Roadway Improvements to Increase Motorcycle Safety in Puerto Rico

by
Alberto M. Figueroa Medina, PhD, PE
Benjamín Colucci Ríos, PhD, PE, PTOE
Juan C. Torréns, EIT

ABSTRACT

The registration of motorcycles in Puerto Rico increased by 243%, from about 33,000 in 1997 to more than 115,000 in 2007. The increase in motorcycles (including motor scooters) on the road network of the island has resulted in substantial increases in motorcycle-related crashes and fatalities. This article presents the results of a research project that studied the frequency and severity of motorcycle-related crashes in Puerto Rico to identify roadway contributory aspects and safety countermeasures. The research project was sponsored by the Puerto Rico Traffic Safety Commission as part of an integrated approach to counter the increasing trend of motorcycle-related fatalities in recent years in Puerto Rico.

INTRODUCTION

The increasing trend of motorcycle-related crashes and fatalities rapidly became a major traffic safety and public health issue in Puerto Rico, increasing the percentage of motorcycle-related fatalities in the annual road fatalities from 4.6% in 1997 to 22.7% in 2006 (NCSA, 2007) and totaling $368 million in compensations from 1998 to 2004 (ACAA, 2004). The increase in motorcycle use is not exclusive of Puerto Rico as similar trends have occurred in the United States, Europe, and other countries. The increase in motorcycle use might be associated to a variety of factors, such as the rising cost of fuel, the severe traffic congestion in urban areas, the relatively low acquisition vehicle cost, the search for recreational activities, and the attraction and rising fascination for these vehicles among the population.

The lack of motorcycle riding experience, the sudden increase of motorcycles in the traffic mix, and the need for strict motorcycle training and licensing requirements in Puerto Rico are some of the factors that might be associated with the recent increase in motorcycle crashes and the apparent inadequate motorcycle riding habits in the island. In addition, drivers of passenger vehicles and heavy vehicles not familiarized to look for motorcycles in the road are also responsible for the negative safety trend. Amendments to the Puerto Rico Traffic and Motor Vehicles Law #22, approved in August 10, 2007, established minimum requirements to ride a motorcycle, stricter motorcycle licensing and operating regulations, and a strategic motorcycle safety education plan and funding.

Although negligent human behavior is predominantly linked to road crashes (Johnston, 1994), the roadway design, condition and environment also play a significant role in the safety of motorcycle riders. The roadway effect is particularly important in an island with significant number of fixed obstacles on the roadside, with a diverse topography in the central mountain range, as compared to the coastal valleys, in a tropical setting with high precipitation, and unique cultural and traditions that present road conditions that are not necessarily similar to other countries. Motorcycles are not considered generally in the geometry

design of road curves, intersections, and other road components, and the consideration of roadside safety devices, as performance and attributes of passenger vehicles and trucks govern the design decisions. For example, metal guardrails are designed to redirect passenger vehicles, but could be fatal when a motorcycle rider crashes against them (Berg et al., 2005). Lack of or poor pavement maintenance can also contribute to increase the potential of motorcycle crashes and their severity. The overloading of heavy vehicles, road construction defects and lack of preventive maintenance are issues related to the standard of care of the highway system in Puerto Rico that need to be corrected in order to improve the safety level of the network (Colucci and Figueroa, 2007).

MAJOR ASPECTS OF MOTORCYCLE-RELATED CRASHES

Crashes for the period of 2002-2004 from the Puerto Rico Department of Transportation and Public Works (DTPW) and road fatalities for the year 2006 from the Fatal Analysis Reporting System (FARS) were used as data sources of motorcycle crashes. The data included 9,823 motorcycle crashes for the 2002-2004 period (60% resulted in injuries or fatalities) and 115 motorcycle fatalities for 2006.

The distribution of motorcycle crashes per day of the week in Figure 1 presents a trend toward a higher frequency and severity of crashes occurring during weekends, particularly on Sundays, with 22% of crashes. If the weekend period includes from 6 PM on Fridays to 6 AM on Mondays the data reflect that 41% of the motorcycle crashes and 48% of the severe motorcycle crashes occurred on that period. The daily crash distribution for passenger vehicles shows that only 11% of the crashes occurred on Sundays, while from Mondays to Thursdays the daily percentage of crashes was 14.5%.

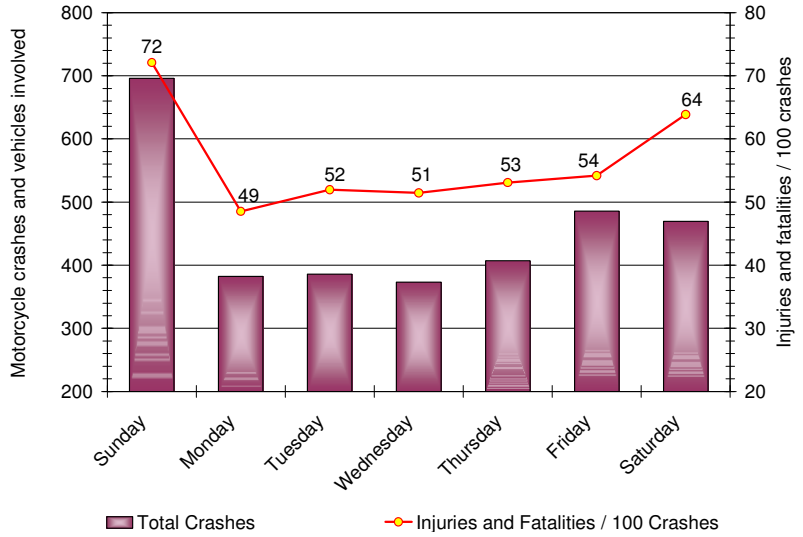


Figure 1 Frequency and severity rate of motorcycle crashes by day of the week

The risk of crash and the potential for higher severity once a crash happens is undeniable higher for motorcycles than for other types of motor vehicles, because of the exposed motorcycle engine parts, the limited rider protection, and the instability of the two-wheeled vehicles (Heger and Zenh, 2005). For

every 100 motorcycle crashes on Sundays there were 72 people injured or dead, in comparison with 52 people injured or dead, on average, from Mondays to Fridays. In contrast, the severity rate for passenger vehicles was 20 people per 100 crashes on Sundays and a daily average of 13 people per 100 crashes on weekdays. On average, the severity rate for motorcycles is four times higher than for passenger vehicles.

The motorcycle crash data by municipality was analyzed to identify crash trends and target enforcement or roadway maintenance strategies. The top 15 motorcycle crash frequency positions include municipalities from the San Juan Metropolitan Area and other major population areas such as: Caguas, Mayagüez, Ponce, Arecibo, Aguadilla and Humacao, representing 64% of all crashes and 60% of all injuries and fatalities during the analysis period. In order to circumvent the evident relationship between crash frequency and traffic volume, crash rates were calculated for each municipality. Table 1 presents the top 15 municipalities in terms of their motorcycle crash rate and severity rate per 10,000 registered motorcycles.

Table 1 Puerto Rico municipalities with highest motorcycle crash rates per registered motorcycles

Municipality	Registered motorcycles	Motorcycle crashes per 10,000 registered motorcycles	Ranking	Injuries and fatalities per 10,000 registered motorcycles	Ranking
San Juan	10,615	661	1	1,155	2
Culebra	137	560	2	1,168	1
Loíza	950	491	3	1,011	3
Guaynabo	2,739	404	4	701	12
Carolina	5,507	392	5	828	6
Bayamón	6,820	342	6	614	22
Caguas	4,121	336	7	706	11
Ponce	3,270	326	8	676	13
Dorado	1,283	322	9	670	14
Barranquitas	1,010	320	10	634	18
Fajardo	1,153	312	11	772	7
Maricao	183	310	12	929	4
Salinas	625	309	13	896	5
Mayagüez	2,712	305	14	656	17
Rincón	498	294	15	723	10

The top 15 municipalities with the highest motorcycle crash rates include municipalities not included in the top 15 list of highest crash frequency, which merit attention. Culebra is frequently visited by tourists and Puerto Rico residents from other municipalities that might rent motorcycles as a way to move around the island, including inexperienced and first-time riders. As with other places with high numbers of visitors and tourists, Culebra might be identified with road safety issues as a major concentration of drivers, both passenger vehicles and motorcycles, visit the area during their leisure time and might not be familiarized with the road environment or the road characteristics making them prone to mistakes in the identification of hazards on unfamiliar roads. In summary, 60 percent of the

municipalities in the list are related to places with a variety of tourist attractions and the remaining 40 percent are major metropolitan hubs with a well-developed network of highways with high traffic volumes during peak hours and drastically-reduced volumes at nighttime that offers an attraction for increasing speeds for risk-prone motorcycle riders.

The rankings also identify municipalities of less than 33,000 inhabitants, which are frequently visited by motorcycle riders from other municipalities (floating population), such as Loíza, Barranquitas, and Rincón, or have recurrent motorcycling routes through the municipality for other frequent destinations in Puerto Rico. Rincón and Loíza are other recognized tourist areas with beautiful beaches and other regularly visited attractions, such as the mountainous scenery of Rincón and the kiosks of Piñones. Another possible reason for the high ranking of municipalities of reduced population is the celebration of special events (e.g., Fiesta del Acabe del Café in Maricao) that attract a high concentration of riders not familiarized with the area, that put less attention to the driving task, or high concentration of riders under the influence of alcohol or drugs. These municipalities might be targeted for an aggressive campaign of adequate pavement and roadside maintenance and road signage to alert unfamiliar riders of any roadway hazard that might trigger a motorcycle crash on the routes frequently used by riders.

INSPECTION OF ROAD SEGMENTS AND ROADWAY DATA COLLECTION

The DTPW crash data was used to identify segments in the road network with a high frequency of motorcycle crashes. A random sample of in-service road segments with a high motorcycle crash frequency and rate was inspected to complement the information available on the crash database about the road design and condition and to determine relationships between roadway characteristics and safety.

A criterion of at least 20 motorcycle-related crashes occurring during the 3-year study period was used to identify high crash frequency segments on the road network. A total of 81 segments were identified and organized in descending order by their crash frequency, and divided into three sub-groups of 27 road segments. A random selection of nine segments from each one of the three sub-groups was made. The objective of the inspections was to collect information about the roadway geometry and other road features in order to assess the influence of such road characteristics on motorcycle safety. The motorcycle crash rate (crashes per million vehicle-miles traveled) for the 27 segments was calculated as

$$CR_m = \frac{A_m}{L \times AADT \times n \times 365} \cdot 1 \times 10^7$$

where A_m is the motorcycle crash annual frequency, L is the segment length, $AADT$ is the annual average daily traffic, and n is the number of years (3) in the study period. The data collected included:

- *General information*: posted speed limit, functional class (arterial, collector), location (urban, rural), density of intersections and driveways, development type, and terrain type

- *Road geometry information*: horizontal and vertical alignment, cross section elements and dimensions, median type, shoulder type, and roadside and obstacle types
- *Pavement condition information*: surface type and primary defects based on the Pavement Condition Index (PCI) procedure (ASTM D6433-99, 1999)

A total of 39 road sections were inspected. Table 2 shows descriptive statistics of the primary roadway characteristics observed. Fourteen of the segments were located in urban zones, nine sections included a median, and 20 segments were paved with hot-mix asphalt. Figure 2 shows representative pictures of the roadway characteristics and environments observed in four of the selected road segments.

Table 2 Descriptive statistics of major roadway characteristics

Road Feature	Mean value	Standard deviation	Minimum value	Maximum value
Crash rate, crashes/VMT	104.69	86.17	7.75	329.3
Posted speed limit, mph	35.38	9.55	25	55
Traveled way width, ft	41.12	22.78	18	96
Number of lanes	3.63	1.79	2	6
Driveway density (access/km)	35.41	46.90	0	216.7
Intersection density (intersections/km)	3.42	3.53	0	11.5
Shoulder width, ft	2.79	4.41	0	12
Median width, ft	6.16	11.52	0	61

Figure 2a shows an urban road segment consisting of a narrow median separated four-lane highway with 9-ft wide lanes and no shoulders. The road environment consists of residential and commercial type developments with parking, sidewalks, trees and curbs on the side. The roadway has no access control and includes ten intersections.

Figure 2b shows a two-lane rural segment with 10-ft wide lanes. The rolling type segment is composed primarily by a crest vertical curve with two steep grades between -6.0% and 5.8%, in combination with four horizontal curves, three intersections and multiple driveways.

Figure 2c shows a two-lane rural segment with 9-ft wide lanes, no shoulders and a 25-mph posted speed limit. The alignment includes eight horizontal curves and a gentle vertical profile with grades smaller than 2.1%. The road environment consists of multiple food establishments with limited or no parking facilities for their customers and with uncontrolled and limited sight access points. The roadside surface is composed of mostly sand due to its proximity to the beach and the flow of vehicles exiting the commercial establishments or the roadside area regularly brings sand to the roadway pavement surface.

Figure 2d shows a six-lane suburban segment with 12-ft wide lanes, a 60-ft wide median, and 12-ft wide shoulders, although the roadside includes unshielded trees and concrete illumination posts. The segment operates as an expressway with full access control with an almost straight horizontal alignment and a vertical profile with grades smaller than 2.3%. The 50-mph speed limit segment connects a rural freeway and an urban arterial; drivers exiting the freeway do not experience a major change in the road environment allowing them to maintain high speeds while reaching the urban congested area.

(a) (b)

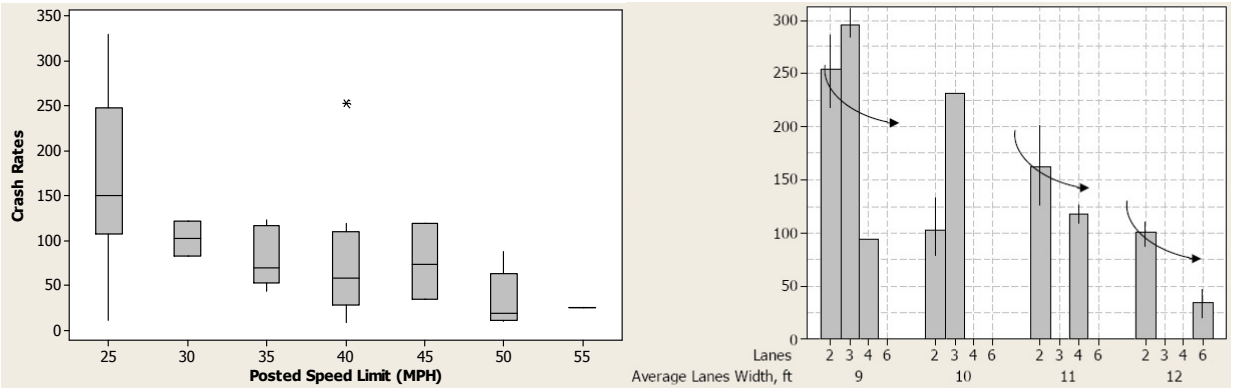
(c) (d)

Figure 2 General roadway environment and cross-section in selected road sections

The inspection findings emphasized that the road network is composed of spots and segments with adverse sharp horizontal curvature conditions, sight distance restrictions, and steep grades that force drivers to constantly change speeds and make them more prone to high motorcycle crash frequencies. Sight distance obstructions along curves, steep grades, and at or near intersections and driveways were frequently observed during the road inspections. The available sight distance in the road is of utmost importance in the safe and efficient operation of any motor vehicle. Sight restrictions due to the presence of vegetation or existing buildings and other man-made obstructions reduce the distance available to motorcycle riders and motor vehicle drivers on the main highway and increase the already difficult task for a driver to identify a motorcycle on a cluttered roadway environment due to its reduced size in comparison with four-wheel vehicles and larger vehicles. Traversing along an adverse horizontal alignment, specially those segments that include sharp and short horizontal curves (very common in the central region of the island) on a motorcycle by an inexperienced rider has a higher crash potential than for a novice driver on a four wheel motor vehicle. Motorcycle riders need to handle their motorcycles in order to manage the center of gravity of the motorcycle across a curve. Rider training sessions need to aggressively address these types of motorcycle maneuvering tasks on sharp and short horizontal curves.

ASSOCIATIONS BETWEEN ROADWAY CHARACTERISTICS AND SAFETY

An Analysis of Variance (ANOVA) focused on the effect of roadway factors on the motorcycle crash rate was performed with the information collected during the inspection process. ANOVA is a statistical model in which the observed variance is partitioned into components due to different explanatory variables. Inferences about the effect of roadway characteristics (i.e., the explanatory variables) in the motorcycle crash rate (i.e., the response variable) were made, with an alpha level of 0.05.



(a) (b)

Figure 3 Variability of motorcycle crash rate based on the speed limit and the number and width of the travel lanes

The roadway characteristics identified from the ANOVA results as significantly increasing the motorcycle crash rate are decreasing posted speed limits (Figure 3a), decreasing number of lanes and narrower travel lanes (Figure 3b), absence of shoulders and medians, and the presence of medium to high severity pavement defects, such as potholes and medium to high severity patches.

Although lower posted speed limits are associated with higher motorcycle crash rates, the effect of the speed limit on the crash rate cannot be simply interpreted as a direct causal relationship. The observed effect on sections with lower posted speed limits might be triggered by the presence of narrower cross-sections, higher access densities, and more hazardous roadway conditions and excessive speeding behavior, compared with segments with higher posted speed limits. The speed limit variable might be replacing the effect of other roadway characteristics, as the posted speed limit is typically correlated with many roadway characteristics due to the application of design standards and guidelines.

ANOVA indicates a negative effect on motorcycle crash rates of narrower cross-sections, including the travel lanes, the roadside clear zone, and the median. The safety effect of the cross-section dimensions is related to the available lateral clearance between vehicles on the road and fixed objects on the median and roadside. Reducing the cross-section increases the spread of the individual vehicle speeds as cautious and slow drivers respond to the extra risk represented by the narrower highway section more strongly than fast and aggressive drivers.

The effect of the pavement condition on motorcycle crash rates is significant. Motorcycles are more vulnerable than passenger vehicles to the presence of hazards created by the road design and the pavement condition; such as road markings, oil spills, loose gravel and debris, potholes, manhole covers, changes in friction of road surfaces, drop-offs, and uneven surfaces. Higher motorcycle crash rates are present in sections with asphalt pavements, in comparison to segments with concrete pavements. The pavement condition refers to the presence of extensive medium to high severity potholes and patches and the ANOVA results for the pavement condition variable indicated significant differences between distressed and non-distressed pavement surfaces.

FINAL REMARKS

Puerto Rico's road network consists of a combination of a well-developed urban highway system located primarily on the coastal level areas and of rural narrow roads located on the central mountainous region. The extent of the road network presents a challenge to public works officials in terms of the magnitude of roadway maintenance and preservation and funding needs. The fact that 80% of the territory is located in mountainous terrain presents engineering challenges associated with roads constructed in cut sections, erosion-related problems, sight distance restrictions at intersections and curves, extensive use of guardrails on steep slopes which creates potential fixed obstacles to users, particularly motorcycle riders. The combination of a tropical setting and high precipitation rate on the central mountain range, and the north, west and southeastern regions, and the high level of erosion on cut sections and the inadequate roadway drainage provided in rural areas provoke the presence of loose material (sand or gravel) on low points and intersections that are potentially hazardous for motorcycle riders, particularly during nighttime conditions and on high-speed roads (speed limit over 45-mph).

The results from the road inspections and the ANOVA of the relationship of the roadway characteristics with the motorcycle crashes highlight the importance of providing timely road maintenance and repair activities and properly address design and construction faults on the road network to improve the safety of all road users. The study results documented in this article are from a project (Figueroa and Colucci, 2008) supported by the Puerto Rico Traffic Safety Commission to analyze the motorcycle safety situation in Puerto Rico and recommend engineering safety countermeasures, such as new roadway signs to alert motorcycle riders of potential safety issues on the road.

REFERENCES

Administración de Compensaciones por Accidentes Automovilísticos. 2004. Prontuario Estadístico. Puerto Rico. ACAA, Commonwealth of Puerto Rico.

American Society for Testing and Materials. 1999. Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. ASTM D6433-99. West Conshohocken, PA.

Berg, F. A., Grzebieta, R., Rucker, P., Gartner, M., Konig, J., & Zou, R. 2005. Motorcycle Impacts into Roadside Barriers – Real-World Accident Studies, Crash Tests and Simulations Carried Out in Germany and Australia. 19th International Technical Conference on the Enhanced Safety of Vehicles.

Colucci, B. and A. Figueroa. 2007. El Estado de la Infraestructura Vial y la Seguridad en Puerto Rico. Dimensión. College of Engineers and Surveyors of Puerto Rico, San Juan, PR.

Figueroa, A. and B. Colucci. 2008. Analysis of Motorcycle-Related Crashes in Puerto Rico. Puerto Rico Traffic Safety Commission, Commonwealth of Puerto Rico.

Johnston, I. 1994. The Civil Engineering Handbook, Second Edition, Victoria, Australia.

Heger, R. and Zenh, A. 2005. Road Design and Human Factors Associated to Motorcycle Accidents. Germany. 3rd International Symposium on Highway Geometric Design. TRB. Chicago, Illinois.

National Center for Statistics and Analysis. 2007. Puerto Rico Toll of Motor Vehicle Crashes. NHTSA, Washington, D.C.

ABOUT THE AUTHORS

Alberto M. Figueroa Medina (amfigueroa@uprm.edu) is a Professional Civil Engineer and holds BS and MS degrees in Civil Engineering from the University of Puerto Rico at Mayagüez (UPRM) and a PhD degree in Civil Engineering from Purdue University. He is Assistant Professor of the Transportation Engineering area at the UPRM Department of Civil Engineering and Surveying and is the Deputy Director of the Puerto Rico Transportation Technology Transfer Center.

Benjamín Colucci Ríos (bcolucci@uprm.edu) is a Professional Civil Engineer and Professional Traffic Operations Engineer. He holds a BS degree in Civil Engineering from the UPRM and MS and PhD degrees in Civil Engineering from Purdue University. He is Professor and Faculty Coordinator of the Transportation Engineering area at the UPRM Department of Civil Engineering and Surveying and is the Director of the Puerto Rico Transportation Technology Transfer Center.

Juan C. Torréns (torrens_inci@yahoo.com) holds a BS degree in Civil Engineering from the University of Puerto Rico at Mayagüez and is currently a graduate student in the Transportation Engineering area at the UPRM Department of Civil Engineering and Surveying.