

PAPER • OPEN ACCESS

Vehicle Lateral Wander Measures Using Ultrasonic Sensors

To cite this article: E Oconitrillo-Varela *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **844** 012072

View the [article online](#) for updates and enhancements.

Vehicle Lateral Wander Measures Using Ultrasonic Sensors

E Oconitrillo-Varela, H Hernández-Vega and J P Aguiar-Moya

Laboratorio Nacional de Materiales y Modelos Estructurales, Escuela de Ingeniería Civil, Universidad de Costa Rica. Ciudad de la Investigación, Finca 2, Apartado Postal: 11501-2060

henry.hernandezvega@ucr.ac.cr

Abstract. This paper evaluates the measurement of vehicle lateral wander using ultrasonic sensors. Measurements were made on different sections of the Costa Rican National Road Network. The recorded data allowed to determine the cumulative frequency distribution, lateral wander data and a confidence interval for the measurements. In some routes, where the sample size is greater than 70 vehicles, the distribution of the lateral wander data adjusted to a normal distribution. However, in several cases the data does not resemble a normal distribution curve, or other distributions reported in the literature. Finally, an Android app was developed to automate the data collection process using the ultrasonic sensor setup, simplifying the measurement process. From the cumulative frequency results, obtained with the ultrasonic sensors, it was determined that most vehicles travel between 50 and 150 cm from the edge of the road. In order to validate the data, the results obtained with the ultrasonic sensor setup were compared with the results obtained by image analysis of video recordings. These image analysis is possible due to pavement markings every five centimeters on the pavement from the lane edge. The results from video recordings and ultrasonic sensors show a high coefficient of correlation.

1. Introduction

After the publication of the Mechanistic-Empirical Pavement Design Guide (MEPDG) [1], its implementation has been pursued in several Latin American countries [2]. One of the input parameters for pavement design is lateral displacement, which is not a parameter that has been extensively studied in the region. Consequently, lateral wander values taken from studies carried out in other countries are usually assumed. Lateral wander is the measurement of how channelized is the traffic traveling through a specific lane [3].

It is possible to adjust the pavement design to the through loading conditions when the real lateral displacement in a section of road is known. Also, the variability associated to the design models can be reduced by using representative field data, improving overall reliability. The accuracy of the measurements represents a key factor because lateral displacement is affected by many variables such as: geometric elements of the road, climatic conditions, traffic, speed, types of vehicles, drivers, among others [4].

It is necessary to determine average values of the lateral displacement in order to generate inputs that can be incorporated into future national pavement guidelines. Furthermore, this research seeks to be a reference for designers to use lateral wander values obtained in Costa Rica, in order to avoid the assumption of values from foreign research, since the University of Costa Rica is currently developing



a pavement design guide, which requires adapted information that considers the specific conditions for the region [5].

In previous research work done in Costa Rica, it has been possible to measure lateral wander by using video recordings and pavement markings, as in the study conducted by [6]. This method is useful; however, it demands long time to process the data if no image analysis automation is used. Furthermore, the precision of this method is about $\pm 6,25$ centimeters.

In other countries, different methods have been developed. Lateral wander has been measured using a carpet of sensors placed on the pavement [3]. Another method consists of using three pneumatic sensors arranged on a Z pattern on the pavement [7]. The researchers were capable of measuring speed, lateral wander and count vehicles. Moreover, this displacement can be measured by video analysis to determine vehicle position on the lane [8]. Other methods consist of placing sensors embedded in the pavement, also in a Z configuration [9]. In general, literature has shown that wandering data follow a normal distribution. However, it was found that only in very specific cases the data collected adjusts to a normal distribution [6].

There is a need to develop new methodologies to obtain this type of data with greater precision, because of the absence of Latin-American studies related to vehicular displacement and the effects of this parameter in different fields of transport engineering. In this research, a method based on ultrasonic measurements is calibrated and validated. The method consists of an ultrasonic sensor controlled by an ArduinoUNO platform that measures distance of the vehicles from the lane edge.

2. Method

This section describes the sensor, how it works and the implementation of the tool.

2.1. Sensor Design

The Arduino tool has increased its popularity due to the benefits of open source hardware/software elements. There are many applications that can benefit from this tool, especially because it allows connecting many devices with relative ease. This application has not been widely applied in transport engineering, although smaller projects with distance sensors has been developed to recognize objects, specially, for home integration.

A description of every module of the prototype is presented below:

a) ArduinoUNO card: free software micro controller, based on the C++ programming language. The device is capable of controlling devices like sensors, lights, LCD screens, Bluetooth, clocks, lasers, GPSs, and others [10].

b) Ultrasonic Sensor HC-SR04: it is a sensor that sends a signal (TRIG) and when the signal hits an object, it is sent back to the sensor (ECHO). The sensor measures the time it takes the signal to return. Because the speed of the signal is known, it is possible to determine the distance from the object to the sensor [10].

c) Real Time Clock (RTC Clock): it works with the satellite time and date, with one calibration of the device it is possible to determine the exact time and date of each measurement.

d) Temperature and humidity sensor: refinements of the readings from the ultrasonic sensor's can be adjusted according to the temperature and humidity recorded.

e) SD Card Module: this module allows the configuration of a SD card in order to store the measurements. The data are saved in a text file, which can be exported to a spreadsheet in order to post-process the results.

f) Bluetooth Module HC-06: this module sends and receives data from/to the ArduinoUNO card. This module was useful to this project because a tablet application was used in order to simultaneously capture the type of vehicle that is measured by the ultrasonic sensor.

Figure 1 shows the different electronic components that were used to produce the prototype used in this study to measure vehicle positioning in the lane.

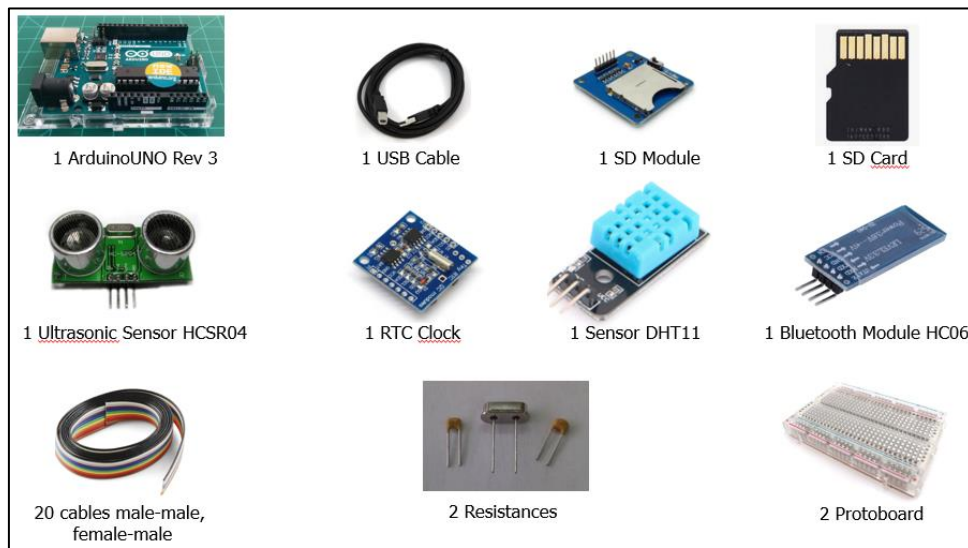


Figure 1. Electronic components necessary to elaborate the vehicular lateral displacement measurements

A code was developed in the Arduino interface using C++ language to control the connection among the devices (sensors, Real Time Clock, SD Card and Bluetooth). It is necessary to specify how the devices are connected to the ArduinoUNO card. The devices must be connected to the Arduino card; figure 2 shows the implemented setup.

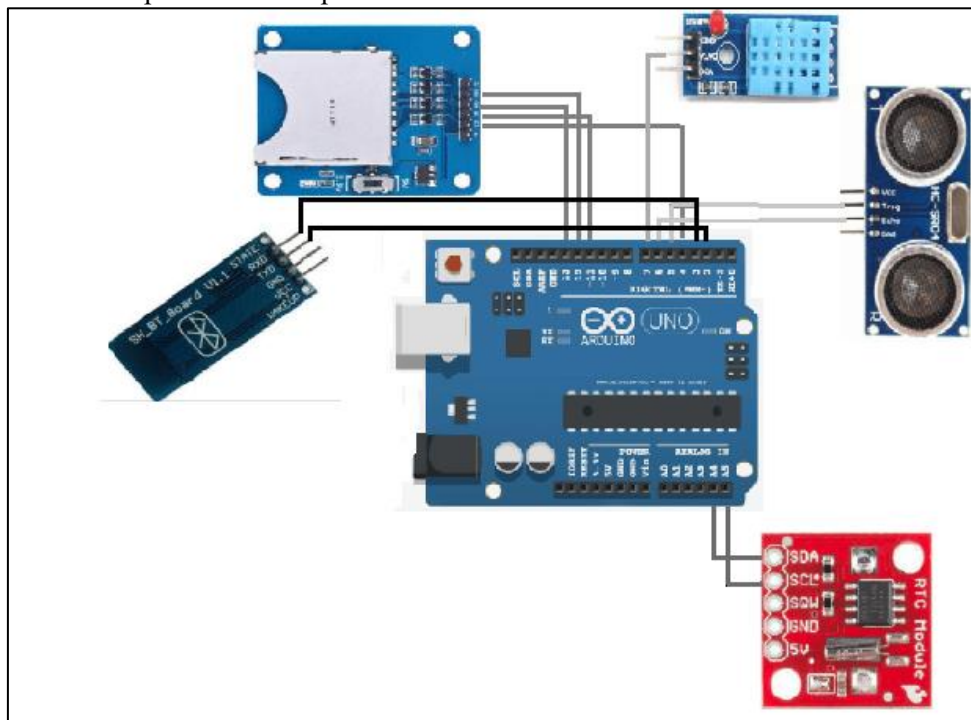


Figure 2. Diagram of modules and sensors connections to ArduinoUNO

2.2. How does it work?

Once the program has been coded and the connections between the different modules and sensors to the ArduinoUNO card are ready, the device is able to proceed performing distance measurements. To

measure distance of the vehicles from the lane edge by the ultrasonic sensor, the following procedure were followed:

- a) Code the controller card: from Arduino Software it is necessary to connect Arduino card to the computer using a USB cable, to download the coded procedure.
- b) Ultrasonic sensor placement: the device must be placed at the road shoulder. The distance between the lane edge and the sensor should be between 30 and 80 centimeters.
- c) Bluetooth connection: in order to classify the vehicles passing through the sensor's measure range, it is necessary to link Arduino to a vehicle classification application (Figure 3 shows the interface of the application developed in this project). The application also shows the distance measurement been recorded by the device.
- d) Measure distance: the sensor is capable of registering every vehicle distance in an SD card. The data must then be downloaded to a computer for further processing.

The vehicles were classified as passenger cars, C2 Bus, C2+, C2, C3, C4, T3S2 and T3S3 as shown in figure 3. Figure 4 shows a schematic of the measuring process.

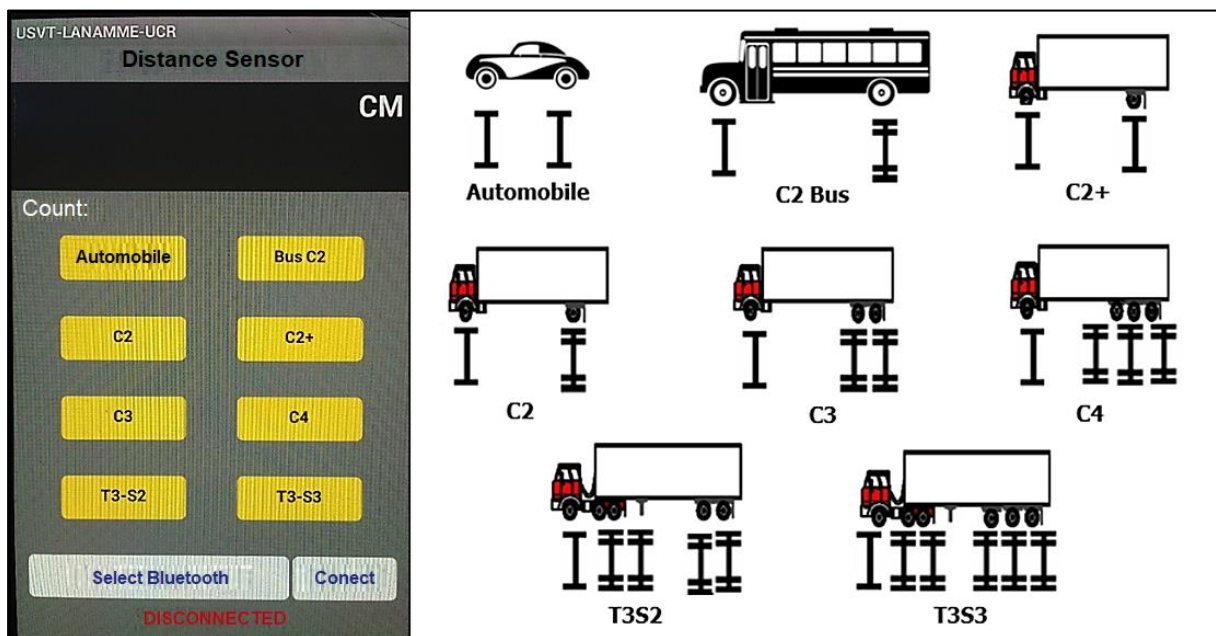


Figure 3. Android application interface (left) and vehicle classification scheme used (right).

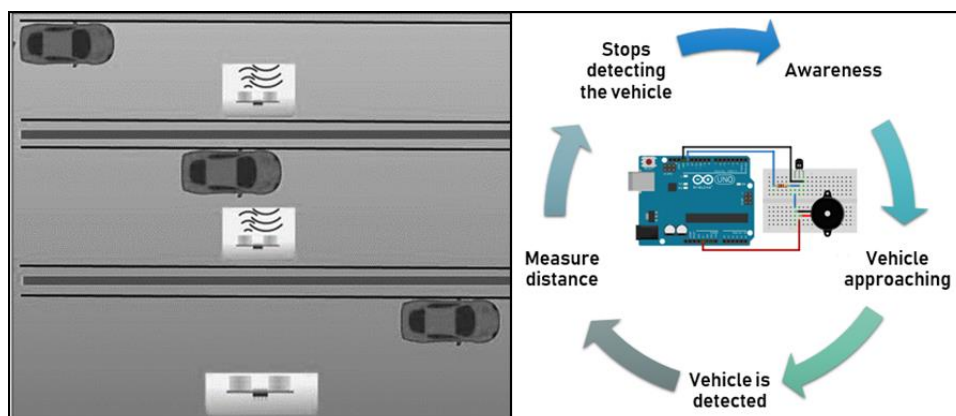


Figure 4. Illustrated process of measure (left) and schematic diagram of distance measure process by an ultrasonic sensor (right)

2.3. Tool implementation

Considering available data from a preceding study [6], six national routes were chosen to test the equipment capability. Every one of the sections had enough previous studies to guarantee a full characterization of traffic behavior in the route based on specific parameters. Some of the parameters are: lane width, shoulder width, operating speed, vehicular classification, average daily traffic, location and others environmental factors. Based on the previous requirements, measurements were made on six routes (see figure 5). Additionally, table 1 shows a summary for every test site.

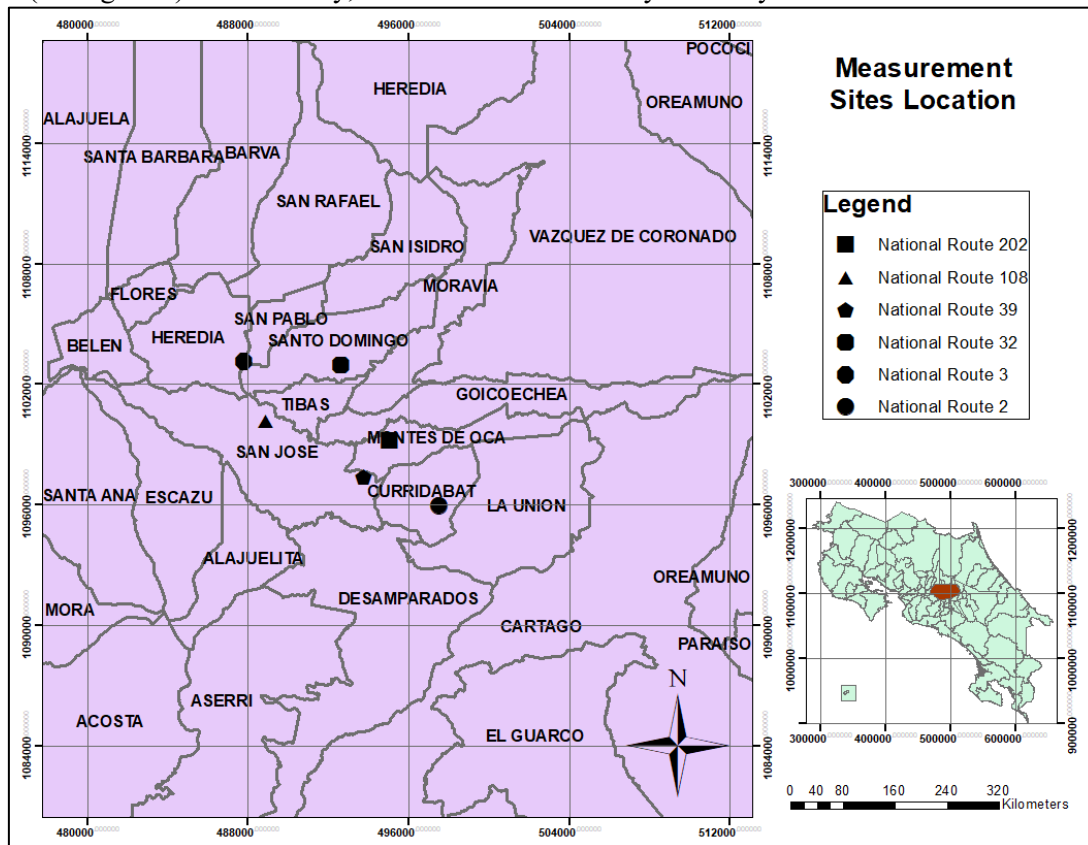


Figure 5. Ultrasonic sensor measurement sites location map

Table 1. Average daily traffic for every route and vehicular composition by vehicle class

Route	2	3	32	39	108	202
Average Daily Traffic (ADT) estimated for 2018	53001	32237	38784	66963	52065	23229
Percentage of passenger cars and motorcycles	68.71	78.79	76.34	84.43	68.61	86.53
Percentage of light Commercial Vehicles	14.65	9.84	11.03	10.51	16.52	8.89
Percentage of buses	4.38	5.38	2.69	0.78	4	2.05
Percentage of two axle trucks	6.65	4.52	3.67	3.22	6.61	2.23
Percentage of three axle trucks	3.23	0.87	0.83	0.51	1.39	0.2
Percentage of trucks with five or more axles	2.38	0.6	5.24	0.55	2.87	0.1

3. Results

3.1. Method validation

The validation of the method was performed by direct comparison to visual measurements of video recordings and the measurements made with the ultrasonic sensor. Figure 6 displays the markings used

for the visual analysis: marks were placed, every five centimeters from the edge of the lane mark, on the pavement. The data from the video recordings were processed by visual inspections in an office environment.



Figure 6. Marks placed on pavement. National Route 32

Figure 7 shows the results of the comparison between the measurements obtained by the ultrasonic sensor and the visual measurements from the video records. The figure demonstrates a high correlation between both methods when used to measure the lateral displacement.

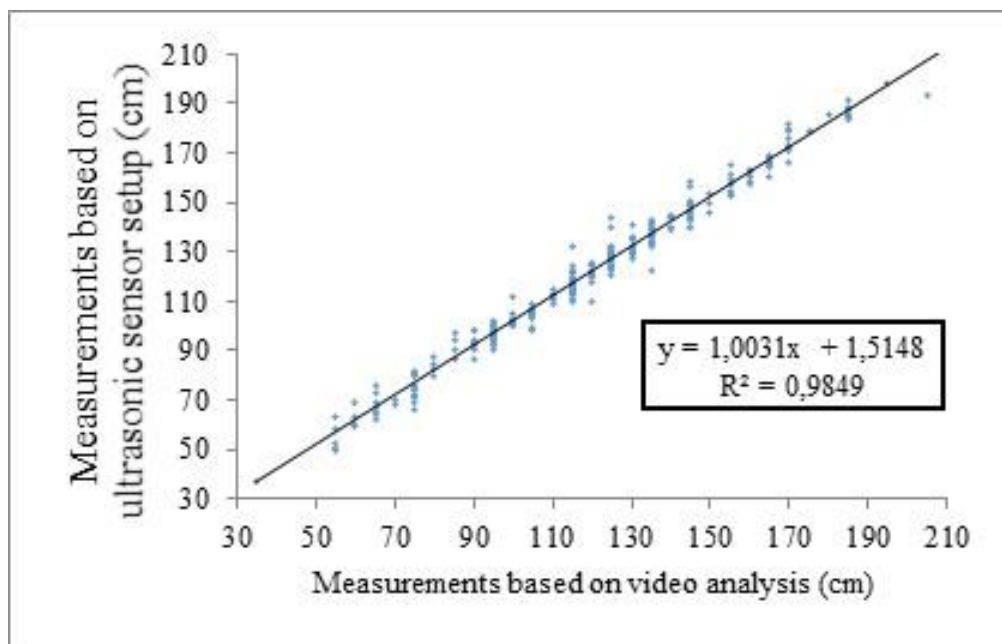


Figure 7. Comparison of measurements obtained by the proposed setup and video analysis (National Route 32, n=262)

The slope coefficient in a linear regression model suggests an almost perfect fit between the ultrasonic method and the visual method ($t\text{-stat} = 127.02$, $p\text{-value} = 5.40 \times 10^{-227}$) indicating that both methods provide similar results. Once the method was validated from the ground truth method, measurements were performed in different sites.

3.2. Lateral wander measurements

Average lateral wander, considering the measurements on all analyzed national routes, is 28.9 cm with a standard error of 0.54. For light vehicles, lateral wander is 31.6 cm with a standard error of 0.68; and for heavy vehicles, is 28.4 cm with a standard error of 1.06. Lateral wander values obtained are consistent with other measurements made in the same routes, by [6]. Some vehicle types present very small sample sizes, considering their small share in total traffic composition and the time dedicated to collect the data for these routes. One device was used at the same time, and the duration of the individual tests varied between two and three hours at each site, and was defined by the run-time of the laptop's battery (a laptop provided the electrical power to the device). Table 2 presents average values for all sites included in the present study.

Table 2. Average lateral wander (Lw) values with the sample size (n) for each vehicle type at each location

Vehicle type		Route						Average	Standard Error
		2	3	32	39	108	202		
Passenger Car	n	388	189	528	591	228	237	31.6	0.68
	Lw (cm)	30.8	32.9	34.9	36.4	24.0	30.6		
C2+	n	50	48	31	66	34	17	32.5	2.07
	Lw (cm)	37.9	34.6	35.7	37.5	20.2	29.0		
C2	n	35	57	37	44	10	14	38.8	2.76
	Lw (cm)	28.5	30.1	55.0	42.7	27.2	49.2		
C3	n	17	11	12	8	-	-	28.2	4.07
	Lw (cm)	28.7	19.6	38.6	25.7	-	-		
Bus	n	37	26	24	7	21	4	26.2	2.40
	Lw (cm)	27.1	37.2	32.1	14.2	21.8	24.8		
T3S2	n	22	6	36	7	10	-	24.3	2.70
	Lw (cm)	17.9	35.5	29.0	23.5	15.7	-		
T3S3	n	9	3	12	-	-	-	20.5	4.18
	Lw (cm)	13.2	21.4	26.8	-	-	-		

Figure 8 shows the lateral wander distribution for truck traffic on the analyzed routes. According to the data obtained, most of the routes exhibit a trend where 50% or more of the measures correspond to a distance less than 100 cm. Only measurements at National Route 202, show 70% of the heavy traffic driving from 100 cm or more from the lane edge. This route has a lane width of 3.7 meters, which is wider than the other analyzed routes where the lane width varies from 3.4 to 3.6 meters.

In order to capture the variability associated to lateral wander, box plots for light vehicles and trucks are shown in figure 9 and figure 10, respectively. Confidence interval is the range in which the average population on national routes for a 95 % level of confidence, it probably locates. For light vehicles, lateral displacement fluctuates from 0.3 to 0.4 meters; except for National Route 108, that shows a lower variation, possibly due to specific geometric and functional conditions of this road. In general, heavy vehicles have lower variability for each route; however, the overall average value differs for each route indicating that it should be considered as a section specific property.

To better characterize the lateral wander data, the distribution for each section was also analyzed. Fit to a given distribution or family of distributions can be made with statistical tests such as Anderson-Darling, Kolmogorov and Ryan Joiner. For each data set at a particular station, the adjustment to a probability distribution was verified. Although the tests can be done for all vehicle classes the analysis

was performed for light and heavy vehicles in order to have an adequate sample size. From the tests, it was confirmed that most of the routes did not adjust to neither the normal or the Laplace probability distribution that were originally considered in this study. Only Route 3, Route 108 (heavy vehicles) and Route 202 (light vehicles) were confirmed that adjust to normal distribution (see table 3).

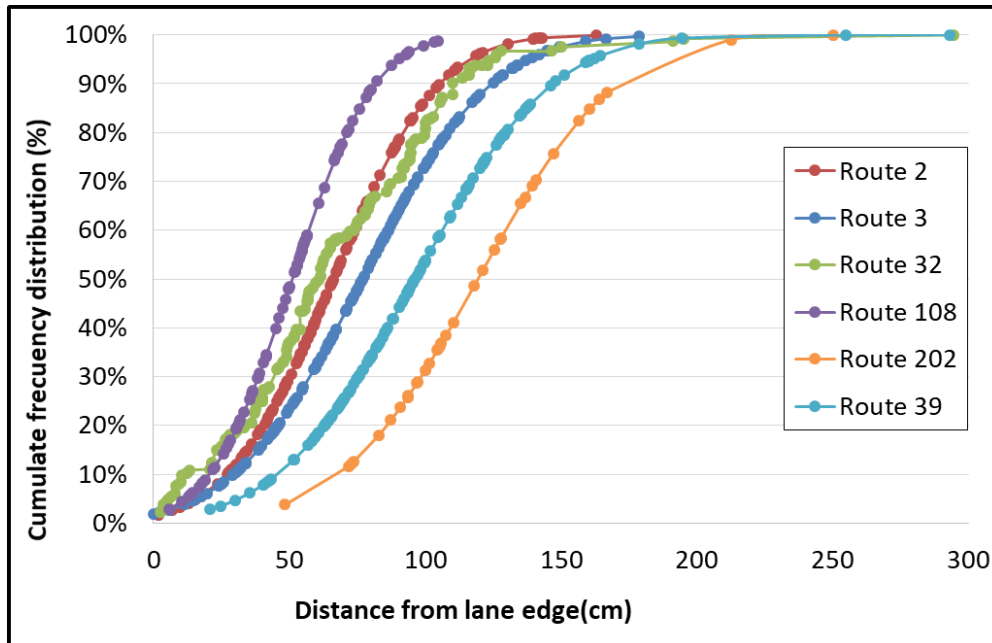


Figure 8. Heavy vehicular cumulate frequency for all the national routes

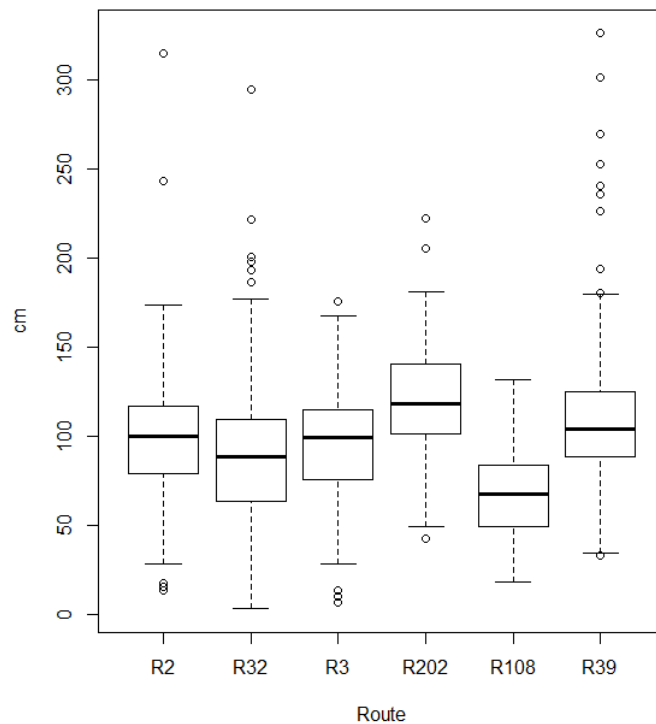


Figure 9. Distribution of passenger cars' lateral wander by route

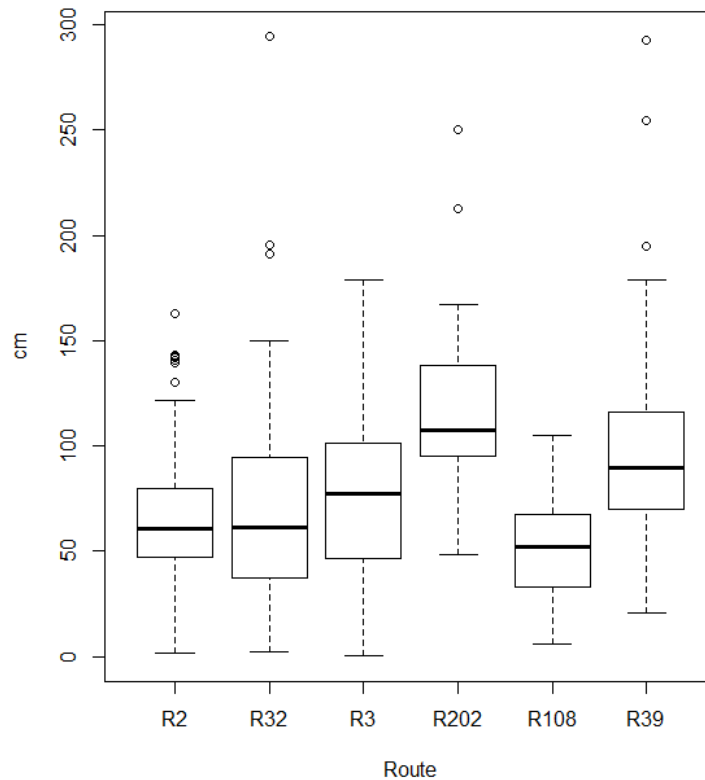


Figure 10. Distribution of heavy vehicles' lateral wander by route

Table 3. P-Values obtained from normality tests (Anderson-Darling)

Route	P-value	
	Non-Trucks	Heavy Vehicles
2	0.005	0.005
3	0.109	0.673
32	0.07	0.01
39	0.005	0.005
108	0.021	0.276
202	0.249	0.036

4. Conclusions

Based on the performed analysis, it is possible to obtain vehicular lateral displacement by ultrasonic sensors. The methodology was applied and validated in some of the most important routes of Costa Rica, such as National Route 2, National Route 3, National Route 32, and National Route 39.

Ultrasonic sensors controlled by Arduino are a useful tool to determine vehicular lateral displacement. It is necessary to visually inspect the type of vehicle passing through the measurement area, using a mobile application developed for this study.

The lateral wander distribution for some of the sections containing a significant sample size follow a normal distribution. When the route section data did not follow a normal distribution, it did not follow any other distribution tested by Minitab 18.

From cumulative frequency results, of the data obtained with the ultrasonic sensor, is determined that vehicles are concentrated between 50 and 150 cm from the edge of the road. Measurements at National Route 202, show 70% of the heavy traffic driving from 150 cm or more from the lane edge, which is

sort of the center of the lane. So, this is a valuable input for pavement designers, because they can have a notion of the load distribution among the lane width.

Future research could compare results from the device proposed in the present study with those of the referenced papers and could discuss how the proposed solution could improve, or not, the state-of-the-art in terms of accuracy, precision, cost of the device, and others.

Acknowledgements

We would to express my gratitude to Jason Zamora and Jorge Mora, for their technical support during the design, developing and calibration of the method proposed in this paper.

References

- [1] AASHTO 2008 *Mechanistic-Empirical Pavement Design Guide* (Washington D.C.: American Association of State Highway and Transportation Officials Executive Committee) pp 1-204
- [2] Loría L, Badilla G, Jimenez M, Elizondo F and Aguiar J P 2011 *Experiences in the Characterization of Materials Used in the Calibration of the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) for Flexible Pavement for Costa Rica*. (Washington D.C.: Transportation Research Board 90th Annual Meeting) pp 11-3359
- [3] Blab R and Litzka J 1995 *Measurements of the lateral distribution of heavy vehicles and its effects on the design of road pavements* (Michigan: Road Transport Technology) pp 389-395
- [4] Stempihar J, Williams R and Drummer T 2005 *Quantifying the Lateral Displacement of Trucks for use in Pavement Design* (Washington D.C.:Transportation Research Board Preprint)
- [5] Leiva F 2006 *Nueva guía mecanística-empírica para estructuras de pavimento* (San José: Programa Infraestructura del Transporte LanammeUCR)
- [6] Morris-Mitchell V and Leiva-Villacorta F 2016 *Determinación del desplazamiento lateral de vehículos en carreteras urbanas de Costa Rica* (San José: Infraestructura Vial) vol 18 no 32 pp 5-11
- [7] Erlingsson S, Said S and McGarvey T 2012 *Influence of heavy traffic lateral wander on pavement deterioration* (Sweden: Swedish National Road and Transport Research Institute)
- [8] Lindheimer T, Fitzpatrick K, Avelar R and Miles J 2017 Effect of geometric factors on lateral position of vehicles in freeway buffer-separated managed lanes *Transportation Research Record: Journal of the Transportation Research Board No 2616* pp 10-18
- [9] Timm D H and Priest A L 2005 *Wheel wander at the NCAT test track* (Auburn: National Center for Asphalt Technology) No 05-02 pp 28
- [10] Fitzgerald S and Shiloh M 2013 *Arduino Projects Book* (Torino: Arduino LCC)