

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

Yanira Rivera, MSCE Candidate, Benjamín Colucci, PhD, Fabiola E. Buitrago, PhD, Enrique González, PhD  
University of Puerto Rico at Mayagüez, Puerto Rico, yanira.rivera4@upr.edu, benjamin.colucci1@upr.edu,  
fabiola.buitrago@upr.edu, enrique.gonzalez1@upr.edu

## 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 methodology includes a comprehensive literature review of CLRS, its policies, standards, and guidelines in the United States, a before-and-after study, spot speed analyses, and an observational analysis of the treated segment of PR-114. Transportation studies include spot speed analyses, crash data analysis, and observational studies. The primary focus of this paper is on the spot speed analysis of vehicles inside and outside of the segment treated with CLRS.*

*The findings of this research are 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 was exceeded at both km 14.3 and 14.6 locations by up to 11 mph for mean speeds and 17 mph for 85<sup>th</sup> percentile speeds and the speeds recorded ranged from 27 to 68 mph. This suggests that the posted speed limit should be re-evaluated to be raised in order to decrease the large speed differential associated with serious and fatal crashes. When there is a large speed differential, 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.*

*Finally, raising the speed limit to 40 or 45 mph is recommended combined with police enforcement during the first three months of implementation.*

**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. CLRS considered to be a cost-effective alternative in the prevention of ROR crashes, specifically head-on and opposite direction sideswipe crashes [1,2,3,4]. 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 the safety of the roadways, 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 [1]. 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)[14]. In 2013, 41% of total traffic fatalities were attributed to ROR crashes. Among the top contributing circumstances noted for the cause of these types of collisions were "driver lost control" and "exceeded speed limit".

## II. LITERATURE REVIEW

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 2004 to 2013. 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 1.82 fatalities per million vehicle miles traveled (MVMT) in 2011, 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 [2]. 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.

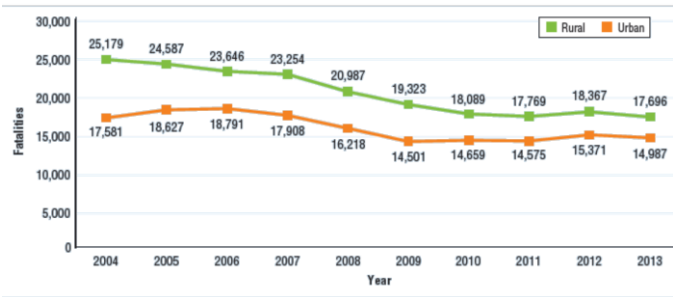


Fig. 1 Motor Vehicle Traffic Fatalities by Year in Location (2004-2013)  
Source: FARS Annual Report File (NHTSA, 2015)

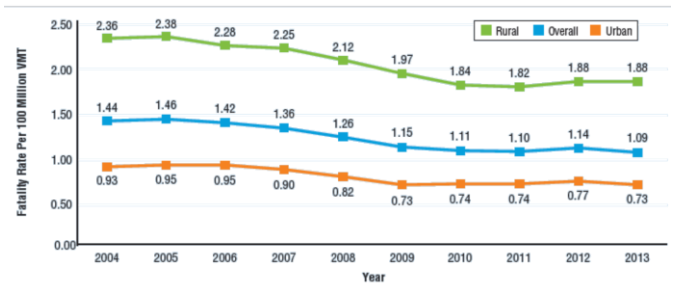


Fig. 2 Fatality Rates per 100 MVMT by Year and Location (2004 -2013)  
Sources: FARS Annual Report File; VMT-FHWA [2]

### 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)[3] 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, in which the grooves milled along the centerline cause vibration and noise alerting the driver 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.

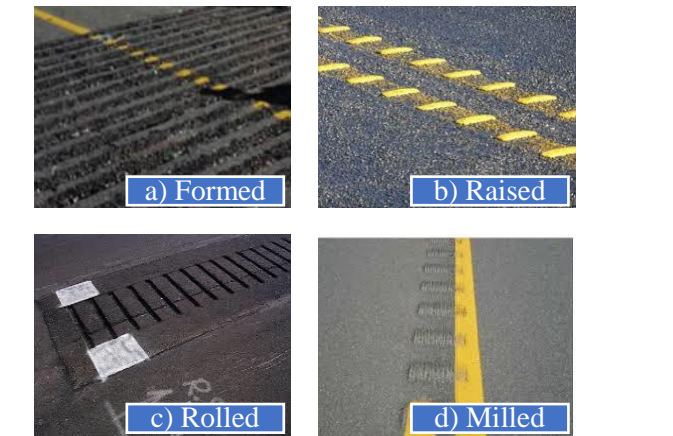


Fig. 3 Rumble Strip Types [3]  
Image Sources: a) www.brp.co.za; b) driverknowledgetests.com; c) www.dot.ca.gov; d) fhwa.dot.gov

The CLRS dimensions recommended by the Federal Highway Administration (FHWA) are published in the Technical Advisory T5040.40 and reproduced in Figure 4.[3]

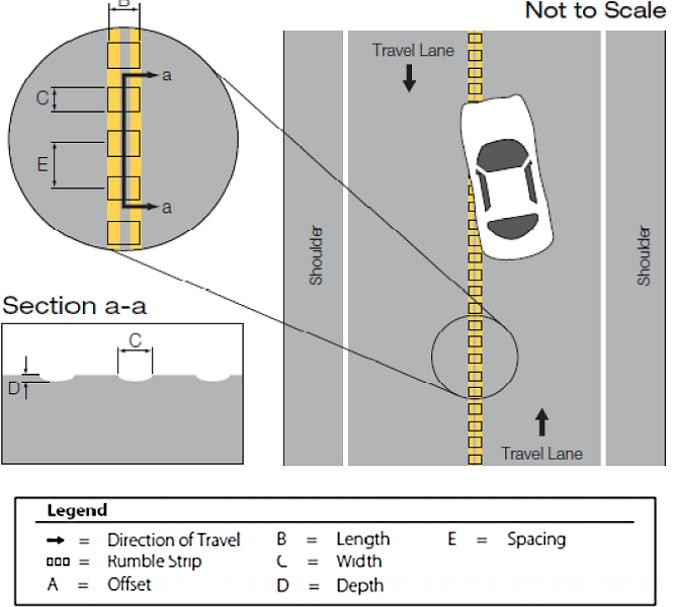


Fig. 4 CLRS Dimensions [3]

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. 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 [4]. That 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" [5]. 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 [5].

**Table 1 Michigan DOT CLRS "Before & After" Research Findings by Corrected Crash Type [5]**

CORRECTED CRASH TYPE	THREE-YEAR TARGET CRASH FREQUENCY		PERCENT REDUCTION IN TARGET CRASHES	STATISTICALLY 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

In FHWA's informational report: *Methods and Practices for Setting Speed Limits* [6], four general approaches in setting speed limits are defined:

1. **Engineering Approach** – Where a base speed limit is set according to the 85<sup>th</sup> 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 to 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 85<sup>th</sup> 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 100-sample size 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 because it 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 85<sup>th</sup> percentile speed. At this speed, it is considered to yield the lowest crash risk. [6] 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 85<sup>th</sup> 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 85<sup>th</sup> percentile, and traffic engineers say agencies set limits by the 85<sup>th</sup> percentile, in actuality speed limits are set lower, and in many cases lower than the 50<sup>th</sup> percentile speed. It was found that these lower speed limits were set due to political pressures, however setting the speed limit below the 85<sup>th</sup> percentile has not been found to increase speed limit compliance. [6]

Another method under the engineering approach is the road risk method, where the base speed limit is based off the 85<sup>th</sup> 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. [6]

**Table 2 Base Speeds by Road Class and Land Use for Canada Roads [6]**

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

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 85<sup>th</sup> 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. [4]

A comprehensive literature review of CLRS experience in United States is summarized in a 2013 LACCEI paper by Colucci and Rivera[7].

### III. SPOT SPEED STUDIES (SSS)

Two methods were used to perform a 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 speeds studies were conducted are described below.

#### 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 5 [8].



Fig. 5 Pro Laser III Speed Radar Gun Front and Back Views.  
Image Source: ProLaser4.com [8]

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 Table 3.

**Table 2 Speed Survey Field Sheet for Radar Gun SSS**

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						

#### 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 collect the data, and depending on the length of time in place, the ability to collect a large quantity of data. The spot speed study pneumatic tube configuration is illustrated in Figure 6.

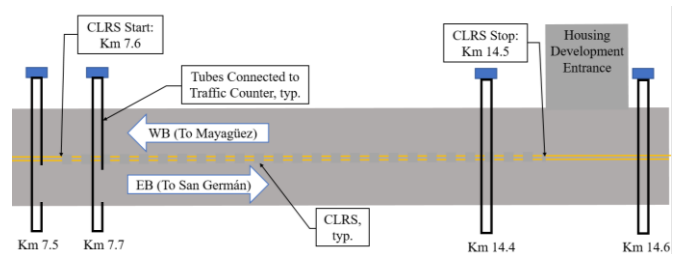


Fig. 6 PR-114 Spot Speed Study Pneumatic Tube Configuration.

The challenges associated with the SSS using pneumatic tube method are the permissions required to be obtained from the state highway agencies that has jurisdiction on the highway prior to installing the tubes on the particular segment of the road. The road was a “state” owned road, so permission was required from the Puerto Rico Department of Transportation and Public Works (DTPW), a 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. At the time of the study new tubes with mounting hardware were not available, therefore used tubes from the transportation lab were used. 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 are fastened with tie-downs nailed into the asphalt at each end while ensuring not to interfere with the air flow of the tube and secured with mastic tape throughout its length. Each tube is 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 and the front tires hitting the second tube. Then with the programmed distance between the tubes, the counter can calculate the velocities of the vehicles.

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 four locations: kilometers 7.5, 7.7 14.4, and 14.6. To test the tube 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, however the vehicles passed over the tubes and the counters' lights did not blink which indicates that data is being recorded. Since the batteries were new, it was concluded that there was an issue with the calibration of the counter. The counters were taken back to the University during the week and recalibrated. Within the week between the installation of the tubes and the day the recalibrated counters were installed, two of the tubes, km 7.5 and 7.7 were damaged as shown in Figure 7.



Fig. 7 PR-114 SSS Broken Pneumatic Tubes.  
A) Km 7.5 Westbound B) Km 7.7.

Since the counters were programmed to collect data by direction, it was decided to install the counters in the remaining two locations, km 14.4 and 14.6. 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 are entering the CLRS segment and eastbound, exiting.

### C. Data Collection

The speeds were collected from Tuesday, October 25, 2016 through Thursday, October 27, 2016. 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. Holidays, scheduled

events or road construction were not factors during this data collection. The data collected from these two stations were analyzed and it was determined that additional speed data were needed.

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 in 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 4)

TABLE 4  
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.

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].

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.

$$\bar{u} = \frac{\sum u_i}{N} \quad (1)$$

where:

$\bar{u}$  = arithmetic mean,

$u_i$  = mid-value for the  $i^{\text{th}}$  speed group, and

$N$  = number of observed values.

In addition to finding the average speed, the 85<sup>th</sup>, 90<sup>th</sup> and 95<sup>th</sup> percentile were determined. The 85<sup>th</sup> percentile, which is the speed at which 85% of the vehicles travel below, and is the value used to determine speeding characteristics. The 90<sup>th</sup> and 95<sup>th</sup> 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 [10].

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 [10].

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

where:

$Z = 1.96$  (for a 95% confidence level),

$\sigma$  = standard deviation (mph), and

$d$  = limit of acceptable error in the average speed estimate (mph).

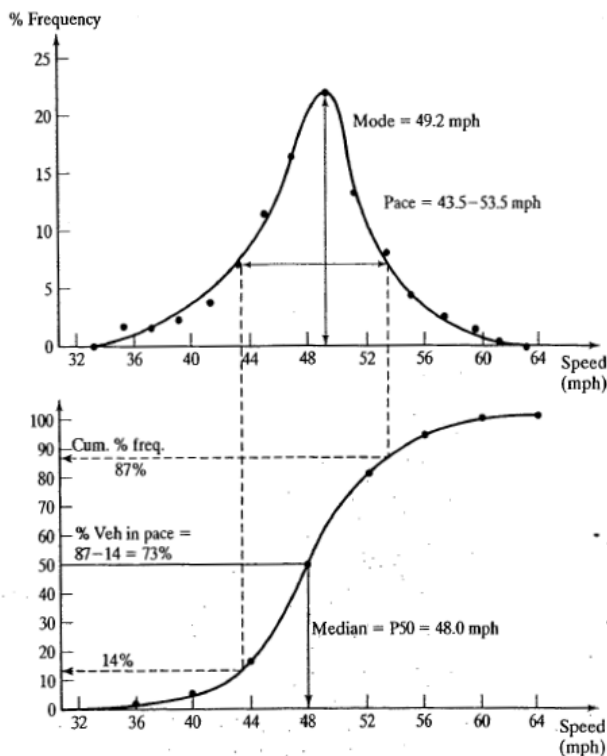


Fig. 8 Frequency and Cumulative Frequency Distribution Curves.[10]

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

$$S = \sqrt{\frac{\sum(u_j - \bar{u})^2}{N-1}} \quad (3)$$

where:

$S$  = standard deviation,

$\bar{u}$  = arithmetic mean,

$u_j = j^{\text{th}}$  observation, and

$N$  = number of observations.

Assuming a standard deviation,  $\sigma$ , of 5 mph and an acceptable error,  $d$ , of 1.5 mph, the minimum sample size required is 43. 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. After the pneumatic tube study, 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.

The spot speed study was performed using pneumatic tubes connected to a Metro Count traffic counter. Data was collected from Monday, October 24 through Friday, October 28, 2016, however 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.

#### A. PR-114 Speed Characteristics

The speed characteristics determined include the average speed, the median speed, the modal speed, the 95<sup>th</sup>, 90<sup>th</sup>, and 85<sup>th</sup> percentile speeds, the standard deviation of the speeds, and the sample size. The speed tendencies will then be compared to the posted 35 mph speed limit and it will be determined if the difference is significant at the 95 percent confidence level.

#### B. CLRS Entrance & Exit Speed Comparison

In this analysis, the speeds of drivers entering and exiting the road with CLRS were compared to evaluate the speed tendencies. Vehicles headed westbound are considering entering the CLRS and vehicles headed eastbound are exiting, as depicted in Figure 9. The average speed at the km 14.4 location was 40 mph compared to 34 mph at the km. 14.6 location, a significant difference up to a 95% level of confidence. 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.

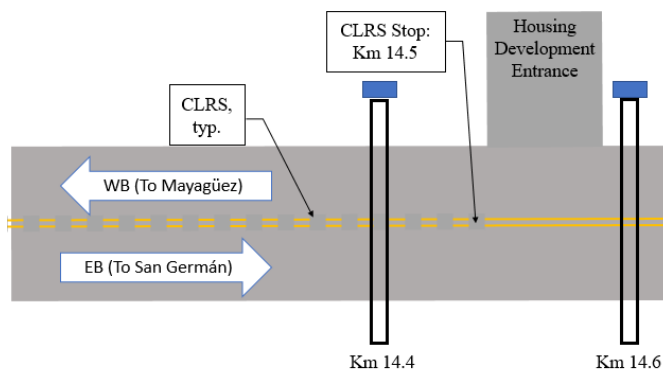


Fig. 9 Detail of Entering & Exiting Vehicles along Study Site.

Based on the speed characteristics collected with pneumatic tubes, summarized in Table 5, 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 5**  
**PR-114 SPEED CHARACTERISTICS SUMMARY FOR STUDY WITH PNEUMATIC TUBES**

Km	Pneumatic Tube SSS Results											
	14.4	14.4	14.4	14.4	14.4	14.4	14.6	14.6	14.6	14.6	14.6	14.6
Direction	WB	WB	WB	EB	EB	EB	WB	WB	WB	EB	EB	EB
	Day	Night		Day	Night		Day	Night		Day	Night	
Mean Speed (mph)	40	40	40	41	41	40	32	32	32	36	36	36
85th Percentile Speed (mph)	46	46	47	46	46	46	36	36	37	43	43	43
Standard Deviation	6.2	5.8	5.8	6.1	5.8	6.8	4.3	4.1	4.9	6.8	6.6	7.3
Coefficient of Variation (CV)	0.16	0.15	0.18	0.15	0.14	0.17	0.13	0.13	0.15	0.19	0.18	0.20
Sample, n	8674	6529	2145	7456	5458	1998	8674	6806	2380	5832	4385	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. This was decided for the reason advised in the literature review, to ensure that the speed data is collected at a location with a sufficient distance from intersections or other accesses because accelerating and decelerating vehicles can affect the speed profile. 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.

Another 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 to with the intent of collecting additional speeds at km 4.61, the distance predetermined to not be influenced by the development entrance, and the km 14.6 was to be used as verification between the two collection methods. During the data collection of speeds in km 14.6, it was noticed that cars began to hit their brakes around km 14.61 due to the road's Y-intersection with PR-102 and PR-318, therefore no data was collected at km 14.61, and instead collected at km 7.3 and 7.9 at the other terminus of the CLRS. Speed characteristics for radar gun SSS are summarized in Table 6. The mean speeds along km 7.3 and 7.6 are greater than the 35 mph posted speed limit by up to 11 mph, and the 85<sup>th</sup> percentile speeds by up to 17 mph. The average and 8<sup>th</sup> 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. Comparing the mean and 85<sup>th</sup> percentile speeds by direction, vehicles traveling EB were traveling up to 2 mph faster than those traveling the opposite direction.

**TABLE 6**  
**SPEED CHARACTERISTICS SUMMARY FOR RADAR GUN SSS**

Km	Radar Gun SSS								
	7.3	7.3	7.3	7.9	7.9	7.9	14.6	14.6	14.6
Direction	WB	EB	BOTH	WB	EB	BOTH	WB	EB	BOTH
Mean Speed (mph)	42	43	43	45	46	45	33.4	35.5	34.4
85th Percentile Speed (mph)	47	49	48	49	52	51	37	40	39
Standard Deviation	5.1	5.6	5.4	5.9	7	6.5	4.1	4.6	4.4
Coefficient of Variation (CV)	0.12	0.13	0.13	0.13	0.15	0.14	0.12	0.13	0.13
Sample, n	131	142	273	106	106	212	125	108	233

The mean and 85<sup>th</sup> percentile speeds suggest two things: the posted speed limit of 35 mph is not being obeyed by the majority of drivers, with 85<sup>th</sup> 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 speed differential. The speeds recorded along km 7.3 and 7.9 ranged from 27 to 68 mph. When there is a large speed differential, drivers will feel more inclined to pass slower vehicles, making them prone to head-on and sideswipe crashes. The passing driver will then position their vehicle further into the opposing lane to prevent hitting the rumbles throughout the entire passing maneuver.



Fig. 11 Passing Maneuver Around Vehicle Going the Speed Limit on PR-114

Since the implementation of the CLRS along PR-114 in 2013, there have 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 too closely to a vehicle in front, one of the possible reasons are slow moving vehicles. Raising the speed limit alone is not recommended. In addition to raising the speed limit to either 40 or 45 mph, it is recommended that enforcement play an active role to discourage speeding.

#### D. CONCLUSIONS

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

- 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 major benefits of CLRS were detected with a combination spot speed and observation studies, in terms of significant reduction in opposite lane passing maneuver, and reduction in the standard deviation of speed in both eastbound and westbound directions.
- Increases in average speed within the CLRS by up to 3 mph were recorded.
- Vehicles traveling eastbound traveled on an average 2 mph greater than the opposing traffic.
- 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 85<sup>th</sup> percentile speeds and the speeds recorded ranged from 27 to 68 mph.

#### E. RECOMMENDATIONS

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

- The posted 35 mph speed limit should be re-evaluated to be raised in order to decrease the large speed differential associated with serious and fatal crashes. This is due to the fact that when there is a large speed variance and range, driver's 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.
- To raise the speed limit to 40 or 45 mph combined with police enforcement during the first three months of implementation.
- In section of road with 2 narrow bridges, km 12.0, use a speed zone with lower speed limit, or a "narrow bridge ahead" (W5-2) warning sign.

#### F. 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 countermeasures 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) [13], 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) [14].

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