Development of Crash Modification Factors for Rumble Strips Treatment for Freeway Applications: Phase I Development of Safety Performance Functions

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Abstract

Longitudinal rumble strips is a safety feature or treatment on a paved shoulder capable of alerting drivers that their motor vehicle is departing the traveled lane. This treatment has proven to be effective specially preventing roadway departure crashes.

In 2009, Puerto Rico started the implementation of longitudinal shoulder rumble strips on freeways. In 2010, the Highway Safety Manual (HSM) provide tools for decision making to estimate how effective a countermeasure or set of countermeasures will be in reducing crashes at a specific location. The Crash Modification Factors (CMF) are used to quantify the effect of a particular treatment on expected crash frequency adjusting the estimate of crash frequency from a base condition defined by a Safety Performance Function (SPF) to the specific conditions present at a site. In the 2010 HSM, CMF's for freeway applications using intermittent longitudinal rumble strips on shoulders were not included.

This paper documents the process of developing CMF for intermittent rumble strips on freeway segments, in rolling to mountainous topography and the development of SPF's. The study area is PR-52, a 108.3 km toll freeway facility, part of NHS originating in San Juan, crossing the central mountain range and ends in the city of Ponce.

Keywords: Crash Modification Factors, Rumble Strips, Freeways, Puerto Rico

1. Introduction

The Global Status Report on Road Safety published by the World Health Organization (WHO) estimates that in the year 2010, 1.24 million persons were killed on traffic crashes on roads worldwide and approximately 20 to 50 million people were injured. They also reported that crashes are the 8th leading cause of death worldwide and the top leading cause of death for people aged between 15 to 29 years old. Trends suggest that in the future, road traffic injuries will become the 5th leading cause of death worldwide if proven safety measures are not implemented (WHO, 2013).

In the United States, there have been approximately 392,890 fatalities from 2002 through 2011 reported by the National Center for Statistics and Analysis of the National Highway Traffic Safety Administration (NHTSA). In 2011, an average of 89 people were killed daily on road crashes with an estimated value of one fatality per every 16 minutes. Traffic crashes were the number one leading cause of death for people aged between 11 to 27 years old (NHTSA, 2013). There have been approximately 4,397 fatalities, related to traffic crashes during the last decade on the road network of the Commonwealth of Puerto Rico (PR) as reported by the Police Department and the Traffic Safety Commission of PR (TSC, 2013).

In 2009, Puerto Rico Highway and Transportation Authority started the implementation of intermittent longitudinal rumble strips on the right hand shoulder on freeways on the island. Crash Modification Factor (CMF) is defined as a factor that is used to predict the expected count of crashes after implementing a given treatment in a specific facility.(HSM, 2010) CMF are use to adjust the estimate of crash frequency from a base condition defined by a Safety Performance Function (SPF) to the specific conditions present at a site. In the initial edition of the 2010 Highway Safety Manual (HSM), CMF's for freeway applications using intermittent longitudinal rumble strips on shoulders were not included.

This investigation pretends to develop CMF for intermittent longitudinal shoulder rumble strips. This paper will focus on the development of preliminary SPF's for freeway segments.

2. OBJECTIVES

The main objective of this research is to develop CMF for intermittent shoulder rumble strips on freeway segments. The specific objective discuss in this paper is the development of SPF's associated to freeway segments in order to perform the Empirical Bayes Method to evaluate the effectiveness of longitudinal shoulder rumble strips.

3. METHODOLOGY

The first task performed in the development of this study was a literature review that included a research of previous studies related to the development of CMF for shoulder rumble strips, a review of the Highway Safety Manual and a complete review of the specification or guidelines for the design and installation of shoulder rumble strips in Puerto Rico.

In order to achieved the objective of the study, an observational study will be perform which will include a "before and after design". Observational studies are use when the treatment is already implemented and data has to be collected retrospectively in order to achieve the analysis required to acquire the effectiveness of the treatment. The before and after design consists in the estimation of CMF using the change in crash counts between the before and after the implementation of a treatment (FHA, 2010).

As mention before, the PR Transportation and Public Works Department performed a pilot project of installation of milled-in, intermittent, longitudinal rumble strips, located on PR-52 freeway. The rumble strips was installed only on the right shoulders from the South Caguas Toll Plaza (km 23.1) ends at the exit ramp towards the town of Salinas (km 66.3). The period of this observational study will be a 2 to 3 year "before and after" study. The period of the observational study depends on the crash data available for the "after period". Figure 1 shows the methodology to be applied in order to develop CMF's for intermittent shoulder rumble strips on freeways in Puerto Rico.

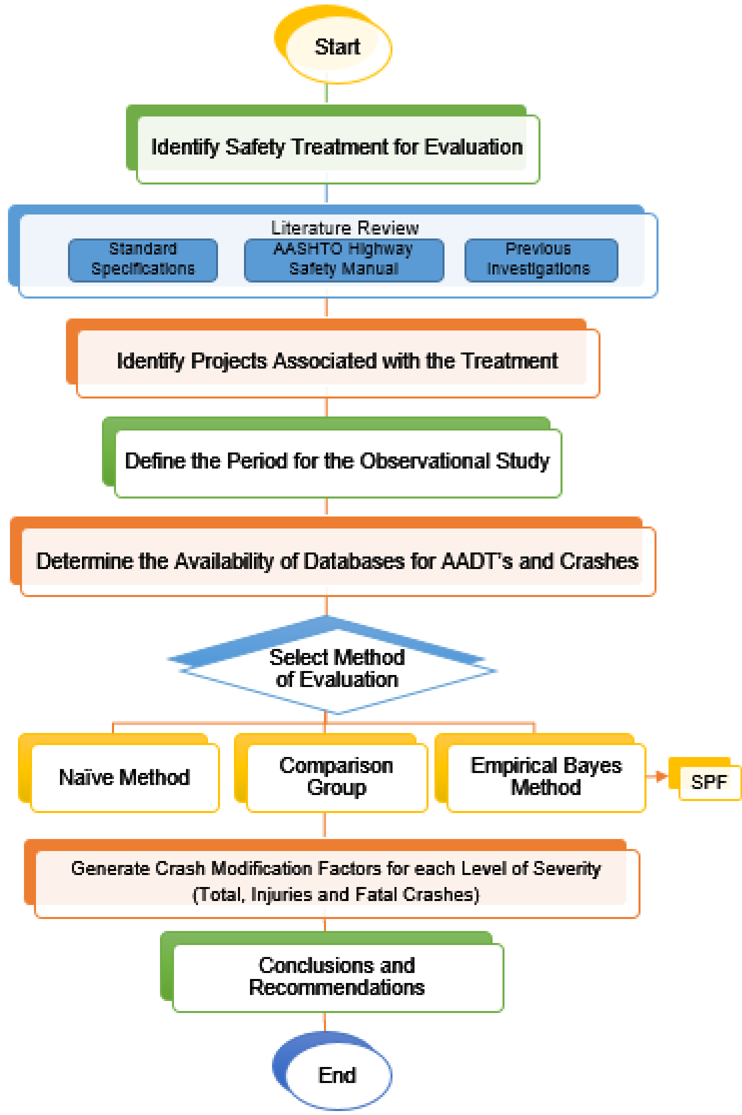

Figure 1: Methodology of the Research Study

In "Before and After Studies" information regarding crashes is needed in order to quantify the reduction of crashes per site. In the Empirical Bayes method, characteristics such as length of the segment and AADT's are necessary in order to develop a Safety Performance Function (SPF). Two databases are essential for the completion of this investigation:

- **Crash Database:**

The Traffic Division of the Bureau of Highway Patrol is the entity in charge of monitoring the principal roads in the different police regions of the island. They have trained and specialized police personal that goes to the scene of the crash and gathers the information using a standardized police crash report (PPR-93).

The Crash Analysis Office of the Puerto Rico Highway and Transportation Authority (PRHTA) is in charge of digitalize and create a database of all the crashes (including fatal, injuries and property damage) reported by the Traffic Division of the Bureau of Highway Patrol. They will provide two separate databases needed in order to complete our analysis, a crash database from a period covering 2004-2006 and another database from a period covering 2007-2012. Important information such as: crash case ID, municipality, road number, kilometer and type of severity is necessary in order to complete a before and after study.

•Highway Performance Monitoring System Database:

The Annual Average Daily Traffic (AADT) values for all the principal highways in Puerto Rico is provided by the Highway Performance Monitoring System Database. This database is managed by the Office of Highway System of the PRHTA. They will provide separate databases needed in order to complete the analysis starting from the year 2004 through 2012. This database provides information such as: route number, county code, municipality, description, begin and end stations, segment length, AADT and functional classification.

The select method of evaluation of the observational study is the ***Empirical Bayes Method (EB Method)***. This methodology is the most robust of all the methodologies used to evaluate safety effectiveness of treatments or countermeasures. This method can predict the count of crashes that would occurred in the "after" period if the treatment or countermeasure had not been implemented and then compares this values with the actual count of crashes in the "before" period of the treated site. The first step in on this methodology is the development of local "Safety Performance Functions" (SPF) specifically adapted to Puerto Rico's jurisdiction.

This paper will focus on the preliminary development of the SPF's for freeway segments in Puerto Rico. A SPF is a statistical model that is used to predict crashes in the future at a particular location such a road, segment or intersections. On highway segments they usually involved variables such as segment length and AADT which expresses exposure measures. Other more complex SPF can include roadway characteristics, weather conditions, type of terrain and other characteristics.

The next section will discuss a brief literature review that includes a general description of rumble strips, the guidelines for the design and installation of rumble strips in Puerto Rico and a summary the latest investigation related to the effectiveness of rumble strips.

4. RELATED LITERATURE

4.1 GENERAL DESCRIPTION OF RUMBLE STRIPS

Rumble strips is a safety feature or treatment on a paved roadway, capable of alerting drivers that their vehicle is leaving the travel lane. In the United States, this special treatment has proven to be effective (FHA, 2013). Rumble strips can be either permanent or provisional. Examples of permanent installment of rumble strips are: on the centerline of a two way roadway or in the shoulder of a roadway. In the case of provisional rumble strips, they are commonly used to alert vehicles of changes in the roadway. One of the most common applications for this treatment is on temporary working zones.

They are longitudinal or transverse rumble strips. Longitudinal rumble strips can be installed either in the center line, edge line or shoulder of a roadway. Edge line rumble strips are placed in the edge line of the pavement and they help prevent vehicles from leaving the road. Shoulder rumble strips have the same functionality as edge line rumble strips but they are usually installed on the shoulder near the edge line of the pavement. Center line rumble strips are installed on the centerline of a two lanes roadway and they prevent head on collisions between vehicles that are traveling from two different directions.

The purpose of transverse rumble strips is to alert drivers of a potential change or hazards in the roadway. This can be applied on the approaches of intersections, temporary work zones, toll lanes and others. Figure 2 represents a diagram with the application categories of rumble strips.

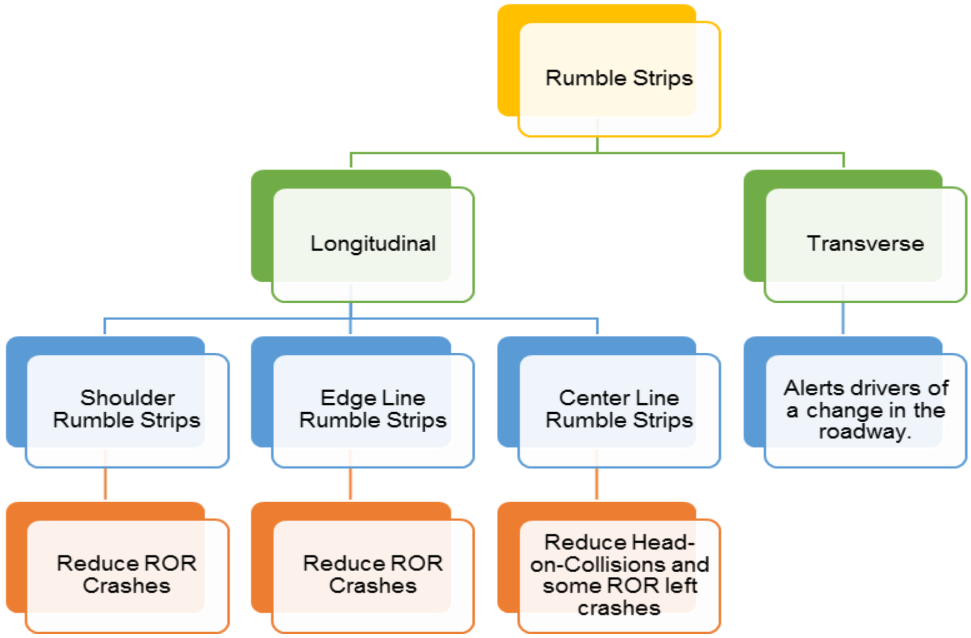

Figure 2: Categories for Rumble Strips

There are four types of rumble strips designs. The first one, the milled-in rumble strips, is a texture or groove in the pavement made by a rotary cutting machine. The milled-in has proven to be effective because of its noise level performance. The second type of rumble strips is the rolled rumble strips. The rolled rumble strips are rounded grooves that are made during the process of compaction of the hot asphalt pavement. The noise level on this kind of rumble strips is less than the milled-in rumble strips. To install the rolled rumble strips they use a roller with steel pipes welded to drums that creates grooves on the asphalt surface (FHA, 2013).

The other two types of rumble strips are raised and formed. The raised rumble strips can be shaped either round or rectangular and are recommended in warm climates. The raise rumble strips is commonly use in work zones because it can easily adhere to the pavement. The formed rumble strips or corrugated is similar to the rolled type but they are typically use in concrete pave shoulders. Their shape can be either rounded or a V type groove (FHA, 2013).

4.2 Puerto Rico Design Guidelines for Rumble Strips

The PRHTA "Standard Specifications for Road and Bridge Construction" do not provide a specific specification concerning rumble strips. In 2012, the authority issued Design Directive No. 409 for the installment of rumble strips in the island highway system (PRHTA, 2012). This document detailed the following guidelines:

- •Minimum Shoulder Width: 4 feet
- •Minimum Lateral Clearance: 12 inches
- •Rumble Strips Width: 7 inches
- •Rumble Strips Length: Between 16 to 18 inches
- •Rumble Strips Depth: Between 1/2 to 5/8 inches
- •Center to Center Spacing: 12 inches

It also detailed that the rumble strips cannot be installed on any structure or bridge. Rumble strips has to be installed 82 feet before and after any structure. Rumble strips are not permitted over pavement joints and special provisions are detailed for bicycle crossings. The next section will summarizes previous studies related to the effectiveness of shoulder rumble strips.

4.3 PREVIOUS STUDIES RELATED TO EFFECTIVENESS OF SHOULDER RUMBLE STRIPS

Multiple researchers have conducted studies of the effectiveness and development of CMF's for different types of rumble strips on diverse locations. The more recent ones are discussed in this section.

The NCHRP 641 "Guidance for the Design and Application of Shoulder and Centerline Rumble Strips" had contributed with a significant number of CMF and CRF published by the CMF Clearinghouse (NCHRP, 2009). The objective of this study was to quantify the safety of milled-in shoulder rumble strips on different types of roads. They had two different approaches in order to convey the analysis. The first approach used was the before and after Empirical Bayes Method and the second was a Cross-Sectional Generalized Linear Model Analysis. On this investigation a large quantity of crash reduction factors were developed. The report concluded that due to the proven effectiveness of shoulder rumble strips on different types of roadways, the low cost of installation and maintenance and the relative few concerns, it is a suitable safety related treatment.

In 2010, Sayed studied the impact of rumble strips on highways located on British Columbia (Sayed, 2010). A "before and after analysis" with reference group was performed. For this specific methodology a collision prediction model was developed for segments of roads with similar characteristics to the sites were the treatment was implemented. They develop the models using the generalized linear modeling tool with a negative binomial distribution. The model included variables such as AADT and segment length in order to predict expected collision frequency which is the dependent variable. Results indicated that shoulder rumble strips reduce severe collisions 18% and run off the road collisions by 22.5%. They concluded that shoulder rumble strips is an effective way to reduce the severity of collisions.

The latest investigation on rumble strips, submitted on April 2013, was performed by the Washington State DOT (Olson, Sujka, Manchas, 2013) They evaluated the performance of the combination of centerline and rumble strips on two-lane rural highway system. A total of 135.88 miles of treated and untreated highways segments were evaluated. Overall, the before and after analysis showed that there was a reduction of 66% of lane departure collisions and 56% decrease of this type of collision involving fatal-serious injuries. They also reported a reduction of 61.6% of all run off the road collisions and 53.7% of this type of collision involving fatal-serious injuries. They concluded that the combination of both treatments is a low cost tool in reducing the run off the road and lane departure collisions.

5. LOCATION OF THE PILOT PROJECT OF SHOULDER RUMBLE STRIPS

The PRHTA performed a pilot project of installation of milled-in, intermittent shoulder rumble strips, located on PR-52 freeway. The study area is highway PR-52 a 108.3 kilometers toll freeway facility that is part of the National Highway System that originates in the north at San Juan, Capital of Puerto Rico, crossing the central mountain range and ends in the city of Ponce. Both cities have shipping ports that receive and deliver commercial freight. Its AADT's ranges from 165,800 vpd in its urban area origin to a minimum of 18,600 vpd in a rural mountainous region. The maximum speed limit is 65 mph and approximately 8% of heavy trucks.

The specific segment evaluated in this phase starts on the South Caguas Toll Plaza (km 23.1) and ends at the exit ramp towards the town of Salinas (km 66.3). Figure 3 shows the location of the shoulder rumble strips pilot project from an image extracted from Google Earth.

Figure 3: Location of the Shoulder Rumble Strips Pilot Project:
NHS PR-52 Freeway between Caguas and Salinas (Source: Google Earth)

Figure 4 shows the sign alerting drivers of the shoulder rumble strips, a photo of the shoulder rumble strips on NHS PR- 52 freeway and the approximate dimensions of the longitudinal shoulder rumble strips. The non-continuous longitudinal shoulder rumble strips installed on this freeway are 5.7 feet long, 1 feet wide and 10.8 feet gap between the strips.

Figure 4: Rumble Strip Sign, Photo of the Rumble Strips on NHS PR-52 Freeway and Dimensions

6. DEVELOPMENT OF PRELIMINARY SAFETY PERFORMANCE FUNCTIONS

The first step of the Empirical Bayes Method was the development of preliminary Safety Performance Functions for each level of severity. As mention earlier, a SPF is a statistical model that is used to predict crashes in the future at a particular location such a road, segment or intersections. The first step in developing a SPF on the Empirical Bayes Method was the identification of a reference group. A reference group is a collection of untreated segments that have similar characteristics as the treated segments.

The segment selection for the reference group were a combination of untreated segments in the NHS PR-52 and untreated segments of the NHS PR-22 with similar characteristics that totalized 43 segments. The segmentation is based upon the segmentation use in the Highway Performance Monitoring System Database which defines segment for each road in Puerto Rico based upon the AADT's. Table 1 presents the principal characteristics of the segments selected for both NHS toll freeways using as a base year 2009.

Table 1: Characteristics of the Segments Selected for the Reference Group

Characteristics of the Segments of the Reference Group	NHS PR-52	NHS PR-22
Number of Lanes	4 to 6 lanes	4 to 6 lanes
Lane Width	12 feet	12 feet
Average Segments AADT's (vehicles/day)	70,677	77,438
Average Crashes for Segments (per year)	30	23
Total Untreated Segments	22	21

The second major task was the data cleaning process in which inaccurate or incomplete records were eliminated from the database. Two crash databases were use in the development of the SPF. The first crash database had the crashes covering the periods from the years 2004 to 2006 and the other one covering the periods from the years 2007 to 2008. The data cleaning process was performed for the total segments for both freeways including the reference group. A total of 491 crash records were eliminated because they lack the exact location of the crash or had errors related to the exact kilometer location.

The actual development of the SPF was done using a methodology proposed by Ezra Hauer on a publication from a seminar called "The Art of Regression Modeling in Road Safety". Hauer suggest that SPF can be built by adding the variables on the model equation one at a time. If the modeler reports every SPF gradually obtained, practitioners than can use the model for which they have data available (Hauer, 2014). He suggest to start the modeling process with segment length as a simple model equation and then add the rest of the variables. The development of the preliminary SPF's for this investigation were obtained by using a curve fitting spreadsheet using Microsoft Excel. The curve – fitting spreadsheet was used in combination of a function called the "Solver Parameter" which can solve the parameters of practically any function that better fit the model.

The preliminary SPF's were developed assuming a Negative Binomial Distribution. In the past, many researchers used Poisson Distribution but recently researchers had shown that the Negative Binomial Distribution offers better fitted models than the Poisson Distribution. An important parameter for the development of the EB method is the negative binomial dispersion parameter (Φ) obtained from this regression.

The first preliminary models were performed by fitting a power function. On the first trail the segment length (kilometers) as our independent variable was added. The first model is represented by the following formula, were $E(\mu)$ is defined as expected crashes, X_1 is the segment length (kilometers) and β_0 and β_1 are regression parameters.

$$E(\mu) = \beta_0 * X_1^{\beta 1} \quad (1)$$

Table 2: Results of the Models with Segment Length for 2 to 3 Year Periods

Model for Each Severity Type	Model for a 2 Year Period				Model for a 3 Year Period			
	β_0	β_1	Φ	Pearson Function Index	β_0	β_1	Φ	Pearson Function Index
Total Crashes	22.245	0.737	1.155	0.57	34.279	0.719	1.129	0.56
Crashes with Injuries	21.899	0.737	1.144	0.57	21.899	0.737	1.144	0.57
Fatal Crashes	0.338	0.744	5.95	0.36	0.483	0.760	1.813	0.39

Table 2 provides the values of the parameters (β), over dispersion parameter (Φ) and the value of the Pearson Index obtained by Excel. The Pearson Index can range from -1 to 1 and reflects the relationship between two data sets. On the initial analysis, with a model based upon segment length, it was noted that the Pearson Function Index value was low for all the models. To better improve the model an additional variable, which was the average AADT for each segment was added. The second model is represented by the following formula, were E(μ) is defined as expected crashes, X_1 is the segment length (kilometers), X_2 as the Average AADT (vehicles/day) and β_0, β_1 and β_2 are regression parameters.

$$E(\mu) = \beta_0 * X_1^{\beta 1} * X_2^{\beta 2} \quad (2)$$

Table 3: Results of the Models with Segment Length and AADT's for 2 to 3 Year Periods

Model for Each Severity Type	Model for a 2 Year Period					Model for a 3 Year Period				
	β_0	β_1	β_2	Φ	Pearson Function Index	β_0	β_1	β_2	Φ	Pearson Function Index
Total Crashes	0.00042	0.847	0.963	2.576	0.85	0.00160	0.781	0.889	2.254	0.85
Crashes with Injuries	0.00037	0.855	0.974	2.554	0.85	0.00169	0.780	0.883	2.185	0.85
Fatal Crashes	0.0000034	0.928	1.012	2.666	0.61	0.000005	0.928	1.012	2.666	0.66

Table 3 provides the values of the parameters (β), over dispersion parameter (Φ) and the value of the Pearson Index obtained by Excel for the models that included the segment length and the average AADT's variables. The Pearson Index gets closer to 1 and reflects that there is a better relationship between two data sets (observed vs. fitted values).

7. Conclusions

The results discussed above are the first attempts to develop a SPF for the reference group of freeway segments using Microsoft Excel in order to achieve the objective of creating CMF's for intermittent shoulder rumble strips on freeways. The first preliminary results showed that a better prediction can be obtained by adding variables to the model. The model that included the variables segment length and AADT's showed a better relationship between the data sets than the model that only included the variable segment length. Due to the lack of fatal crashes per segment, the SPF's regarding fatal crashes are not well adjusted.

This is an ongoing investigation and further models will be develop by using a statistical software package. Future work will include the inclusion of a model to predict run-off the road crashes for a 2 and a 3 year period. Other variables such as speed limit, topography and other geometrical characteristics of the reference group will be added to the models.

8. AKNOWLEDGMENTS

Special acknowledgement to the Division of Road Safety Audit of the PRHTA for allowing information for the development of the SPF. Special thanks to the personnel of the PR Transportation and Technology Transfer Center at the Mayagüez Campus for additional assistance.

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