Preliminary Before and After Speed Studies as a Tool to Assess the Effectiveness of Centerline Rumble Strips in Rural Roads

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ABSTRACT - A research study completed in 2016 by the National Highway Traffic Safety Administration (NHTSA), showed that 51% of the 32,675 motor vehicle traffic crash fatalities reported in 2014 occurred on the rural road network in the United States and 64% in Puerto Rico. Centerline rumble strips, (CLRS) have been proven in the United States to be an effective, low-cost countermeasure, however, it is yet to be tested in Puerto Rico. The focus of this research is to study the safety effectiveness of CLRS on highway PR-114, a rural two-lane two-way road connecting the municipalities of Hormigueros and San Germán in the Commonwealth of Puerto Rico. The CLRS and corresponding signage were installed from km 7.6 to 14.5 along this highway and is the first to be treated with this safety countermeasure in Puerto Rico. The primary focus of this paper is spot speed analyses of vehicles inside and outside of the segment treated with CLRS. The findings of this research show increased speeds within the CLRS by up to 3 mph. Vehicles traveling eastbound traveled on an average 2 mph greater than the opposing traffic. The posted speed limit of 35 mph was exceeded at both km 14.3 and 14.6 locations by up to 11 mph for mean speeds and 17 mph for 85th percentile speeds and the speeds recorded ranged from 27 to 69 mph. This suggests that the posted speed limit should be raised in order to decrease the large range of speeds which has been associated with serious and fatal crashes. When there is a large range of speeds, drivers will feel more inclined to pass slower vehicles, making them prone to head-on and sideswipe same direction crashes. The passing driver will then position their vehicle further into the opposing lane to prevent hitting the rumbles throughout the entire passing maneuver. Raising the speed limit to 40 mph is recommended combined with strict police enforcement during the first three months of implementation, and regular law enforcement afterwards.

Keywords--CLRS, Rumble Strips, Safety Countermeasures, Speed Studies, ROR Crashes.

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I. INTRODUCTION

Centerline rumble strips (CLRS) have been increasingly implemented along rural roads in the United States. This treatment is installed to address the high number of run-off-the-road (ROR) crashes in rural road networks nationwide with the purpose of keeping vehicles on the roadway and their travel lanes and reduce crash severity. The National Highway Traffic Safety Administration (NHTSA) defines a roadway departure crash, also referred to as run-off-the-road (ROR) crashes, *as a crash in which a vehicle crosses an edge line, a centerline, or leaves the traveled way. Types of crashes fitting the definition include fatal crashes in which the first event for at least one of the involved vehicles ran-off-road (right or left), crossed the centerline or median, went airborne, or hit a fixed object.* [1].

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In 2015, 53.3% of all traffic fatalities in the United States occurred as a result of roadway departure crashes. [2] The CLRS countermeasure is considered to be a cost-effective alternative in the prevention of ROR crashes, specifically head-on and opposite direction sideswipe crashes [1-4]. As a result of the high incidence of road departure crashes on PR-114, a two-lane, two-way rural road in Western Puerto Rico, a pavement rehabilitation project was expanded to include CLRS [7,12]. This is the first road to have the CLRS safety treatment constructed in Puerto Rico and this is the first case study in which the performance of the CLRS countermeasure will be evaluated. The findings of this study will assist the highway and transportation authorities in establishing this safety countermeasure's potential for further implementation along the Puerto Rico rural road highway network with similar geometric and traffic characteristics.

To improve roadway safety, there must be an understanding of the extent of the problem. Puerto Rico rural roads are not included in the nationwide statistics; however, it was reported that 64% of all traffic fatalities in 2014 occurred in rural areas, 13% higher than the national average [3]. Roadway departure crashes was a crash type identified as one of the nine major emphasis areas of the Puerto Rico Strategic Highway Safety Plan (SHSP) and in 2013, 41% of total traffic fatalities were attributed to ROR crashes. Among the top contributing circumstances noted in the SHSP for the cause of these types of collisions were "driver lost control" and "exceeded speed limit" [14].

II. LITERATURE REVIEW

A. Rural Road Crashes Overview

Rural roads continue to have the highest fatal crash occurrence. Figure 1 provides a graphical representation of the tendency of motor vehicle traffic fatalities to be greater on rural roads between the years 2005 to 2014. Figure 2 shows the fatality rates for the same period of time. The fatality rate on rural roads is more than double than that of urban areas. Rural fatality rates range from 2.38 in 2005 to 1.81 fatalities per million vehicle miles traveled (MVMT) in 2014, whereas urban rates range from 0.95 in 2005 and 2006 to 0.73 fatalities per MVMT in 2009 and 2013.

The probability of a crash victim to die en route to a hospital is greater if the crash occurred on a rural road. Of the drivers that died en route to the hospital, 65% were rural drivers and 35% were urban drivers [3]. An explanation for this statistic is the longer distance for a medical responder to transport a crash victim from a rural crash scene to an urban trauma center than a victim from an urban crash scene.

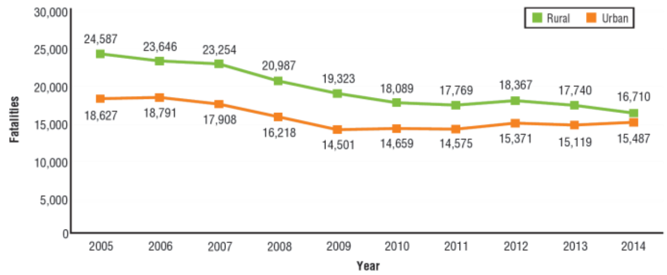


Fig. 1 Motor Vehicle Traffic Fatalities by Year in Location (2005-2014)
Source: FARS Annual Report File [3]

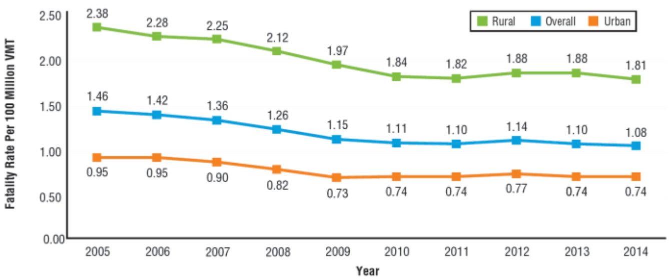


Fig. 2 Fatality Rates per 100 MVMT by Year and Location (2005 -2014)
Sources: FARS Annual Report File; VMT-FHWA [3]

B. Types of Centerline Rumble Strips

There are four primary types of CLRS that have been implemented by state highway agencies in Puerto Rico and the United States, namely, formed, raised, rolled, and milled. (See Figure 3) [7] For the remainder of the document any reference to CLRS shall be of the milled type, unless otherwise noted. The CLRS are designed similarly to shoulder rumble strips (SRS), in which the grooves milled along the centerline cause vibration and noise alerting drivers to get back into their travel lane. Typically, the centerline marking is painted over the rumble in order to increase visibility during inclement weather and in night time driving.

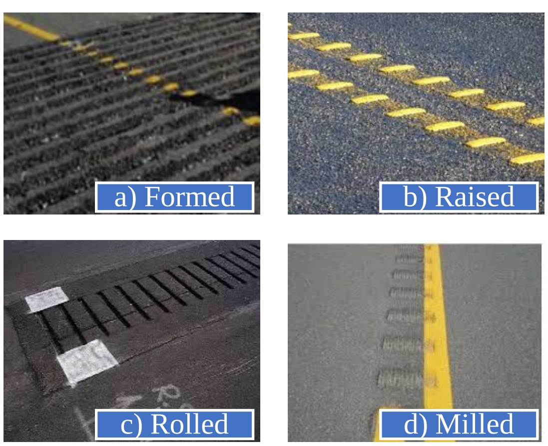


Fig. 3 Rumble Strip Types [3]
Image Sources: a) www.brp.co.za; b) driverknowledgetests.com; c) www.dot.ca.gov; d) fhwa.dot.gov

The CLRS dimensions recommended by the Federal Highway Administration (FHWA) are published in the Technical Advisory T5040.40 and reproduced in Figure 4. [5]

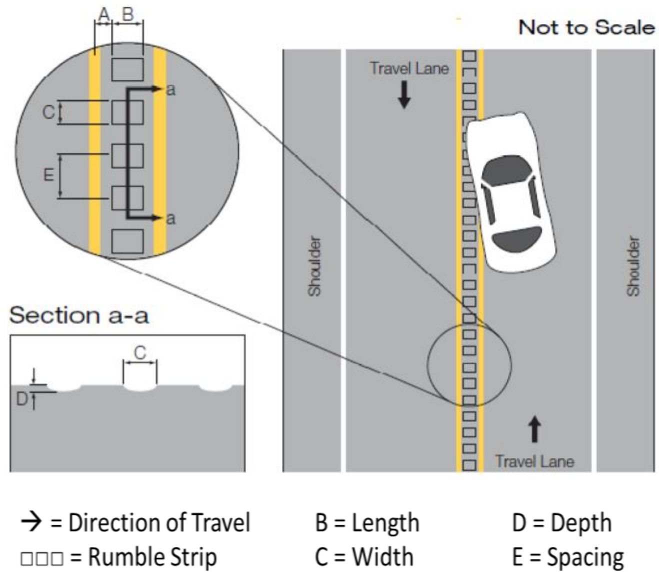


Fig. 4 CLRS Dimensions [5]

This safety countermeasure was implemented to aid drowsy and distracted drivers. If the crash cannot be prevented, the countermeasure can reduce the severity of the crash due to the additional reaction time provided by the rumbles' warning. The crash types reduced with the CLRS include head on, opposite direction sideswipe, and roadway departure to the left [5]. The use of CLRS has increased substantially since its first implementation in the 1990's. In 2003, there were 22 states with installed CLRS and by 2005 that number increased to 46 out of the 50 states [6]. This increase resulted in growing concerns regarding the effectiveness of the safety countermeasure.

A non-freeway rumble strip study conducted by Wayne State University Transportation Research Group (WSUTRG) for the Michigan DOT analyzed three years of "before" and "after" data to evaluate the performance of their 5,400 miles of rumble strips that were installed between the years 2008 and 2010, along their two-lane, rural non-freeway roads with "posted speed limits of 55 mph and appropriate paved lane and shoulder widths" [7]. The study segments consisted of 73% of CLRS only applications and the remainder were a combination of CLRS and SRS. The crash dataset consisted of 38,700 "before" crashes and 33,985 "after" crashes. While filtering the crash data for the crash types that CLRS are expected to influence, the researchers came across instances where the crash was miscoded. As a result, 72,785 crash reports were manually checked and verified. After correctly recoding 10% of the total crash reports, the dataset consisted of 2,488 "before" target crashes and 1,306 "after" target crashes.

The study reported significant reductions in angle, head-on, sideswipe opposite, sideswipe same and single vehicle run-off-the road (ROR) crashes. (See Table 1) The reductions included 47.5% in total target crashes, 51.8% in fatal target crashes, and 48.1% in property damage only (PDO) target crashes. The reductions exceeded 50% for all target crash types [7].

TABLE 1
MICHIGAN DOT CLRS "BEFORE & AFTER" RESEARCH FINDINGS BY CORRECTED CRASH TYPE [7]

Corrected Crash Type	Three-Year Target Crash Frequency		Reduction in Target Crashes (%)	Significant at 95% Level of Confidence
	"Before" Period	"After" Period		
Angle	13	3	76.92	Yes
Head-On	240	118	50.83	Yes
Other	16	22	-37.50	No
Rear End	4	6	-50.00	No
Sideswipe Opposite	365	161	55.89	Yes
Sideswipe Same	121	68	43.80	Yes
Single Vehicle ROR	1,729	928	46.33	Yes
TOTAL	**2,488**	**1,306**	**47.51**	**Yes**

C. Setting Speed Limits

In FHWA's informational report, *Methods and Practices for Setting Speed Limits* [8], four general approaches in setting speed limits are defined:

1) *Engineering Approach:* Where a base speed limit is set according to the 85th percentile speed or the road's design speed, and then adjusted depending on geometric or road user conditions.
2) *Expert System Approach:* Speed limits are set by a computer that uses an algorithm to calculate speed based on knowledge and inference procedures in the computer program.
3) *Optimization:* Setting a speed limit that provides a balance of benefits between travel time, delays, crashes, traffic noise, air pollution, and vehicle operation costs.
4) *Safe System Approach:* Speed limits are set depending on crash types most likely to occur and the consequences of those types of crashes to the road user.

The report suggests several reasons to reevaluate the speed limit of a roadway such as change in road geometry, traffic volume, or land use. For example, in Massachusetts it is recommended to reevaluate a speed limit if the 85th percentile on the road is found to be equal to or greater than 7 mph. An engineering study is done to reevaluate the speed limit.

A common target for data collection is a sample size of 100 speed measurements. For example, in Massachusetts and Ohio there is a minimum of 100 recorded speeds per direction of travel, and for lower volume roads a maximum of two hours or one hour, respectively, even if the sample size of 100 was not obtained. The report states that care should be exercised in the data collection to ensure that free-flow speeds are collected, and that the data collection is done with a sufficient distance from intersections or other points of access which can affect the speed profile with accelerating and decelerating vehicles.

The operating speed method, an example within the engineering approach, sets the speed limit by the 85th percentile speed. At this speed, it is considered to yield the lowest crash risk. [8] Section 2B.13.12 of the MUTCD provides the following guidance, "When a speed limit within a speed zone is posted, it should be within 5 mph of the 85th percentile speed of free-flowing traffic." Speed zones are defined in the MUTCD as a regulatory speed limit along a section of highway that is different from the statutory speed limit. [13] However, FHWA's report finds that while the MUTCD recommends setting the speed limit within 5 mph of the 85th percentile, and traffic engineers say agencies set limits by the 85th percentile, in actuality speed limits are set lower, and in many cases lower than the 50th percentile speed. It was found that these lower speed limits were set due to political pressures, however setting the speed limit below the 85th percentile has not been found to increase speed limit compliance. [8]

Another method under the engineering approach is the road risk method, where the base speed limit is based off the 85th percentile speed and then adjusted depending on the potential road risks. The potential road risks include the function of the road and the road geometry. The following table is an example of base speed classifications using the road risk method used in Canada. [8]

TABLE 2
BASE SPEEDS BY ROAD CLASS AND LAND USE FOR CANADA ROADS [8]

Classification		**Base Speeds, mph (km/h)**							
		Land Use: Rural				Land Use: Urban			
		Undivided		Divided		Undivided		Divided	
		Lanes per direction							
		1	2+	1	2+	1	2+	1	2+
Arterial	Major	55 (90)	60 (100)	60 (100)	70 (110)	50 (80)		55 (90)	
	Minor	50 (80)	55 (90)	55 (90)	60 (100)	45 (70)		50 (80)	
Collector	Major	45 (70)	50 (80)	50 (80)	55 (90)	45 (70)		50 (80)	
	Minor	35 (60)	45 (70)	45 (70)	50 (80)	35 (60)		45 (70)	
Local		35 (60)				30 (50)			

Lane = through lane

Divided = a median that separates travel lanes of traffic in opposing directions, which may be flush with, raised above, or depressed below adjacent travel lanes

In another study evaluating the effect of differential speeds between trucks and vehicles, there was a finding relevant to this study. A simulation model was programmed to simulate the speed measurements taken from two sites along I-44; in the cities of Joplin and Rolla, Missouri. There were 858 vehicle speeds measures at these locations where there was a 70 mph speed limit. The mean speed was calculated to be 71.46 mph, the standard deviation 5.16 mph, the 85th percentile speed 77 mph, the median speed 72 mph, which translates to a speed variance of 5 mph.

The simulation was created to measure the number of interactions between vehicles (vehicles passing or being passed). Speed variance has been linked to the increase in two-vehicle crashes. On a highway where the posted uniform speed limit was 70 mph, the frequency of interactions between a vehicle with another vehicle traveling 10 mph below the speed limit was 227% greater than the interactions encountered with vehicles traveling the average speed. On the other hand, the percent of interactions between vehicles encountering another traveling 10 mph above the average speed limit were 90.67% greater. [8]

A comprehensive literature review of CLRS experience in United States is summarized in a 2013 LACCEI paper by Colucci and Rivera [9].

III. Spot Speed Studies (SSS)

A spot speed analysis is performed to determine the distribution of speeds of the vehicles over a specific location of highway. This analysis is conducted for several studies, but the most relevant includes evaluating the effectiveness of traffic control devices, evaluating the effect of speed on highway safety, and in determining speed trends [9].

Two methods were used to perform the spot speed studies (SSS) of vehicles inside and outside of the segment treated with CLRS namely, radar gun technology and the installation of pneumatic tubes. The manner the speed studies were conducted are described below. Figure 5 demonstrates the locations where the studies were performed using the two methods.

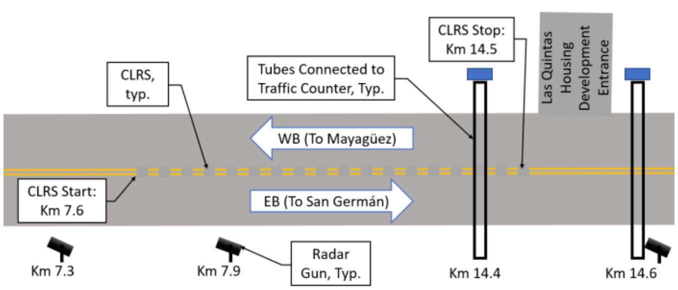


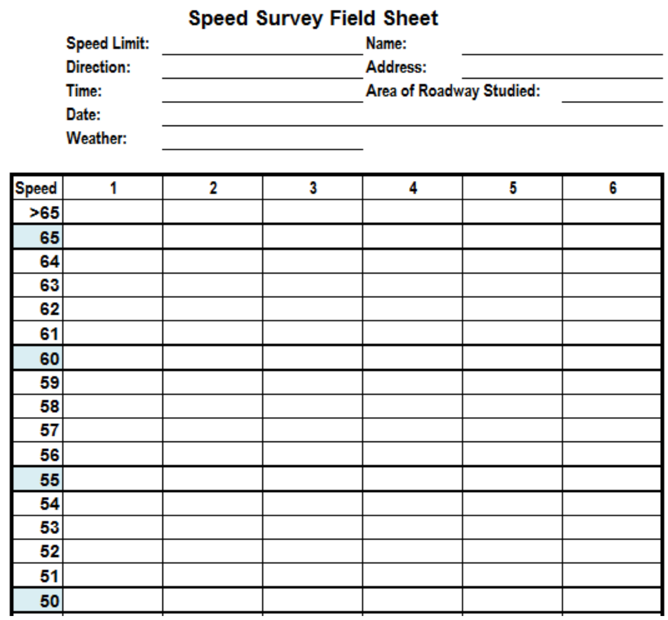
Fig. 5 PR-114 Spot Speed Studies – Data Collection Locations, Not to Scale

A. *Radar Gun Technology*

The radar gun method was chosen for the convenience of going to the site for collecting sufficient speed data at a given location within an hour, without the need of interrupting traffic flow and unnecessary lane closures. The SSS was performed using a ProLaser III radar speed gun as illustrated in Figure 6 [9].

Fig. 6 Pro Laser III Speed Radar Gun Front and Back Views. Image Source: ProLaser4.com [10]

The ProLaser III speed radar gun uses lidar technology, high frequency light waves that are focused into a narrow beam allowing an accurate reading of the vehicle once the trigger is pulled. Hundreds of light pulses are emitted per second, and when the laser pulse is reflected back, the timer is stopped, and the speed is calculated. The speed reading then appears on the two displays. The reading was then manually recorded using a speed survey field sheet, as shown in Figure 7.



Speed Survey Field Sheet

Speed Limit: ____ Name: ____
Direction: ____ Address: ____
Time: ____ Area of Roadway Studied: ____
Date: ____
Weather: ____

Speed	1	2	3	4	5	6
>65						
65						
64						
63						
62						
61						
60						
59						
58						
57						
56						
55						
54						
53						
52						
51						
50						

Figure 7. Sample of Speed Survey Field Sheet for Radar Gun SSS.

B. *Pneumatic Tubes*

The pneumatic tubes alternative was chosen for the speed study for the benefit of not having to be present while the traffic counters collected the data, and depending on the length of time in place, the ability to collect a large quantity of data. The pneumatic tube SSS also allowed data collection during nighttime and daytime determined by sunrise and sunset. Sunrise occurred at 6:30 am and the sun set at 6:00 pm. The spot speed study pneumatic tube configuration is illustrated in Figure 5.

The challenges associated with using pneumatic tube method for the SSS are the permissions required to be obtained from the state highway agencies that have jurisdiction on the highway prior to installing the tubes. The road was a "state" owned road, so permission was required from the Puerto Rico Department of Transportation and Public Works (DTPW), another permission from the regional DTPW office, insurance coverage, and permissions and coordination with the police from the two jurisdictions that the project covers to ensure the safety of all during the placement of the tubes.

A team of students, volunteers from the student chapter of the Institute of Transportation Engineers (ITE) at UPRM, assisted with the field study. Two pneumatic tubes are laid across the road, perpendicular to the lane striping. A pre-measured ruler was created and used to maintain a consistent 1 meter spacing between the tubes. The tubes were fastened with tie-downs nailed into the asphalt at each end while ensuring non-interference with the air flow of the tube. Each tube was secured with mastic tape throughout its length and then connected to a traffic counter. The speed of the passing vehicle is calculated by taking the difference in time from the moment the front wheels strikes the first tube, sending a pulse of air to the counter, to the time the front tires hit the second tube. Then the counter can calculate the velocities of the vehicles using the distance between the tubes that was entered into the software.

Metro Count Traffic counters from the UPRM transportation lab were used for this study and were calibrated before the date of the tube installation. The tubes were placed in at kilometers 14.4 (with CLRS) and 14.6 (without CLRS). To test the tubes for leaks, the tubes were inspected visually and by striking the tube with a hammer while one person held the tube end to their ear to hear and feel the air. All the tubes were tested and considered functional for the study. The pre-calibrated traffic counters were then connected to the tubes. The counters were checked to make sure they were recording data. When the vehicles passed over the tubes, the counters' lights blinked which indicated that data were being recorded.

The counters were programmed to collect data by direction. By analyzing the speeds of the vehicles by direction, the speeds of the vehicles entering and exiting the CLRS can still be compared. In this study, the westbound vehicles were entering the CLRS segment and eastbound, exiting.

C. Data Collection

A spot speed analysis was performed to determine the distribution of speeds of the vehicles in along a segment of PR-114. The speeds were collected on a weekday, specifically on a Tuesday, Wednesday, and/or Thursday. Holidays, scheduled events or road construction were not factors during this data collection. The weather during these days was mostly dry and sunny to partly sunny with an afternoon passing shower of less than 1 hour of duration, very typical of that region of Puerto Rico.

The mean speed, or the average speed, of the vehicles were determined using the following equation, which is the sum of all the spot speeds obtained divided by the number of recorded speeds.

$$\bar{u} = \frac{\sum u_i}{N} \tag{1}$$

where:
$\bar{u}$= arithmetic mean,
u_i = mid-value for the i^{th} speed group, and
N = number of observed values.

In addition to finding the average speed, the 85th, 90th and 95th percentile were determined. The 85th percentile, which is the speed at which 85% of the vehicles travel below, and is the value used to determine speeding characteristics. The 90th and 95th percentile speeds were calculated to determine the top 10% and 5% speeding velocities, respectively. Fig. 8 is an example of a cumulative distribution curve used to determine the percentile speeds [12].

In order to get a representative sample for the spot speed analysis, the minimum sample size required was determined by using equation 2. The assumption made in calculating the minimum sample size in this manner is that the speed distribution follows a normal bell curve [12].

$$N = \left(\frac{Z\sigma}{d}\right)^2 \tag{2}$$

where:
Z= 1.96 (for a 95% confidence level),
σ=standard deviation (mph), and
d= limit of acceptable error in the average speed estimate (mph).

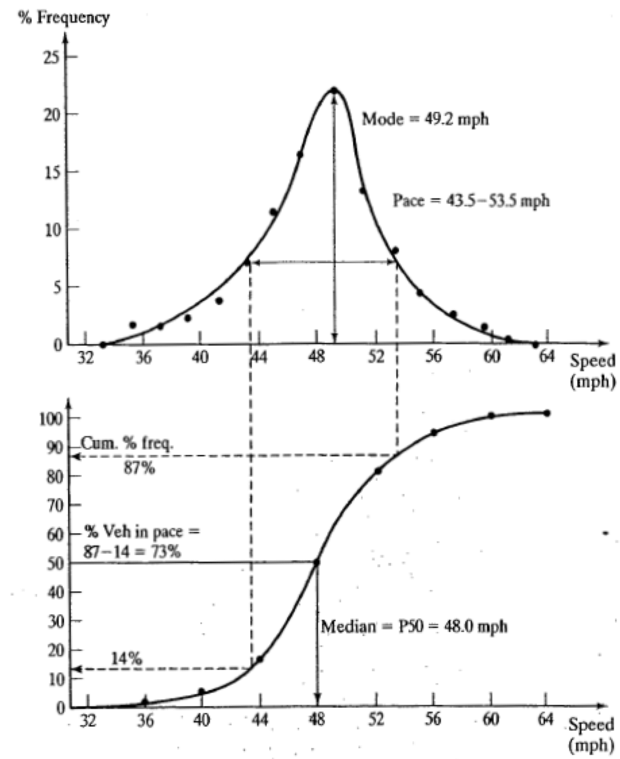


Fig. **8 Frequency and Cumulative Frequency Distribution Curves [12].**

The standard deviation was calculated using equation 3 below. The standard deviation is a measure of the spread of the individual speeds recorded.

$$S = \sqrt{\frac{\sum(u_j - \bar{u})}{N-1}} \tag{3}$$

where:
S = standard deviation,
$\bar{u}$ = arithmetic mean,
u_j = j^{th} observation, and
N= number of observations.

Assuming a standard deviation, σ, of 5 mph and an acceptable error, d, of 1.5 mph, the minimum sample size of 43 speeds were required. In the case that the standard deviation was assumed lower than the actual spread, a larger sample size, of approximately 100, was collected at each collection point.

1) Pneumatic Tube SSS Data Collection

The pneumatic tube SSS collected data from Monday, October 24 through Friday, October 28, 2016, although only the data from Tuesday through Thursday was used for the speed analysis. These days were considered most representative of the week. During the days of data collection, school was in session and there were no reported festivals or activities in the region. The data with a minimum of 5 second headway, the time spacing between vehicles, were used to ensure that only free-flow speed data was analyzed. The weather during the analysis days was mostly sunny and clear, except for Tuesday around noon when there were thundershowers, and Thursday from 2 pm – 5pm, also with thundershowers or light rain.

After the spot speed studies, the analysis of the data returned a standard deviation ranging from 4.12 to 7.28. Recalculating the minimum standard size needed for a standard deviation of 7.28 returns a minimum sample size of 90.5. The 100-sample size preference exceeds the minimum sample size required for the highest standard deviation obtained in the pneumatic tube SSS.

2) *Radar SSS Data Collection*

The radar gun SSS was taken on Thursday, February 2, 2017 at km 7.3, 7.9, and 14.6. Speeds were re-recorded at km 14.6 and the additional data collection at km 14.6 was used as verification between the two collection methods. During the data collection of speeds at km 14.6, it was noticed that cars began to hit their brakes after km 14.6 due to the road's Y-intersection with PR-102 and PR-318**.** Therefore, additional data was collected at km 7.3 and 7.9 at the other terminus of the CLRS.

Before recording speed readings at each location, the gun performed self-tests for internal and external memory, the configuration of the programmable options, the accuracy test to verify the range and speed determination are operational, and a program memory test. Once the radar passes the self-tests, several distances are measured to calculate the cosine effect of the radar. The cosine effect is the error that is attributed to the angle at which the gun is measuring the speeds with respect to the direction of travel of the vehicle (the center of the lane). This error will cause a speed reading lower than the actual speed. The greater the angle between the radar gun and the traffic, the greater the cosine error. (See Table 3)

TABLE 3
PROLASER III COSINE ERROR GUIDELINES

Angle (degrees, °)	Cosine Error (Percent, %)
<5.7	<1/2
<8.0	<1
<14.0	<3

The angles calculated at km 7.3 are 2.9° and 5.5° for the WB and EB directions, respectively. Per the guidelines by the manufacturer, this means there is less than 1/2% error for the speeds recorded at km 14.3. For example, a speed reading of 50 mph and a maximum error of 0.25 mph, which would mean the actual speed was 50.25 mph. In km 7.9, the angles were 5.2° and 7.8° for the EB and WB directions, respectively. The WB angle returns a higher cosine error of 1%. For this study, these errors are acceptable and for a vehicle to surpass the 1.5 mph acceptable error used in calculating the sample size, it would have to travel at a speed greater than 150 mph with a 1% cosine error and 300 mph with a 1/2% cosine error.

D. *Data Analysis*

The speed characteristics determined include the average speed, the median speed, the modal speed, the 95th, 90th, and 85th percentile speeds, and the standard deviation of the speeds. The speed tendencies were compared to the posted 35 mph speed limit and by direction of vehicular travel. The pneumatic tube SSS allowed data collection during nighttime and daytime determined by sunrise and sunset. Sunrise occurred at 6:30 am and the sun set at 6:00 pm. Data was collected in four stations along PR-114: two stations, km 7.3 and 14.6, without CLRS and two stations, km. 7.9 and 14.4, within the section treated with CLRS.

1) *Pneumatic Tube SSS Data*

In this analysis, the speeds of drivers entering and exiting the road with CLRS were compared to evaluate the speed tendencies. A tube was installed in two locations: km 14.4 with CLRS, and km 14.6 without CLRS. Vehicles headed westbound are considered to enter the CLRS and vehicles headed eastbound are exiting, as depicted in Figure 9. The average speed at the km 14.4 location (with CLRS) was 40 mph compared to 34 mph at the km. 14.6 location (without CLRS). Evaluating the percentiles, 85% of the vehicles traveled 46 mph and 39 mph or lower going both directions in km 14.4 and 14.6, respectively.

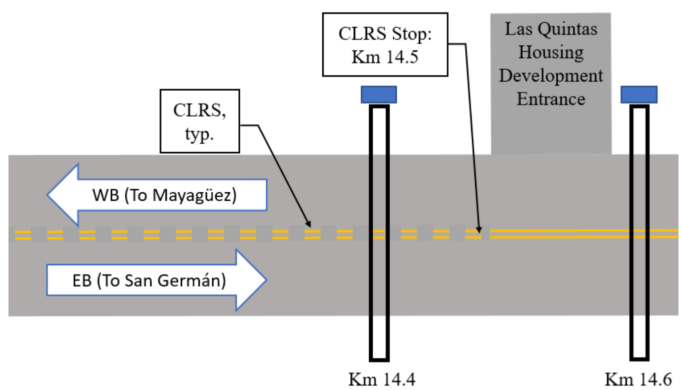


Fig. 9 Detail of Entering & Exiting Vehicles along Study Site.

The data show that the nighttime and daytime mean and 85th percentile speeds are within 1 mph of each other at each location. The speeds of the vehicles exiting the CLRS, going eastbound and hitting the tubes at km 14.4 then 14.6, were analyzed. The mean speed of the eastbound vehicles decreased from 41 to 36 mph, and their 85th percentiles decreased from 46 to 43 mph. In the case of vehicles entering the CLRS and going westbound, the mean speeds at km 14.6 were lower than at km 14.4, 32 to 40 mph, respectively. The 85th percentiles were 36 mph at km 14.6 and 46 mph at km 14.4. A larger percentage of speeds over the posted speed limit were recorded at km 14.4 (82%), as compared with km 14.6 (39%).

TABLE 4
PR-114 SPEED CHARACTERISTICS SUMMARY FOR STUDY WITH PNEUMATIC TUBES

Km	Direction	Mean Speed (mph)	85th Percentile Speed (mph)	Standard Deviation	Coefficient of Variation (CV)	Sample, n
14.4	WB	40	46	6.2	0.16	8674
	WB Day	40	46	5.8	0.15	6529
	WB Night	40	47	5.8	0.18	2145
	EB	41	46	6.1	0.15	7456
	EB Day	41	46	5.8	0.14	5458
	EB Night	40	46	6.8	0.17	1998
14.6	WB	32	36	4.3	0.13	8674
	WB Day	32	36	4.1	0.13	6806
	WB Night	32	37	4.9	0.15	2380
	EB	36	43	6.8	0.19	5832
	EB Day	36	43	6.6	0.18	4385
	EB Night	36	43	7.3	0.20	1447

However, taking into account the location of an entrance to a housing development and an intersection east of the two stations, additional data was collected at the other terminus of the CLRS segment to evaluate the speeds before and after. Figure 10 is an aerial image of the study location that shows the location of the entrance to the housing development relative to where the speeds were collecting using the pneumatic tubes method.

Fig. 10 Google Map Image of SSS Stations Km 14.4 and 14.6.

2) Radar Gun SSS Data

Speed characteristics for radar gun SSS are summarized in Table 5. The mean speeds along km 7.3 and 7.9 are greater than the 35-mph posted speed limit by up to 11 mph, and the 85th percentile speeds by up to 17 mph. The average and 85th percentile speeds recorded within the treated section, km 7.9, were higher by up to 3 mph than the speeds outside of the CLRS at km 7.3. The histograms for km 7.3 and 7.9 are shown in Figures 11 and 12 and depict the range of speeds encountered in that section of PR-114.

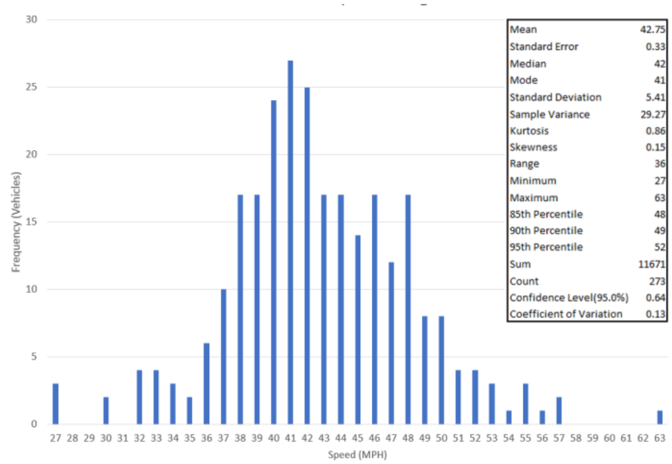


Figure 11 Km 7.3 Speed Histogram

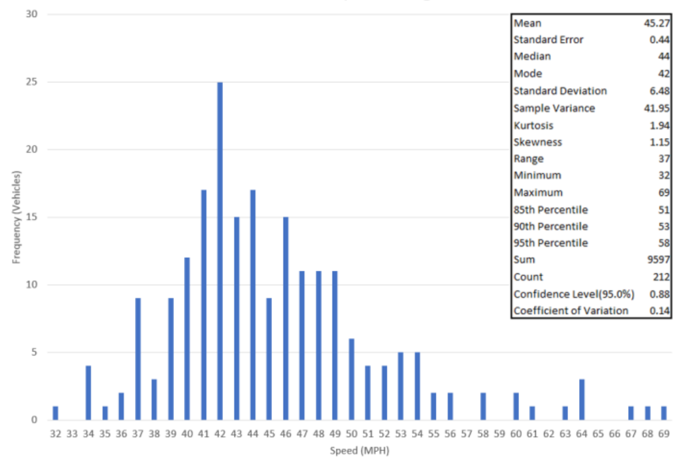


Figure 12 Km 7.9 Speed Histogram

In this SSS scenario, the vehicles entering the CLRS are the vehicles going eastbound, and exiting westbound as depicted in Figure 6. The mean speeds for vehicles exiting the CLRS (westbound) decreased from km 7.9 to 7.3, 45 to 42 mph, respectively. The mean speeds of the vehicles entering the CLRS (eastbound) increased from km 7.3 to 7.9, 43 to 46 mph, respectively. Comparing the mean and 85th percentile speeds by direction, vehicles traveling eastbound were traveling up to 3 mph faster than those traveling westbound.

TABLE 5
SPEED CHARACTERISTICS SUMMARY FOR RADAR GUN SSS

Km	Direction	Mean Speed (mph)	85th Percentile Speed (mph)	Standard Deviation	Coefficient of Variation (CV)	Sample, n
7.3	WB	42	47	5.1	0.12	131
	EB	43	49	5.6	0.13	142
	BOTH	43	48	5.4	0.13	273
7.9	WB	45	49	5.9	0.13	106
	EB	46	52	7	0.15	106
	BOTH	45	51	6.5	0.14	212

The data summarized in Table 6 show the mean and 85th percentile speeds for both SSS methods provides very similar results at km 14.6.

TABLE 6
KM 14.6 RADAR GUN & PNEUMATIC TUBE SSS SUMMARY

Km	Direction	Mean Speed (mph)	85th Percentile Speed (mph)	Standard Deviation	Coefficient of Variation (CV)	Sample, n
14.6 Radar	WB	33	37	4.1	0.12	125
	EB	36	40	4.6	0.13	108
	BOTH	34	39	4.4	0.13	233
14.6 Tubes	WB	32	36	4.3	0.13	9186
	EB	36	43	6.8	0.19	5832
	BOTH	34	39	5.7	0.17	15018

The mean and 85th percentile speeds suggest two things: the posted speed limit of 35 mph is not being obeyed by the majority of drivers, with 85th percentile speeds up to 52 mph and that the posted speed limit should be re-evaluated. The Puerto Rico Law 22 provides a speed limit of 40 mph for rural roads with no signage. In reviewing nationwide CLRS implementation policy and procedures, 3 states require a minimum speed limit of 40 mph, 11 states require a minimum speed limit of 45 mph, and 10 states require a minimum of 50 mph or greater to be considered for CLRS installation.

Although it seems counterintuitive, raising the speed limit can potentially increase the safety of a road where there is an existing large range of speeds. The speeds recorded along km 7.3 and 7.9 ranged from 27 to 69 mph. When there is a large speed range, drivers will feel more inclined to pass slower vehicles, making them prone to head-on and sideswipe crashes. The passing drivers will then position their vehicles further into the opposing lane to prevent hitting the rumble strip throughout the entire passing maneuver.

Since the implementation of the CLRS along PR-114 in 2013, there has been 3 property damage crashes and 2 injury crashes attributed to improper passing/ driving against traffic in 2014 and 2015, and another 8 injury crashes attributed to tailgating. Tailgating is the act of following the vehicle in front too closely, as a consequence of the presence of too many slow-moving vehicles in the roadway. Raising the speed limit alone is not recommended. In addition to raising the speed limit to 40 mph, it is recommended that enforcement play an active role to discourage speeding.

IV. CONCLUSIONS

The primary conclusions associated with the CLRS research project are summarized below:

- Speeds recorded at the San Germán terminus of the CLRS (km 14.5) were lower than speeds recorded near the Hormigueros end of the CLRS (km 7.6); however, the location of an entrance to a housing development is a probable factor for the lower speeds recorded.
- Evaluating the other terminus of the treated section, increases in average speed within the CLRS by up to 3 mph were recorded. Factors to consider include the long tangent of 2.3 km and smooth pavement.
- The road's narrow 10 feet lane width and roadside vegetation do not seem to deter speeding. Local drivers become accustomed to narrow roads. The road width and roadside does not have the same effect on driving speed as it would a tourist or other drivers not from the area.
- Vehicles traveling eastbound traveled on an average 3 mph greater than the opposing traffic. Eastbound destinations include Universities and tourist attractions.
- The 35-mph posted speed limit was exceeded at both km 14.3 and 14.6 locations by up to 11 mph for mean speeds and 17 mph for 85th percentile speeds and the speeds recorded ranged from 27 to 69 mph. There is a speeding problem and speed reduction techniques should be considered in addition to increased law enforcement.
- Addressing the speeding problem will help reduce the total number of crashes, especially rear-end and ROR, since reducing speeds will allow more reaction time for drivers to respond to unexpected situations on the road.

V. RECOMMENDATIONS

Based on the spot speed studies and an observational study documented on a previous LACCEI report [9], the following recommendations are made:

- Spot Speed Studies is a transportation engineering tool that can be used to assess the effectiveness of centerline rumble strips (CLRS) in rural roads.
- The posted 35 mph speed limit should be raised in order to decrease the large speed range associated with serious and fatal crashes. This is due to the fact that when there is a large range of speeds, driver's will feel more inclined to pass slower vehicles, making them prone to head-on and sideswipe same direction crashes.
- A detailed engineering study is recommended for reevaluating the posted speed limit.
- To raise the speed limit to 40 mph, depending on the findings of the detailed engineering study, combined with police enforcement during the first three months of implementation.

VI. EXPECTED BENEFITS

Finally, the findings of this research project will benefit Puerto Rico Highway and Transportation Authority and other State highway agencies that are in the process of considering implementing CLRS as a safety countermeasure for rural roads. Furthermore, the research findings can assist in improving future CLRS designs integrated with adequate signage following the Manual on Uniform Traffic Control Devices (MUTCD) [15], thus having the potential of reducing serious injuries and fatalities, and supporting the goals and objectives of the Puerto Rico Strategic Highway Safety Plan (SHSP) [16].

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