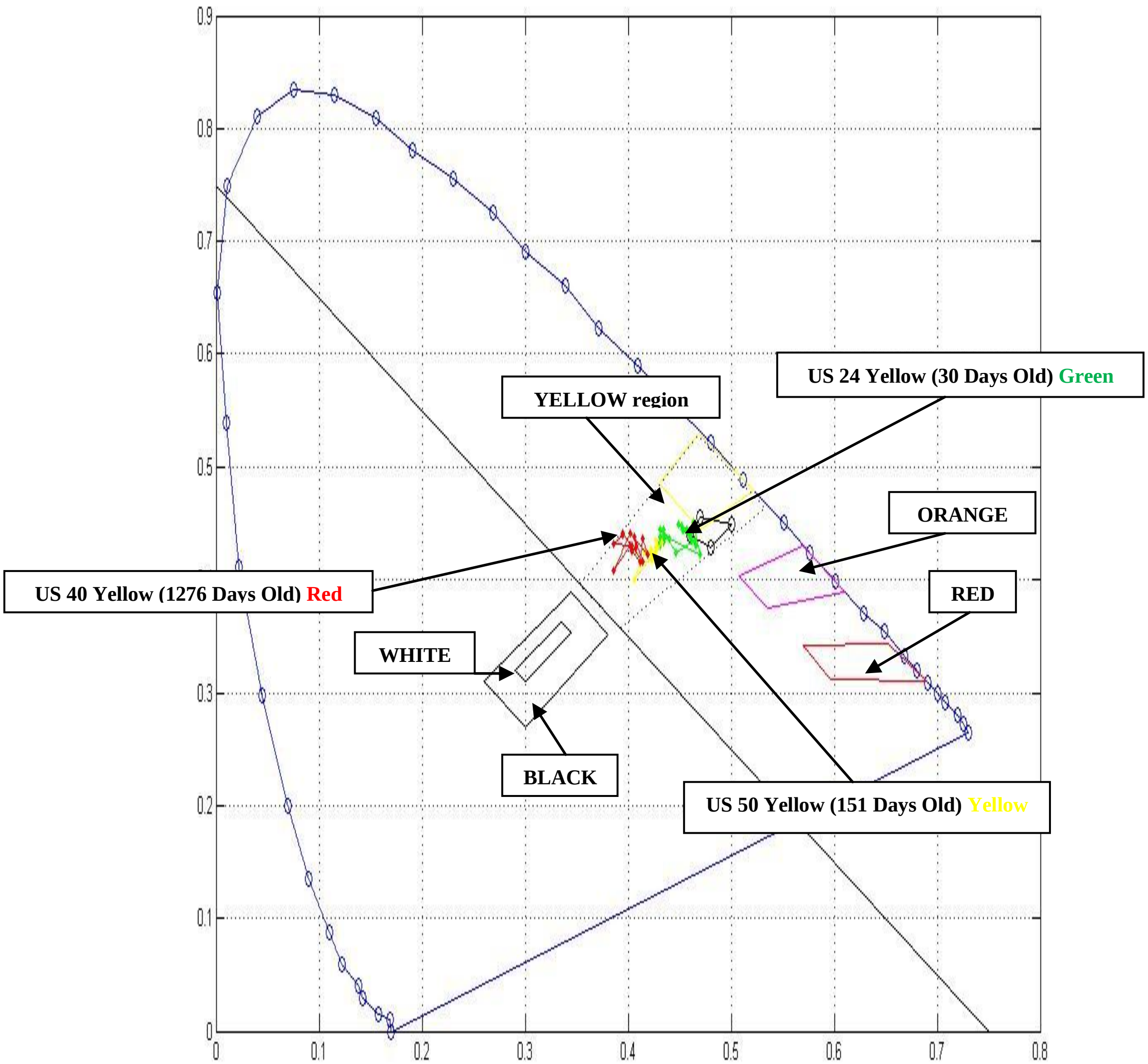
From Table 5.7 it can be seen that the dry retroreflectivity of RRPMs in location without CLRS were all well below the acceptance level. Also from Table 5.7 it can be seen that in locations without CLRS wet retroreflectivity is higher than dry retroreflectivity.

5.5 Spectrometry Data Analysis

Spectrometry data was also collected from US 24, US 50 and US 40 using the procedure explained in section 5.3 of this chapter. Spectrometry measurements were taken from US 24 and US 40 on October 31st 2008 and those on US 50 on October 24th 2008. Measurements on US 24 were from markings that were 30 days and those on US 50 and US 40 were 151 days and 1,279 days, respectively, from the date of installation. These measurements were taken with the intention of obtaining the regions where new and old yellow retroreflective, beaded paint fall in CIE standard illuminant D_{65} chromaticity chart.

Spectrometry data were collected from all test sites with CLRS. The measurements were obtained as chromaticity coordinates from the Minolta CL 100 spectrometer described earlier. The data points thus obtained were plotted on a CIE standard illuminant D_{65} (beaded retroreflective paint) chromaticity chart, using MATLAB R2007 program shown in Appendix C. Chromaticity measurements from US 24, US 50 and US 40 were plotted as three different colored regions in the chromaticity chart. Highway US 24 measurements are shown in Blue colored region, US 50 in green colored region and US 40 in red colored region. Plot thus created is shows in Figure 5.10.

Figure 5.10 D_{65} chromaticity chart obtained from Highway US 24, US 50 and US 40 measurements.



From Figure 5.21 it is seen that all data coordinates lie in the yellow region of the D_{65} chromaticity chart. Again, it can be seen that in the chart, the US 24 measurements which are in green, lie in the upper plane of the yellow region, US 40 measurements, which are in red, lie in the lower plane of the yellow region and the US 50 measurements, which are in yellow, lie in between the red and green regions.

5.6 RRPM Coverage and Retroreflectivity Data Analysis

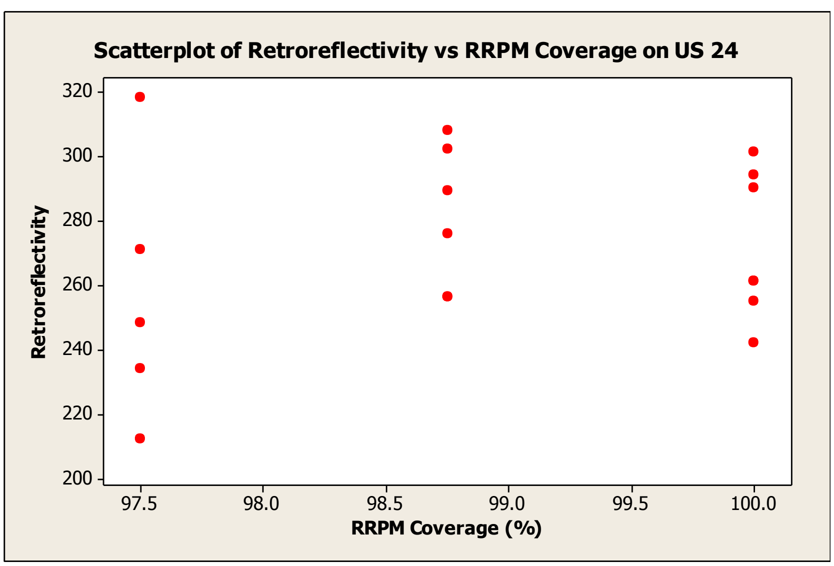
RRPM paint coverage measurements, a measure of the uniformity of the paint line of the pavement markings, were collected from US 24, US 50 and US 40 using the procedure explained in section 5.3 of this chapter, and shown in figure 5.8. Like spectrometry, RRPMs coverage measurements were also taken from US 24 and US 40 on October 31st 2008 and from US 50 on October 24th 2008. Coverage measurements on US 24 were taken 30 days after installation and those on US 50 and US 40 were taken 151 days and 1279 days after installation, respectively, from the date of installation. RRPM coverage measurements were taken only from locations with CLRS. Coverage measurements were obtained for understanding the correlation of pavement marking over CLRS with retroreflectivity. Retroreflectivity data was collected from the RRPM, and paint coverage was checked for the same area where the reflectometers' reading head was exposed while taking the retroreflectivity measurements. Several such measurements were taken and their correlations were checked. Results from the correlation analysis are explained below.

5.6.1 Results of RRPM Paint Coverage and Retroreflectivity Correlation analysis on US 24

Correlation analysis is done for the measurements from US 24 and the results are as follows,

Pearson correlation of Retroreflectivity and paint Coverage (%) = 0.197 with a P-Value = 0.433

Figure 5.11 Scatterplot of Retroreflectivity versus RRPM coverage on US 24



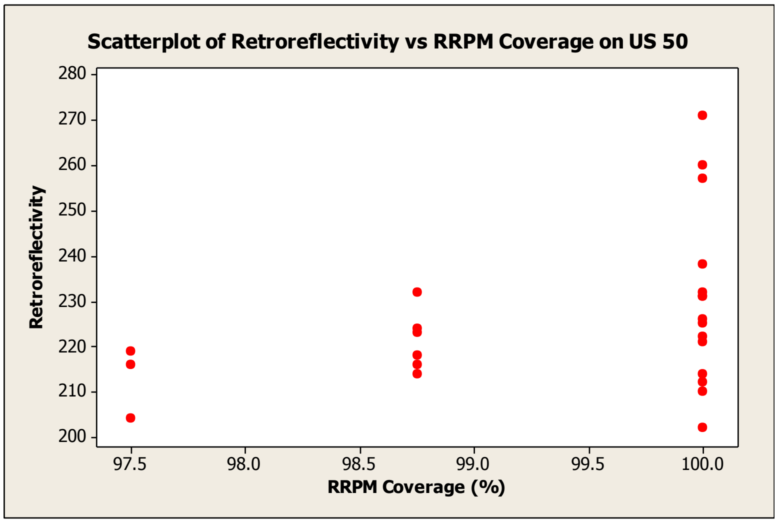
From the negative Pearson correlation coefficient value of 0.197 and P-value of the test it could be seen that there is no significant correlation between RRPM paint coverage and retroreflectivity.

5.6.2 Results of RRPM Paint Coverage and Retroreflectivity Correlation analysis on US 50

Correlation analysis was conducted for the measurements from US 50 and the results are as follows,

The Pearson correlation of Retroreflectivity and paint Coverage (%) = 0.370 with a P-Value = 0.075

Figure 5.12 Scatterplot of Retroreflectivity versus RRPM coverage on US 50



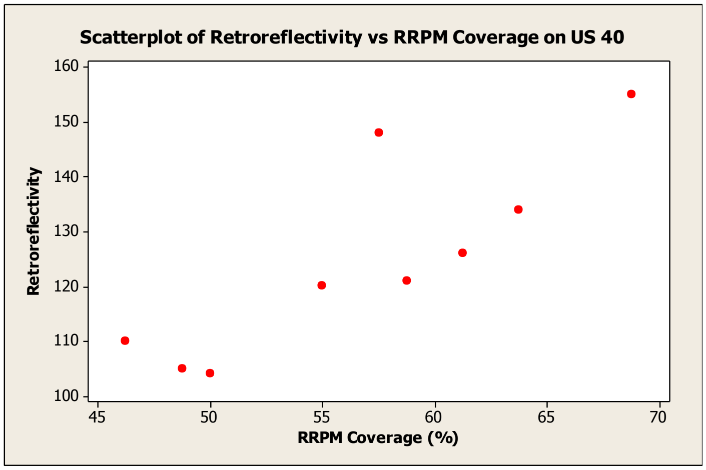
From the P-value of the test it can be seen that there is no significant correlation between RRPM paint coverage and retroreflectivity. Also the scatter plot in Figure 5.12 and the Pearson correlation coefficient value of 0.370 substantiate the result.

5.6.3 Results of RRPM Paint Coverage and Retroreflectivity Correlation analysis on US 40

Correlation analysis was conducted for the measurements from US 40 and the results are as follows.

The Pearson correlation of Retroreflectivity and Paint Coverage (%) = 0.842 with a P-Value = 0.004

Figure 5.13 Scatterplot of Retroreflectivity versus RRPM coverage on US 40



The P-value of this test shows highly significant correlation between RRPM coverage and retroreflectivity. Also the scatter plot in Figure 5.13 and the Pearson correlation coefficient value of 0.842 substantiate the result.

5.6.4 RRPM paint coverage and retroreflectivity correlation discussion.

From the results of the analysis above it is found that there is a highly significant correlation between that paint coverage retroreflectivity at the sites on US 40, but no such correlation exists on US 24 or US 50. The reason for this result is that the RRPM on US 24 and US 50 are only 30 and 151 days old (since installation), whereas RRPM on US 40 is 1279 days old. The RRPM coverage percentage range can be seen in Table 5.8.

Table 5.8 RRPM Coverage percentage range for US 24, US 50 and US 40.

Highway	RRPM Coverage % Range
US 24	98 to 100 %
US 50	99 to 100 %
US 40	46 to 69 %

It can be seen that the RRPM paint coverage on US 24 and US 50 is nearly one hundred percent and coverage on US 40 is between 46 to 69%. The paint coverage range on US 24 and US 50 is almost constant, probably due to being relatively new, and that is the cause for showing no significant correlation with retroreflectivity on these two test locations.

5.7 Field Evaluation Result Discussion

5.7.1 Comparing the retroreflectivity findings with published literature

In the study conducted by TTI (Pike et al., 2007) it was found that retroreflectivity decreases as the rate of wetting increases. Even for the lowest wetting rate (0.28 inches/hr) it was seen that there is a considerable reduction in retroreflectivity.

In this study conducted by K-State research team on US 24, US 50 and US 40 highways the following is determined,

- On locations without CLRS wet retroreflectivity is 35.3 to 84 percent higher than dry retroreflectivity. It is also noted that on all three study locations, wet retroreflectivity measurements are above the acceptable retroreflectivity limit set by federal highway administration for yellow thermoplastic retroreflective paint material.

- On locations with CLRS, wet retroreflectivity is 37.5 to 85.8 percent lower than dry retroreflectivity. It is also noted that on US 24, US 50 and US 40, retroreflectivity measurements are much lower than the acceptable limit set by federal highway administration for yellow thermoplastic retroreflective paint material.

5.7.2 Retroreflectivity trend analysis results

Retroreflectivity trend analysis was performed in Minitab-15 software. Time series trend analysis technique was applied to check the linearity in retroreflectivity reduction over time. Trend analysis was performed on the average of retroreflectivity measurements during each visit taken over a period of 7 months on each highway. Trend analysis result plots retroreflectivity against years from day of installation (which is days from installation date divided by 365.5).

Time series trend analysis is performed on the data by fitting linear, quadratic or exponential models to the data set, and the model with the smaller MSD (Mean Squared Distance) is selected as the best fit model. MAPE (Mean Absolute Percentage Error) and MAD (Median Absolute Deviation) are also obtained with the trend analysis output plot. For a perfect fit MAPE is zero but there is no restriction for its upper level. MAD is the measure of variability in data.

5.7.2.1 Retroreflectivity trend analysis on US 24

Retroreflectivity trend analysis result plots on location with and without CLRS are shown in Figures 5.14 and 5.15 respectively.

Figure 5.14 Retroreflectivity trend analysis plot on US 24 location with CLRS

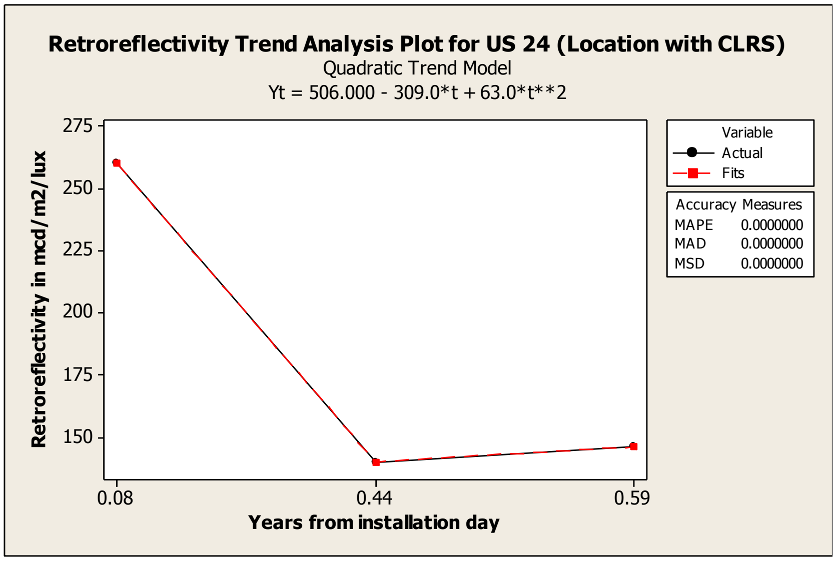
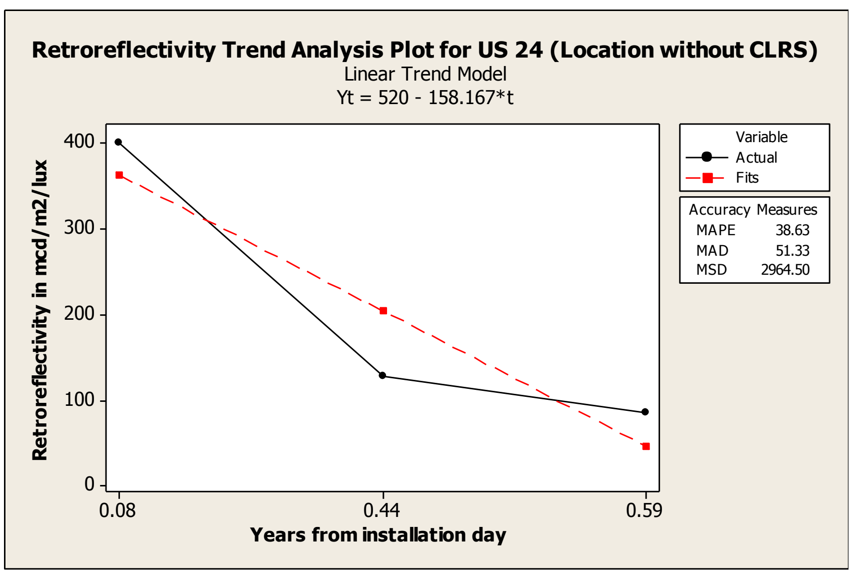


Figure 5.15 Retroreflectivity trend analysis plot on US 24 location without CLRS



From trend analysis model on US 24 it was found that the trend in retroreflectivity reduction at the CLRS location is non-linear but there is a linear trend in retroreflectivity reduction in the location without CLRS.

5.7.2.2 Retroreflectivity trend analysis on US 50

Retroreflectivity trend analysis result plots at locations with and without CLRS are shown in Figures 5.16 and 5.17 respectively.

Figure 5.16 Retroreflectivity trend analysis plot on US 50 location with CLRS

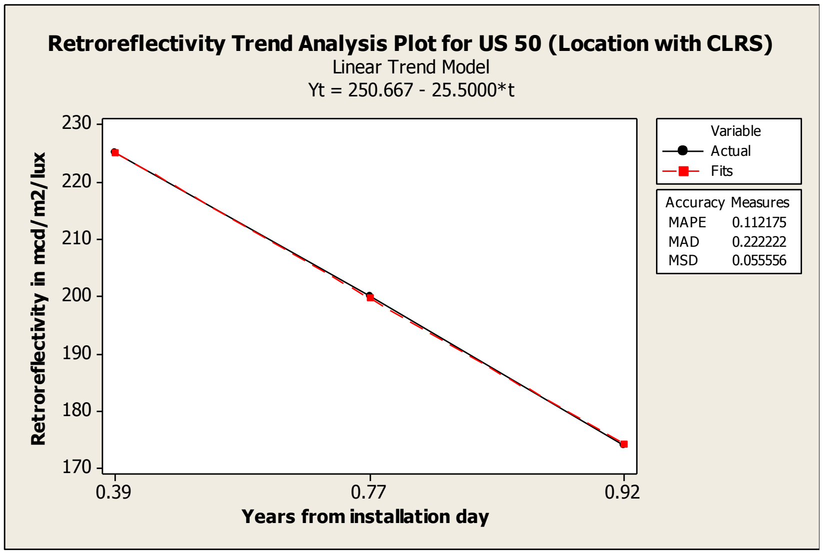
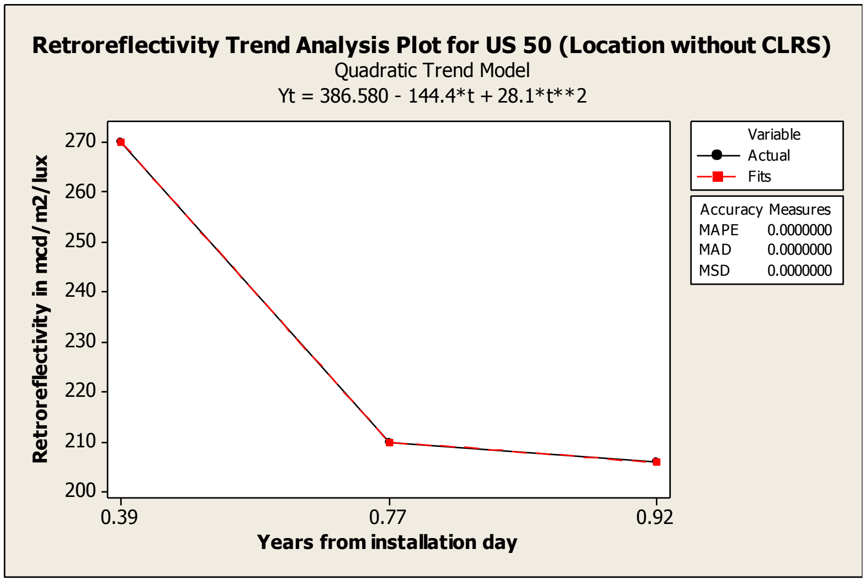


Figure 5.17 Retroreflectivity trend analysis plot on US 50 location without CLRS



From trend analysis model and Figure 5.16 it can be seen that there is perfect linear (MAPE = 0.112) reduction in retroreflectivity in the location with CLRS. Figure 5.17 shows that there is a non-linear reduction in retroreflectivity in the location without CLRS.

5.7.2.3 Retroreflectivity trend analysis on US 40

Retroreflectivity trend analysis result plots at locations with and without CLRS are shown in Figures 5.18 and 5.19 respectively.

Figure 5.18 Retroreflectivity trend analysis plot on US 40 location with CLRS

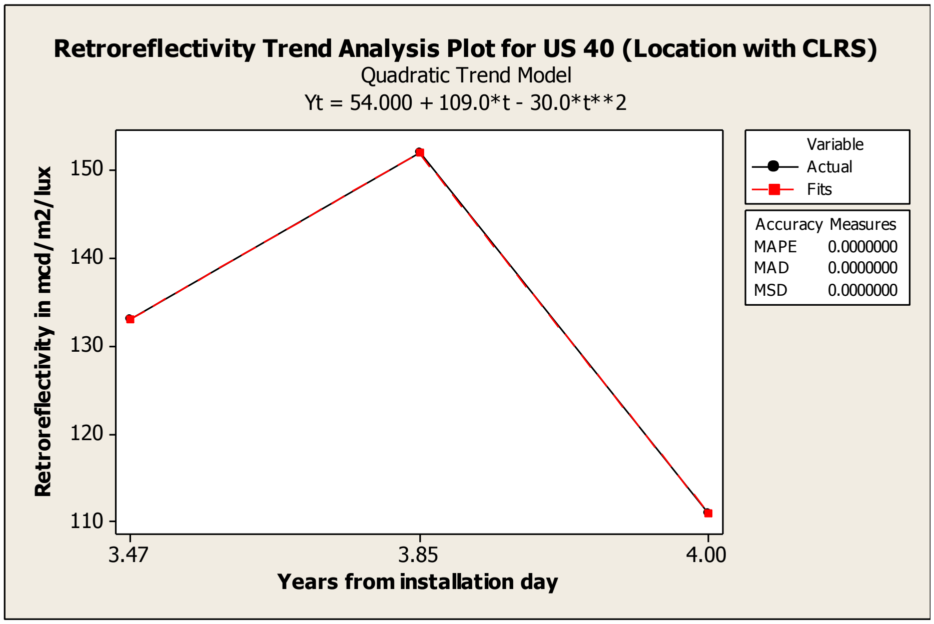
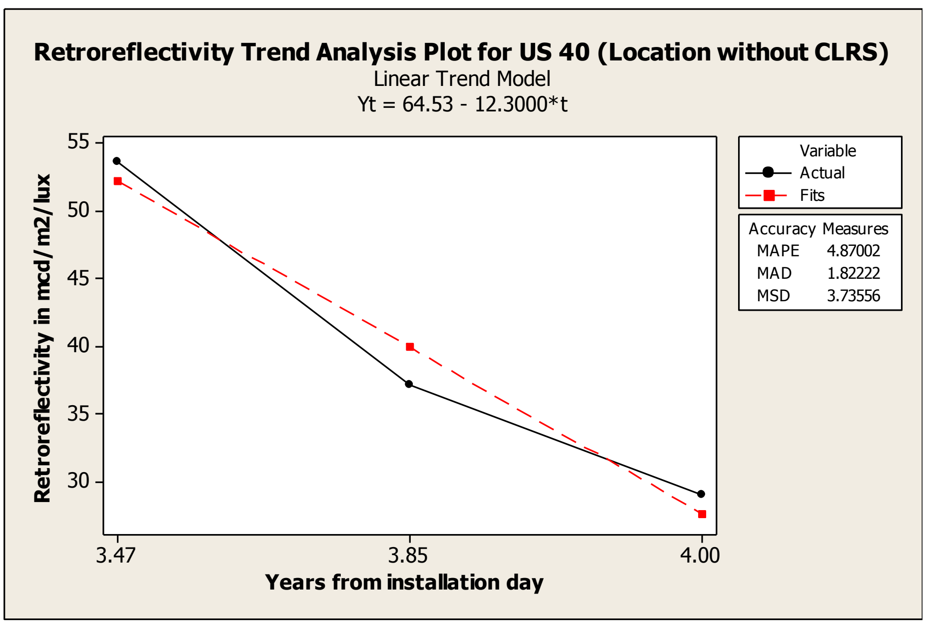


Figure 5.19 Retroreflectivity trend analysis plot on US 40 location without CLRS

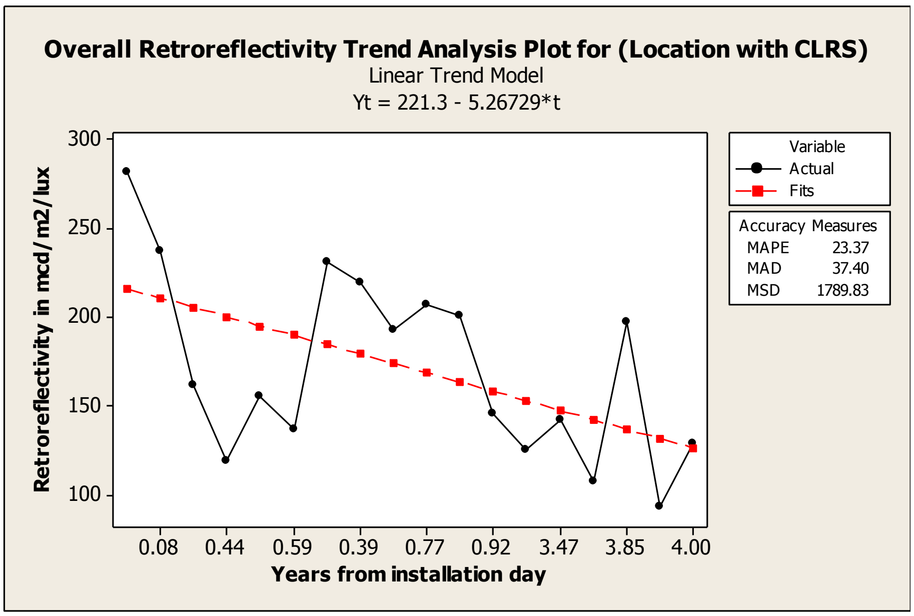


From trend analysis model and Figure 5.18 it can be seen that the trend in retroreflectivity reduction at the CLRS location is non-linear. Figure 5.19 shows a linear trend in retroreflectivity reduction in the location without CLRS. It is noted that average retroreflectivity measurements during all three visits were less than acceptable limit of 175 mcd/m^2/lux.

5.7.2.4 Overall Retroreflectivity trend analysis plot on all study locations with CLRS.

Overall trend in retroreflectivity reduction at locations with CLRS on all three highways was performed. Result plot is shown in Figure 5.20.

Figure 5.20 Overall retroreflectivity trend analysis plot on all study location with CLRS

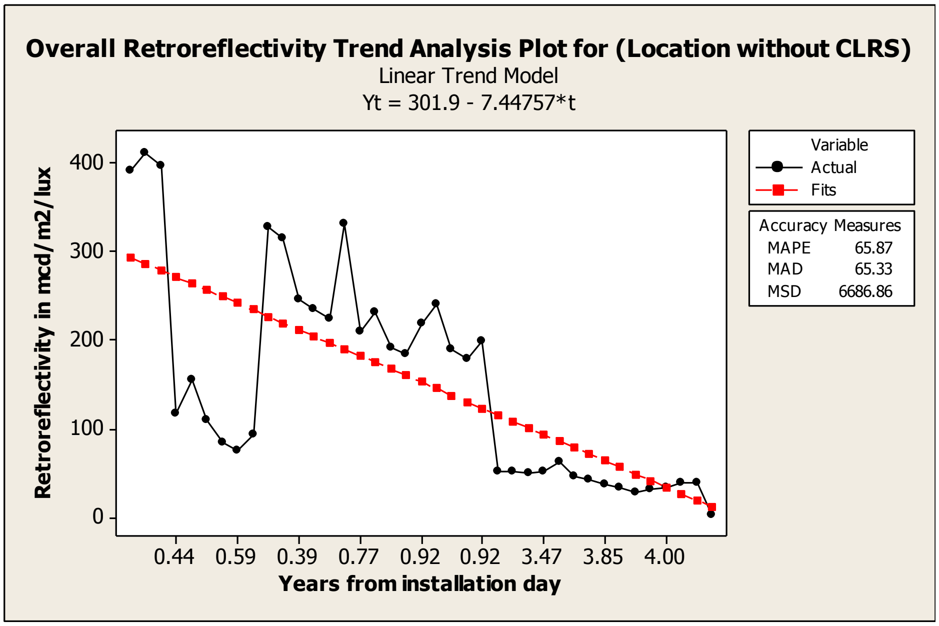


From overall trend analysis model and Figure 5.20 it can be seen that there is a linear reduction in retroreflectivity at all locations with CLRS.

5.7.2.5 Overall Retroreflectivity trend analysis plot on all study locations without CLRS.

Overall trend in retroreflectivity reduction at locations without CLRS on all three highways was performed. Result plot is shown in Figure 5.21.

Figure 5.21 Overall retroreflectivity trend analysis plot on all study location without CLRS



From overall trend analysis model and Figure 5.21 it can be seen that there is a linear reduction in retroreflectivity at all locations without CLRS.

5.7.3 Correlation analysis of AADT & Retroreflectivity

Correlation between AADT (Annual Average Daily Traffic) and average retroreflectivity was tested to find the influence of AADT in retroreflectivity reduction over time. AADT and average retroreflectivity measurements for which the test was performed are shown in Table 5.9.

Table 5.9 AADT and average retroreflectivity data for correlation test.

		Visit 1 (Oct)		Visit 2 (Mar)		Visit 3 (May)	
		Average Retroreflectivity in mcd/m^2/lux					
Location	**AADT**	**With CLRS**	**Without CLRS**	**With CLRS**	**Without CLRS**	**With CLRS**	**Without CLRS**
US 24	5040	260	401	140	127	146	84
US 50	4085	225	270	200	210	174	206
US 40	3320	133	54	152	37	111	29

Correlation test p-values are shown in Table 5.10.

Table 5.10 P-values from correlation test.

	P-Value of test	
Location	**With CLRS**	**Without CLRS**
Visit1	0.202	0.130
Visit 2	0.838	0.629
Visit 3	0.666	0.844

From this correlation test and p-values in Table 5.10 it can be concluded that there is no significant correlation between AADT and rate of reduction in retroreflectivity.

5.7.4 Correlation analysis of Vehicles travelled during RRPM service period & Retroreflectivity.

The correlation between vehicles travelling over a section during the service period and the average retroreflectivity was analyzed to find any influence between the number of vehicles travelling over the section and the retroreflectivity reduction in the section over time.

Vehicles travelling during the RRPM service period = AADT * Days from installation

The data for vehicles travelling over the section during the service period and the average retroreflectivity measurement for which this analysis was performed is shown in table 5.11.

Table 5.11 Vehicles travelling during RRPM service period and the average retroreflectivity data for the correlation test.

US 24		
	Average retroreflectivity in mcd/m2/lux	
Vehicles travelling during RRPM service period	**With CLRS**	**Without CLRS**
151200	260	401
816480	140	127
1083600	146	84
US 50		
Vehicles travelling during RRPM service period	**With CLRS**	**Without CLRS**
588240	225	270
1156055	200	210
1372560	174	206
US 40		
Vehicles travelling during RRPM service period	**With CLRS**	**Without CLRS**
4213080	133	54
4674560	152	37
4850520	111	29

The Pearson correlation coefficient and p-values are shown in Table 5.12.

	P-Value of test		**Pearson correlation coefficient**	
Location	**With CLRS**	**Without CLRS**	**With CLRS**	**Without CLRS**
US 24	0.208	0.100	-0.947	-0.988
US 50	0.168	0.136	-0.965	-0.977
US 40	0.801	0.040	-0.308	-0.998

From this Pearson correlation coefficient and p-values in Table 5.12, it can be concluded that there is no significant correlation between the number of vehicles that were travelling over a section during the RRPM service period and rate of reduction in average retroreflectivity.

5.7.5 Correlation analysis of Age of paint stripe & Retroreflectivity

The correlation between the age of a paint stripe and retroreflectivity was analyzed to see if there was a correlation. The age of the paint material and the average retroreflectivity for which the analysis was performed are shown in Table 5.12.

Table 5.12 Age of paint stripe and average retroreflectivity data for correlation test.

US 24		
	Average retroreflectivity in mcd/m^2/lux	
Age of paint stripe in days from installation	With CLRS	Without CLRS
30	260	401
162	140	127
215	146	84
US 50		
Age of paint stripe in days from installation	With CLRS	Without CLRS
144	225	270
283	200	210
336	174	206
US 40		
Age of paint stripe in days from installation	With CLRS	Without CLRS
1269	133	54
1408	152	37
1461	111	29

The Pearson correlation coefficient and p-values for this analysis are shown in Table 5.13.

Table 5.13 P-values from correlation test.

	P-Value of test		Pearson correlation coefficient	
Location	With CLRS	Without CLRS	With CLRS	Without CLRS
US 24	0.208	0.100	-0.947	-0.988
US 50	0.168	0.136	-0.965	-0.977
US 40	0.801	0.04	-0.308	-0.998

From the Pearson correlation coefficient and p-values in Table 5.13. it can be concluded that there is no significant correlation between the age of the paint stripe and rate of reduction in retroreflectivity.

CHAPTER 6 - Conclusion and Future Research

6.1 Conclusion

Based on the results from the Chapter 3 survey of motorcycle riders it can be concluded that that a substantial share (57%) of survey participants have traversed over CLRS and about half of them reported motorcycle handling problems while traversing CLRS. However it can be seen from the difficulty response distribution that the level of difficulty encountered by riders is not high. Also, 68% of respondents like the rumble effect and 72% believe in their effectiveness in reducing head-on-collisions. In addition, 70% of respondents have strongly recommended that the Kansas Department of Transportation should implement CLRS in more locations across the state. Therefore, it can be concluded that the majority of riders believe in the effectiveness of centerline rumble strips. Also riders indicated that when they were aware of the situation they didn't encounter much difficulty in motorcycle handling.

The results from the Chapter 4 survey on US 40 residents shows that 100% of respondents believe that the visible warning provided by shoulder and centerline retroreflective pavement markings are extremely helpful in maintaining the lateral position of their vehicle. Also, 90% of respondents believe that the retroreflective pavement markings contribute to their driving safety. Majority (60%) of respondents believe that retroreflectivity of pavement markings have deteriorated after a winter season. Also, respondents reported that pavement markings have poor visibility under low visibility conditions (rainy, foggy and snow). Therefore, it can be concluded that majority of the drivers responding believe that retroreflective pavement markings are really important for safe driving, but there has been deterioration in the retroreflective pavement markings over rumble strips on US 40. Respondents also believe that embedding reflectors on pavement markings would enhance their visibility under low visibility conditions.

Based on Chapter 5 analysis of data it can be concluded that in locations without the CLRS wet retroreflectivity is higher than dry retroreflectivity and in locations with the CLRS wet retroreflectivity is lower than dry retroreflectivity. Retroreflectivity trend analysis results show that: 1) on US 24 in locations with CLRS there is non-linear trend in retroreflectivity reduction and in locations without CLRS there is a linear trend, 2) on US 50 in locations with CLRS there is a linear trend and in locations without CLRS there is a non-linear trend, 3) on US 40 there is nonlinear trend in location with CLRS and linear trend in location without CLRS. Overall there is a linear trend in retroreflectivity reduction in locations with and without CLRS. Correlation analysis for AADT and rate of retroreflectivity reduction showed no significant correlation. Results from the correlation analysis on RRPM coverage and retroreflectivity show a highly significant correlation on US 40, but no correlation exists on US 24 and US 50. In addition the correlation analysis of age of paint stripe and retroreflectivity showed no significant correlation. Another correlation analysis of vehicles travelled during RRPM service period and retroreflectivity showed no significant correlation. The chromaticity chart obtained shows the regions where the spectrometry measurements on US 24, US 50 and US 40 fall in the CIE (Commission on Illumination) standard illuminant D_{65} (beaded retroreflective paint) chromaticity chart.

6.2 Future Research

For future work there are several areas that could be researched. Studies should be conducted on undivided highways with CLRS for evaluating the erratic maneuvers which motorcycle riders may face when they traverse CLRS. Also studies should be conducted on the need for providing warning signs before riders approaching highways with CLRS. A longer AADT and retroreflectivity correlation analysis period could be used to determine any possible correlation. Also, more test sites should be considered for data collection. A potential reason for reduction in wet retroreflectivity of RRPM on CLRS could be due to the loss of intensity of light due to refraction caused by the water caught up in the rumble depression. Field experiments should be conducted to evaluate the optimal depth of CLRS which will reflect maximum incident light when water in caught up in the rumble depression. Future research should also be conducted on better understanding the correlation of cross over centerline accidents with retroreflectivity. Research on different paint marking materials over CLRS for improving wet reflectivity, could be another area of study.

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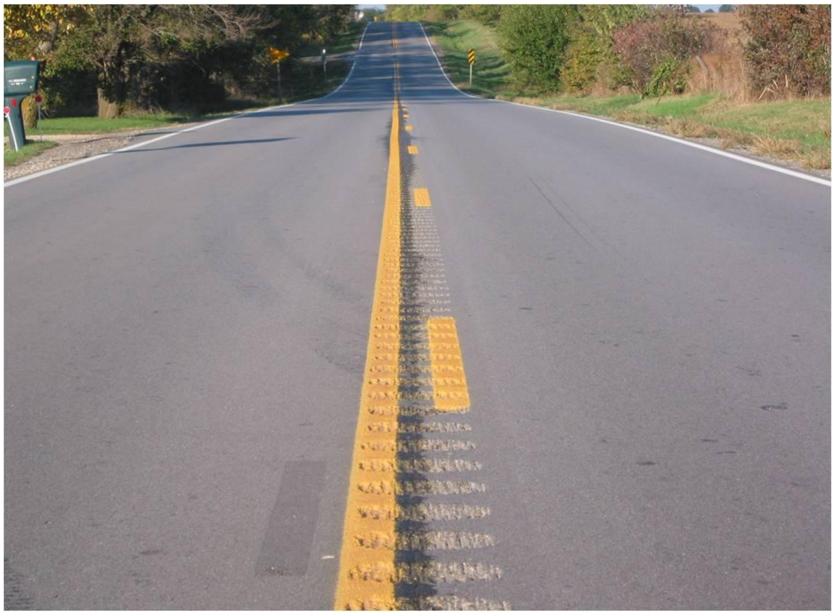
Appendix A - Motorcycle Survey Questionnaire

A Brief Description on the Objective of Survey:



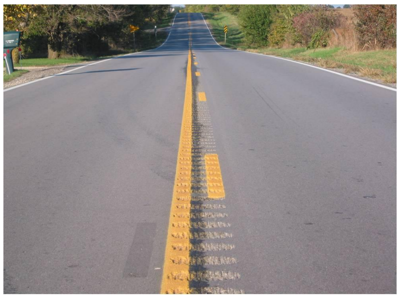
(Milled Centerline Rumble Strips)

The Kansas State University Research team needs your help in a special study on centerline rumble strips on highways. Kansas department of transportation (K-DOT) has installed centerline rumble strips to reduce cross over centerline crashes. This survey is intended for knowing motorcycle riders opinion and concerns regarding centerline rumble strips.

Centerline rumble strips are used as safety enhancement to reduce cross-over centerline crashes on highways. They are milled on to the surface of pavement. Milled centerline rumble strips are indentations placed along the centerline of highways, usually on two-lane two way highways. They are placed to warn drivers drifting on to the wrong lane by giving audible and vibratory alert. They help a great extent to reduce cross-over centerline crashes.

Please provide your valuable comments and suggestions to help K-DOT in improving motorcycle rider's safety on Highways.

Motorcycle Riders Opinion on Centerline Rumble Strips



1. Have you driven over (come in contact with) the Centerline Rumble Strips?

☐ Yes (continue to question 2) ☐ No (continue to question 13)

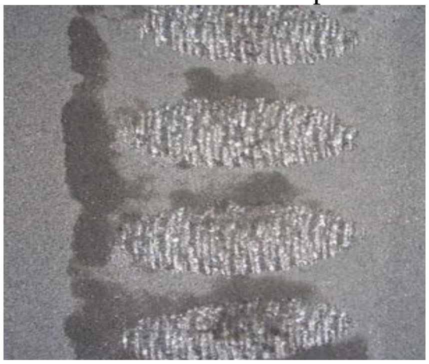
2. Do you remember the location where you encountered Centerline Rumble Strips, if so please write down the location?

____

3. Type of rumble strip encountered (Mark all that applies)?

Rectangular Shaped ☐

Football shaped ☐



4. Did you encounter a motorcycle handling problem?

☐ Yes ☐ No

5. If your answer is 'Yes' to Question # 4, please rate the level of difficulty encountered on a scale of
1-5 (1 for Low and 5 for High). If your answer is 'No' to Question # 4, please continue to Question # 6.

Difficulty encountered in motorcycle handling __________.

6. When you drove over rumble strips what was your initial reaction, did you correct to the left, to the right or overcorrect?

To Left ☐ To Right ☐ Overcorrect ☐

If anything other than the above please explain,

____

7. Did you ride on them unknowingly?

☐ Yes ☐ No

8. What is your initial impression on Centerline Rumble Strips?

☐ Like, please rate your opinion on a scale of 1-5 (1 for Low and 5 for High) on how strongly you like _____
or
☐ Dislike, please rate your opinion on a scale of 1-5 (1 for Low and 5 for High) on how strongly you dislike _____

9. Do you think they are a nuisance while making legal passing maneuvers?

☐ Yes ☐ No

10. What is your impression of the effectiveness of the rumble effect? Giving consideration to vibratory alertness provided by Centerline Rumble Strips please rate your answer on a scale of 1-5 (1 for Low and 5 for High).

Impression on the rumble effect ________.

11. Do you think Centerline rumble strips provide a suitable safety improvement for reducing head-on collisions?

☐ Yes ☐ No

12. If CLRS are proven to reduce head-on collisions and improve safety, would your impression of them change?

☐ Yes ☐ No

13. Do you think Kansas Department of Transportation should implement Centerline Rumble Strips in more locations across the state?

☐ Yes ☐ No

14. Do you prefer wearing helmet while riding motorcycle?

☐ Yes ☐ No

15. Gender: Male ☐ Female ☐

16. Age: ≤17 ☐ 18-24 ☐ 24-45 ☐ 46-65 ☐ >65 ☐

17. Years of motorcycle riding experience?

≤ 1 ☐ 1-5 ☐ Over 5 years ☐

18. Comments/Suggestions: ____

____

Appendix B - Visibility Survey Questionnaire

EVALUATION OF RETRO-REFLECTIVE PAVEMENT MARKING
KANSAS STATE UNIVERSITY RESEARCH TEAM

Your comments concerning the retro-reflective pavement markings 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 noticed the retro-reflective pavement markings over rumble strips?
☐ Yes (continue to question 2) ☐ No (continue to question 8)
2) Do you think that the retro-reflective pavement markings are clearly visible to the driver?
☐ Yes ☐ No
3) Do you find it helpful in correcting the lateral positioning of your vehicle from the visible warning provided by shoulder and centerline retroreflective pavement markings?
☐ Yes ☐ No
4) On a scale of 1-5 (1 for Low and 5 for High) where do you rate the visibility of the retro-reflective pavement markings under the following conditions?
a) Dry day light _____ d) Rainy night _____ g) Snowy day ______
b) Rainy day light_____ e) Foggy day _____ h) Snowy night______
c) Dry night _____ f) Foggy night _____
5) Have you perceived any deterioration in the brightness of the retro-reflective pavement markings after a winter season?
☐ Yes ☐ No
6) Do you believe that the retro-reflective pavement markings on US-40 contribute to your driving safety?
☐ Yes ☐ No
7) Do you think embedded reflectors on centerline pavement markings will enhance the visual warning provided by them?
☐ Yes ☐ No

8) Gender: Male ☐ Female ☐

9) Age: ≤17 ☐ 18-24 ☐ 24-45 ☐ 46-65 ☐ >65 ☐

Comments: ____
Name/Address: ____

EVALUATION OF RETRO-REFLECTIVE PAVEMENT MARKING
KANSAS STATE UNIVERSITY RESEARCH TEAM

Dear Resident:

The Kansas State University Research team needs your help in a special study on the retro-reflective pavement marking on US 40 highway between Lawrence and Topeka. KDOT (Kansas Department of Transportation) has installed retro-reflective pavement markings to provide improved visibility of both shoulder and center-lines. The purpose of this survey is to determine the level of warning provided by the pavement markings under different conditions. To identify problems and/or developing better solutions in the pavement marking design, maintenance and their placement. Kansas State University Research team wishes to get your opinion on any noticeable deterioration on pavement markings, i.e. any noticeable difference in the level of brightness of the pavement marking after one or two winter seasons. Your answers to the attached survey will help provide this valuable information. This survey is solely intended for research purpose, it's voluntary. If you have any concerns please contact, (Dr. M Rys, Associate Professor, IMSE Department, e-mail – malrys@ksu.edu, Phone # 785-532-3733) or (Mr. Rick Jcheidt, IRB Chairman, 203 Fairchild Hall, KSU, KS-66506, Phone # 785-532-3224)

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SYSTEMS ENGINEERING
2037 DURLAND HALL
KANSAS STATE UNIVERSITY
MANHATTAN KS 66502 – 5101

Appendix C - Mat lab code for D_{65} Spectrometry chart generation.

Mat lab code for D_{65} chart generation

```
%%
close all;
im = imread('D65 Chromaticity Chart.jpg');
%%
%%611 591
figure(1);imshow(im);
% hold on;plot([0 591],[46 46]);plot([0 591],[102 102]);
% x = [67 67];
% for i = 1:81
%     figure(1);plot(x,[0 611]);
%     x = x + 5.7;
% end
%
% y = [46 46];
% for i = 1:91
%     figure(1);plot([0 591], y);
%     y = y + 5.65;
% end

%%
line = [0, .75;
        .75, 0];
figure (2);plot(line(:,1),line(:,2),'k');axis([0 .8 0 .9]);hold on;grid on;


ra = [.170,.000;
      .169,.010;
      .158,.015;
      .142,.030;
      .138,.040;
      .122,.059;
      .110,.088;
      %---
      .090,.135;
      .070,.200;
      .045,.298;
      %---
      .022,.411;
      .010,.539;
      .001,.655;
      %--
      .011,.750;
      .040,.811;
      .075,.835;
      .115,.829;
      .155,.809;
      .191,.780;
      %--
      .230,.755;
      .269,.725;
      .300,.691;
      .339,.660;
      .371,.623;
      .409,.590;
      .445,.555;
      .480,.522;
      %--
      .512,.489;
      .551,.451;
```

```
      .576,.424;
      .601,.398;
      .629,.371;
      .649,.354;
      .668,.332;
      .680,.320;
      .691,.309;
      .700,.300;
      .708,.291;
      .720,.281;
      .725,.273;
      .730,.265;
      %--
      .170, 0;];
  figure (2);plot(ra(:,1),ra(:,2),'o-');
white = [.3, .31;
         .29,.32;
         .335,.363;
         .345,.353;
         .3, .31;];
     figure (2);plot(white(:,1),white(:,2),'k');
black = [.3, .27;
         .26,.31;
         .345,.39;
         .380,.352
         .3, .27];
     figure (2);plot(black(:,1),black(:,2),'k');
faa =    [.48,.428;
          .46,.44;
          .47,.455;
          .50,.449;
          .48,.428];
      figure (2);plot(faa(:,1),faa(:,2),'ko-');
yellow = [.47,.445;
          .43,.485;
          .468,.53;
          .522,.479;
          .470,.445];
      figure (2);plot(yellow(:,1),yellow(:,2),'y');
dotted = [.392,.358;
          .353,.395;
          .468,.528;
          .533,.463;
          .392,.358];
      figure (2);plot(dotted(:,1),dotted(:,2),'k:');
orange = [.535,.375;
          .508,.404;
          .570,.430;
          .610,.389;
          .535,.375];
      figure (2);plot(orange(:,1),orange(:,2),'m');
red    = [.596,.312;
          .570,.342;
          .652,.344;
          .690,.310;
          .596,.312];
      figure (2);plot(red(:,1),red(:,2),'r');

us24 =  [0.470  0.423;
        0.463   0.451;
        0.459   0.440;
        0.454   0.445;
```

```
        0.462   0.435;
        0.461   0.442;
        0.453   0.445;
        0.457   0.445;
        0.449   0.450;
        0.452   0.448;
        0.466   0.430;
        0.465   0.435;
        0.446   0.424;
        0.434   0.445;
        0.431   0.444;
        0.435   0.440;
        0.432   0.434;
        0.430   0.432;
        0.436   0.438;
        0.434   0.434;
        0.434   0.434;
        0.431   0.430;
        0.431   0.438;
        0.440   0.436;
        0.470   0.423];
        figure (2);plot(us24(:,1),us24(:,2),'g.-');

us50 = [0.427   0.435;
        0.428   0.430;
        0.426   0.421;
        0.433   0.434;
        0.406   0.401;
        0.412   0.414;
        0.423   0.418;
        0.422   0.424;
        0.416   0.424;
        0.422   0.427;
        0.429   0.428;
        0.424   0.420;
        0.426   0.424;
        0.427   0.435];
figure (2);plot(us50(:,1),us50(:,2),'y.-');

us40 = [0.414   0.416;
        0.406   0.438;
        0.408   0.428;
        0.404   0.430;
        0.404   0.425;
        0.412   0.416;
        0.414   0.436;
        0.419   0.423;
        0.402   0.442;
        0.386   0.408;
        0.402   0.431;
        0.386   0.432;
        0.395   0.439;
        0.395   0.441;
        0.414   0.416];

    figure (2);plot(us40(:,1),us40(:,2),'r.-');
```

Appendix D - Field Study Pictures

Figure D.1 Taking retroreflective measurements over CLRS on US 50

Figure D.2 Taking retroreflective measurements over CLRS on US 24

Figure D.3 Taking retroreflective measurements in location without CLRS on US 40

Figure D.4 Taking spectrometry measurements of RRPM over CLRS

Figure D.5 Keeping spectrometers' reading head at approximately 2 in above the pavement surface