STATISTICAL ANALYSIS TO ASSESS EFFECTIVENESS OF RUMBLE STRIPES ON HIGHWAY SAFETY
(Part 1: DESCRIPTIVE)

***Tulio Sulbaran, Ph.D*[1]**

Abstract - Although traffic deaths are caused by an array of factors, in the United States more than half of all roadway fatalities are caused by roadway departures [FHWA 2006]. In 2003, there were 25,562 roadway departure fatalities, accounting for 55 percent of all roadway fatalities in the United States. Roadway departure includes run-off-the-road (ROR) and head-on fatalities. In 2003, more than 16,700 people died in ROR crashes (39 percent of all roadway fatalities), and head-on crashes represented 12 percent of all fatal crashes [FHWA 2006]. On average, one roadway departure fatality crash occurred every 23 minutes. An average of one roadway departure injury crash occurred every 43 seconds [FHWA 2006]. In short, roadway departures are a significant and serious problem in the United States.

MDOT through the Traffic Engineering Division is committed to improve Mississippi highway safety. MDOT has invested valuable resources to implement a series of safety improvement programs such as the Rumble Stripes program. Despite MDOT's high commitment and efforts to improve highway safety, MDOT does not know the impact of the Rumble Strip program in reducing crashes. In other words, MDOT lacks quantifiable evidence that demonstrates the effectiveness of this program.

This paper presents the descriptive statistical analysis performed to assess the effectiveness of the Rumble Stripes on Highway Safety. Additionally, this paper provides the lessons that could serve as the foundation for similar studies and/or case studies to facilitate students learning through meaningful real world scenarios.

Keywords: Rumble Stripes, Statistical Analysis, Effectiveness, Safety

INTRODUCTION TO RUMBLE STRIPS AND STRIPES

Two of the countermeasures used to increase roadway safety (especially by preventing roadway departures) are Rumble Strips and Rumble Stripes. Although in many cases Rumble Strips and Rumble Stripes have been used interchangeable, they do not have the same design characteristics.

Rumble strips are raised or grooved patterns on the roadway shoulder or center lines. Figure 1 shows the dimensions and a schematic profile of Rumble Strips used by the Alaska DOT. Figure 2 provides a picture of a Rumble Strip on a Roadway segment. Rumble Strips provide both an audible warning (rumbling sound) and a physical vibration to alert drivers that they are leaving the driving lane [FHWA 2006a]. Noise and vibration produced by shoulder rumble strips are effective alarms for drivers who are leaving the roadway. They are also helpful in areas where motorists battle rain, fog, snow, or dust [FHWA 2007b]. The Rumble Strips give a warning to inattentive drivers. Rumble Strips help drivers stay on the road during inclement weather when visibility is poor [FHWA 2006]. Rumble Strips also help reduce highway hypnosis-a condition where white lines and yellow stripes on long, monotonous stretches of straight freeway can mesmerize and wreak havoc with a driver's concentration [FHWA 2007b].

[1] Associate Professor – School of Construction at the University of Southern Mississippi, Box 5138, Hattiesburg, MS, 39406. E-mail: Tulio.Sulbaran@usm.edu.

. **Lateral Width:** 400mm (16")

. **Longitudinal Milling Pattern:** 175mm (7") cut, 13mm (½") deep, 125mm (5") flat

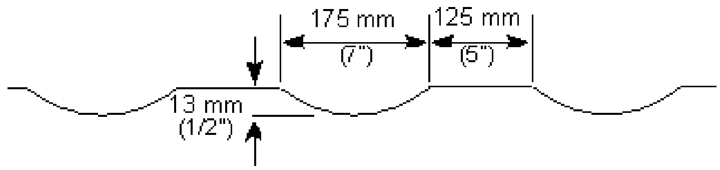

Figure 1. Dimensions and Schematics Profile of Rumble Strips [FHWA 2007c]

Figure 2.. Rumble Strip on a Roadway [Safe Roads 2003]

Rumble Strips can be grouped in three types. The most common type of strip is the continuous shoulder rumble strip. These are located on the road shoulder to prevent roadway departure crashes on expressways, interstates, parkways, and two-lane rural roadways. Centerline rumble strips are used on some two-lane rural highways to prevent head-on collisions. Transverse rumble strips are installed on approaches to intersections, toll plazas, horizontal curves, and work zones [FHWA 2010].

Rumble Stripes are a combination of pavement markings and rumbles strips, with the markings applied on top of the rumble strips. Rumble Stripes enhance visibility as the vertical face of the rumble strip provides a raised texture that enhances the retroreflectivity performance of the striping material [Public Roads 2010a] as presented in Figure 3. Because the vertical edges of the strips are painted, the paint line is more visible at nighttime and during wet conditions [Public Roads 2010b].

Figure 3. Rumble Stripe Sample on Roadways
[Amparano, Morena, 2006] & [*ATSSA 2006* - Picture by Jim Willis-MDOT]

DESCRIPTIVE STATISTICAL ANALYSIS

In most research projects the statistical analysis involves three major steps, done in roughly this order: Cleaning and organizing the data for analysis (Data Preparation), describing the data (Descriptive Statistics), testing hypotheses and models (Inferential Statistics). This paper focuses on the descriptive statistical analysis performed to assess the effectiveness of the Rumble Stripes on Highway Safety

The statistical analysis began by analyzing traffic trends and characteristics of the studied road segments. Several divisions of the Mississippi Department of Transportation provided to the research team a wealth of data to perform the analysis. A total of 14 segments were originally included in the study as shown in Table 1.

The analysis of the studied road segment were organized as follows:

- a - Traffic Volume Over time per Segment
- b - Total Crashes per Segment Before and After Construction
- c - Roadway Departures and Overturn per Segment Before and After Construction
- d - Total Crashes per Segment under Different Lighting Conditions Before and After Construction
- e - Roadway Departures and Overturn per Segment under Different Lighting Conditions Before and After Construction
- f - Total Crashes per Segment under Different Road Condition Before and After Construction
- g - Roadway Departures and Overturn per Segment under Different Road Conditions Before and After Construction

Table 1. Road Segments Included in the Study

ID	Project Name /District	Route	Starting Point (Mile Marker)	Ending Point (Mile marker)
1	US 98 in George County from the Greene County line to SR 63/Dist 6	US 98	Greene County line	SR 63
2	US 98 in Greene County from east of SR 198 in McLain to the George County line/Dist 6	US 98	Greene County from east of SR 198 in McLain	George County line
3	US 98 in Perry County from the Forrest County line east 7.5 miles/Dist 6	US 98	Forrest County line	East 7.5 miles into Perry County
4	US 98 in Forrest County from Interstate 59 to the Perry County line/Dist 6	US 98	Forrest County from Interstate 59	Perry County line
5	SR 589 in Lamar County from Haden Road north to US 98/Dist 6	SR 589	in Lamar County from US 98 north	to US 98
6	SR 589 in Lamar County from US 98 north to the Covington County line/Dist 6	SR 589	in Lamar County from US 98 north	to the Covington County line
7	SR 43 in Hancock County from SR 603 to Dummyline Road/Dist 6	SR 43	in Hancock County from SR 603	to Dummyline Road
8	SR 43 in Hancock County from Dummyline Road to Salem Road/Dist 6	SR 43	in Hancock County from Dummyline Road	to Salem Road

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(Continuation) Table 1. Road Segments Included in the Study

ID	Project Name /District	Route	Starting Point (Mile Marker)	Ending Point (Mile marker)
9	SR 43 in Pearl River County from Pinetucky Road to SR 26/Dist 6	SR 43	in Pearl River County from Pinetucky Road	to SR 26
10	US 11 in Pearl River County from Minkler Road to Charwood Drive/Dist 6	US 11	in Pearl River County from Minkler Road	to Charwood Drive
11	11 in Pearl River County from Charwood Drive to the north corporate limits of Poplarville/Dist 6	US 11	in Pearl River County from Charwood Drive	to the north corporate limits of Poplarville
12	Scooba-Noxubee County Line (7 ½ Miles of 4 lane) in Kemper County /Dist 5	US45	Scooba 0.644 North of	Noxubee County Line
13	Porterville-Scooba (9 ¾ Miles of 4 lane)/Dist 5	US45	Porterville	Scooba
14	Lauderdale to Porterville (10 Miles of 4 lane)/Dist 5	US45	Lauderdale	Porterville

a - Traffic Volume Over time per Segment

One of the most valuable pieces of information provided by the Planning Division to the research team was “Traffic Volume Over time per Segment” in the studied area. The MDOT Planning Division provided historical data regarding traffic flow in various locations of the studied road segments. The traffic volumes provided corresponded to the period before and after the construction on each particular segment. Since construction on each segment of the projects was performed on different dates, the time periods of traffic volume for each segment is different. Figure 4 shows the traffic volume for each segment during the timeframe used for the study. The numbers in black represent the number obtained from the Planning Division, the numbers in red represent extrapolated counts based on the information obtained. Likewise, Figure 5 is a graph showing the traffic volume for the different segments. It is important to highlight that the traffic volume of most of the road segments in the study were similar over time with exception of few segments.

	2000	2001	2002	2003	2004	2005	2006
ID: 1 - US 98 . 1From SR 63 to Greene CL , George			6500	6733.333	6966.667	7200	
ID: 2 - US 98 . 1From Perry CL to Old Hwy 24 , Greene		8500	8633.333	8766.667	8900		
ID: 2 - US 98 . 2From Perry CL to Old Hwy 24 , Greene				10000	9333.333	8666.667	8000
ID: 2 - US 98 . 3From SR 57 to Vernal River Rd , Greene				7300	7033.333	6766.667	6500
ID: 2 - US 98 . 4From Vernal River Rd to George CL , Greene				7700	7633.333	7566.667	7500
ID: 3 - US 98 . 1From Mahned Rd to SR 29 , Perry				10000	9900	9800	9700
ID: 3 - US 98 . 2From SR 29 to SR 198 , Perry		8700	9133.333	9566.667	10000		
ID: 3 - US 98 . 3From SR 198 (W) to Eight Mile Rd , Perry				8400	8500	8600	8700
ID: 4 - US 98 . 1From I-59 to US 49 , Forrest				13000	15000	17000	19000
ID: 5 - SR 589 . 1From WPA to Old Hwy 24 , Lamar		2000	2000		2000		
ID: 6 - SR 589 . 1From US 98 to Epley Rd , Lamar	4300	4475	4650	4825	5000		
ID: 6 - SR 589 . 2From Epley Rd to SR 42 , Lamar	4200	4225	4250	4275	4300		
ID: 6 - SR 589 . 3From SR 42 to Covington CL , La	1800	1900	2000	2100	2200		
ID: 8 - SR 43 . 1From Dummyline Rd to Pearl River CL , Hancock				4000	4800	5600	6400
ID: 8 - SR 43 . 2From Pearl River CL to Salem Rd , Pearl River				4000	4800	5600	6400
ID: 9 - SR 43 . 1From Pinetucky Rd to SR 26 , Pearl River				1600	1700	1800	1900
ID: 10 - US 11 . 1From Derby Whitesand Rd to SR 26 , Pearl River					1900	2600	3300
ID: 11 - US 11 . 1From Derby Whitesand Rd to SR 26 , Pearl River				1900	2366.667	2833.333	3300
ID: 11 - US 11 . 2From SR 26 to North St , Pearl River				6200	6233.333	6266.667	6300
ID: 11 - US 11 . 3From North St to Lamar St , Pearl River				4800	4933.333	5066.667	5200
ID: 11 - US 11 . 4From Lamar St to Springhill Rd , Pearl River				1500	1566.667	1633.333	1700
ID: 14 - US 45 . 1From Old Lauderdale Rd to Kemper CL , Lauderdale				3600	3633.333	3666.667	3700
ID: 14 - US 45 . 2From Lauderdale CL to Dekalb-Porterville Rd , Kemper				3600	3633.333	3666.667	3700

Figure 4. Traffic Volume Over time per Segment

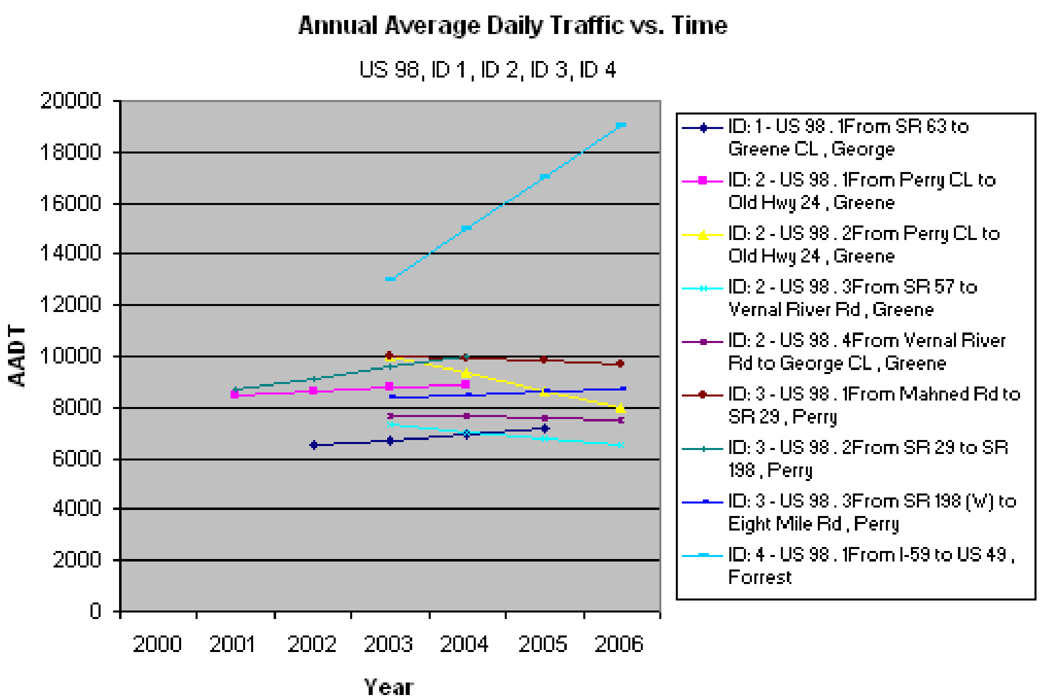

Figure 5. Traffic Volume Over time per Segment

b - Total Crashes per Segment Before and After Construction
Another valuable piece of information provided by the Traffic Engineering Division to the research team was "Total Crashes per Segment Before and After Construction" for the road segment studied. Figure 6 is a graphical representation of the data provided by the Traffic Engineering Division for crashes during the studied period of a sample road segment. This descriptive analysis provides the crash history before and after construction within the individual segments. The number in the table corresponds to the number of crashes during the month, and (c) corresponds to a construction period for the segment.

ID:1														
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec		Total
2002	1	1	2	2	2	1	2	2	2	1	0	2		18
2003	1	3	3	0	4	4	4	2	0	1	2	1		25
2004	2	0	1	(c)	(c)	(c)	(c)	(c)	(c)	1	0	0		
2005	1	0	2	1	0	2	1	3	3	3	0	3		19
2006	0	1	2	1	1	3	1	1	1	1	1	1		14

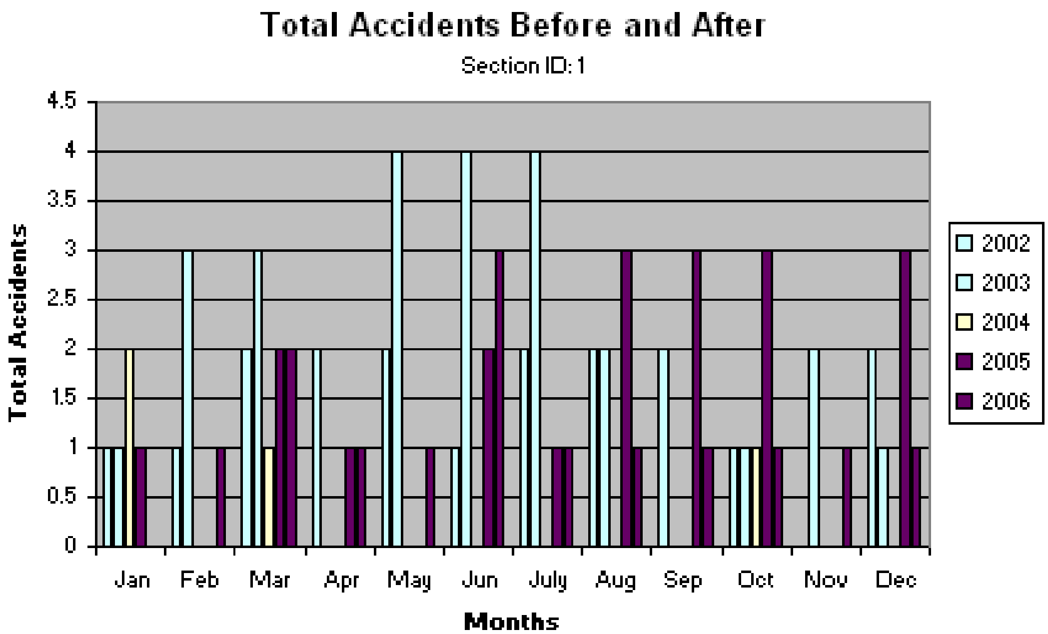

Figure 6. Total Crashes of Sample Segment Before and After Construction
Organized by Month of the Year

c- Roadway Departures and Overturn per Segment Before and After Construction
This analysis is similar to the previous analysis, showing in a graphical format the trend from before to after the placement of construction. The difference between this analysis, and the previous one, is that this analysis focuses only on roadway departures and overturn crashes. Since roadway departures are a leading cause of traffic death, the next logical step for the researchers was to determine if roadway departures were impacted by the placement of construction. Figure 7 shows a sample of roadway departures and overturn crashes. The numbers in the figure correspond to the number of roadway departures and overturns crashes each month, and (c) corresponds to a construction period for the segment.

ID:13														
Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec		Total
1999	2	0	2	1	1	0	0	0	2	1	0	1		10
2000	1	0	1	1	0	1	1	0	3	0	0	2		10
2001	2	1	0	1	(c)	(c)	(c)	(c)	(c)	(c)	(c)	(c)		
2002	(c)	(c)	(c)	(c)	(c)	(c)	(c)	(c)	0	0	2	0		
2003	0	0	0	0	1	4	1	0	0	1	0	0		7
2004	0	0	0	0	0	0	0	0	0	0	0	0		0
2005	0	0	0	0	0	0	0	1	1	0	1	0		3

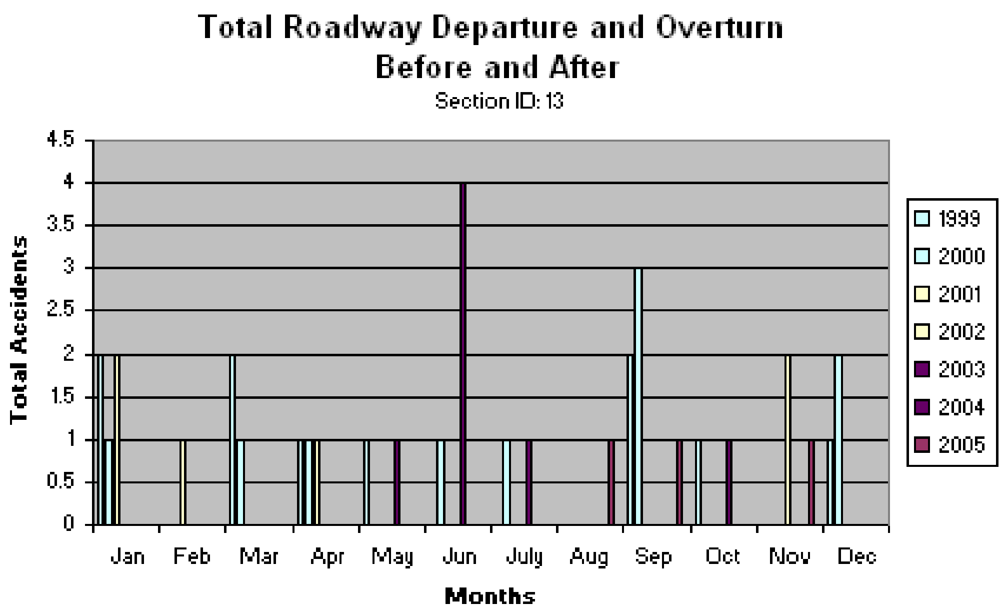

Figure 7. Roadway Departures and Overturn of Sample Segment
Before and After Construction Organized per Month

<u>d - Total Crashes per Segment under Different Lighting Conditions Before and After Construction</u>

In addition to analyzing the data before and after the impact of construction, the data was also analyzed according to the lighting conditions reported for the crashes. Figure 8 and 9 show the lighting conditions for all crashes in the studied road segments. Each segment has information regarding five lighting conditions: Dawn, Daylight, Dusk, Dark-Lighten, and Dark-Un-Lighten. For each lighting condition the following information is provided: Number of Months with Crashes (N), minimum number of crashes in any month with crashes (Min), maximum number of crashes (Max), mean number of crashes months with crashes (Mean) and standard deviation (Std. Dev.). Based on the results of this analysis summarized in Figure 7 and 8, it was determined that different lighting conditions have a definite impact on the number of overall crashes both before and after the construction was put in place.

		ID	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
BEFORE	Dawn	N		2.0	1.0		3.0	3.0	2.0	3.0	2.0		4.0		1.0	21.0
		Min		2.0	1.0		1.0	1.0	6.0	6.0	3.0		4.0		2.0	1.0
		Max		10.0	1.0		6.0	10.0	11.0	8.0	4.0		10.0		2.0	11.0
		Mean		6.0			3.3	4.3	8.5	7.0	3.5		7.0		2.0	
		Std. Dev.		5.7			2.5	4.9	3.5	1.0	0.7		2.6			
	Daylight	N	38.0	27.0	36.0		64.0	24.0	27.0	23.0	42.0	26.0	36.0		29.0	372.0
		Min	1.0	1.0	1.0		1.0	2.0	1.0	2.0	1.0	1.0	1.0		1.0	1.0
		Max	12.0	12.0	12.0		11.0	12.0	12.0	11.0	12.0	12.0	12.0		12.0	12.0
		Mean	5.8	6.7	6.2		5.9	6.8	7.0	6.6	5.5	6.4	6.8		6.3	
		Std. Dev.	2.9	3.6	3.7		2.7	3.2	3.6	2.8	3.3	3.4	3.0		3.9	
	Dusk	N	1.0						1.0				1.0			3.0
		Min	1.0						2.0				6.0			1.0
		Max	1.0						2.0				6.0			6.0
		Mean	1.0						2.0				6.0			
		Std. Dev.														
	Dark-Lit	N			3.0			3.0				1.0	3.0		1.0	11.0
		Min			7.0			1.0				12.0	6.0		1.0	1.0
		Max			12.0			11.0				12.0	11.0		1.0	12.0
		Mean			9.0			7.0				12.0	7.7		1.0	
		Std. Dev.			2.6			5.3					2.9			
	Dark-Unlit	N	6.0	17.0	13.0		34.0	17.0	8.0	15.0	16.0	9.0	13.0		8.0	156.0
		Min	2.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0	2.0	1.0		1.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	9.0	12.0	12.0	11.0	12.0		9.0	12.0
		Mean	7.8	6.4	7.6		6.8	6.2	3.6	5.2	6.7	5.6	6.9		4.3	
		Std. Dev.	4.0	3.6	4.3		3.9	3.5	2.7	3.6	3.5	3.5	4.4		3.2	

Figure 8. Total Accidents per Segment under Different Lighting Conditions
Before Construction

		ID	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	Overall
AFTER	Dawn	N	1.0	1.0			1.0			1.0				6.0	1.0	11.0
		Min	9.0	7.0			4.0			7.0				1.0	10.0	1.0
		Max	9.0	7.0			4.0			7.0				11.0	10.0	11.0
		Mean	9.0	7.0			4.0			7.0				6.7	10.0	
		Std. Dev.												4.4		
	Daylight	N	20.0	28.0	73.0		99.0	40.0	52.0	19.0	41.0	40.0	28.0	73.0	38.0	551.0
		Min	1.0	1.0	1.0		1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	11.0	12.0	12.0	12.0	12.0
		Mean	7.0	7.0	6.8		7.6	7.3	7.1	6.5	7.2	6.9	7.1	6.6	7.3	
		Std. Dev.	3.3	3.5	3.4		3.5	3.3	3.8	3.3	4.1	3.1	3.6	3.3	2.7	
	Dusk	N	1.0	1.0	1.0		4.0	2.0					1.0			10.0
		Min	5.0	11.0	4.0		1.0	3.0					12.0			1.0
		Max	5.0	11.0	4.0		12.0	12.0					12.0			12.0
		Mean	5.0	11.0	4.0		5.8	7.5					12.0			
		Std. Dev.					5.6	6.4								
	Dark-Lit	N	3.0		1.0		7.0	3.0	2.0	4.0	1.0	3.0	1.0	5.0	3.0	33.0
		Min	4.0		12.0		1.0	9.0	9.0	2.0	3.0	1.0	9.0	2.0	4.0	1.0
		Max	10.0		12.0		12.0	10.0	9.0	12.0	3.0	12.0	9.0	12.0	11.0	12.0
		Mean	6.7		12.0		8.1	9.7	9.0	7.3	3.0	7.3	9.0	7.4	7.7	
		Std. Dev.	3.1				4.5	0.6	0.0	5.0		5.7		3.9	3.5	
	Dark-Unlit	N	9.0	17.0	17.0		42.0	17.0	9.0	4.0	13.0	9.0	6.0	31.0	28.0	
		Min	3.0	2.0	1.0		1.0	1.0	3.0	2.0	1.0	2.0	4.0	1.0	1.0	22.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	11.0	12.0	11.0	12.0	12.0	12.0	11.0
		Mean	8.4	8.5	6.6		7.7	8.2	9.1	7.0	4.4	7.2	7.7	7.5	7.1	9.1
		Std. Dev.	3.1	3.1	4.0		3.6	4.3	3.7	4.7	3.7	3.1	2.9	4.2	3.6	

Figure 9. Total Accidents per Segment under Different Lighting Conditions
After Construction

e - Roadway Departures and Overturn per Segment under Different Lighting Conditions Before and After Construction

Similar to the previous analysis, the roadway departures and overturn crashes were analyzed according to the lighting conditions. Figure 10 and 11 shows only the roadway departures and overturn crashes for the studied road segments. Each segment has information regarding five lighting conditions: Dawn, Daylight, Dusk, Dark-Lighten, and Dark-Un-Lighten. For each lighting condition, the following information is provided: Number of Months with roadway departures and overturn crashes are provided (N), minimum number of roadway departures and overturn crashes on any month with roadway departures and overturn crashes (Min), maximum number of roadway departures and overturn crashes (Max), mean number of roadway departures and overturn crashes for the months with roadway departures and overturn crashes (Mean) and standard deviation (Std. Dev.). Based on the results of this analysis summarized in Figure 10 and 11, it was determined that as in the previous analysis, different lighting conditions have a definite impact on the number of roadway departures and overturn crashes both before and after construction.

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
BEFORE	Dawn	N		2.0			1.0	1.0	2.0	2.0	1.0		2.0		1.0	12.0
		Min		2.0			1.0	10.0	6.0	7.0	3.0		6.0		2.0	1.0
		Max		10.0			1.0	10.0	11.0	8.0	3.0		10.0		2.0	11.0
		Mean		6.0			1.0	10.0	8.5	7.5	3.0		8.0		2.0	
		Std. Dev.		5.7					3.5	0.7			2.8			
	Daylight	N	17.0	22.0	15.0		18.0	8.0	9.0	12.0	24.0	4.0	10.0		16.0	155.0
		Min	2.0	1.0	2.0		1.0	2.0	1.0	2.0	1.0	2.0	4.0		1.0	1.0
		Max	12.0	12.0	11.0		10.0	12.0	12.0	10.0	12.0	8.0	12.0		12.0	12.0
		Mean	6.4	6.7	6.3		5.2	7.8	7.1	7.0	5.5	5.5	7.7		6.6	
		Std. Dev.	2.5	3.7	3.2		2.6	3.6	3.6	2.3	3.5	3.0	2.9		4.0	
	Dusk	N														0.0
		Min														0.0
		Max														0.0
		Mean														
		Std. Dev.														
	Dark-Lit	N													1.0	1.0
		Min													1.0	1.0
		Max													1.0	1.0
		Mean													1.0	
		Std. Dev.														
	Dark-Unlit	N	3.0	14.0	5.0		12.0	11.0	3.0	8.0	9.0	5.0	3.0		6.0	79.0
		Min	4.0	3.0	3.0		1.0	1.0	3.0	2.0	3.0	2.0	4.0		1.0	1.0
		Max	11.0	12.0	12.0		12.0	11.0	9.0	10.0	11.0	7.0	12.0		9.0	12.0
		Mean	7.7	7.3	8.6		6.8	5.0	6.0	4.8	7.8	4.6	8.7		4.8	
		Std. Dev.	3.5	3.3	3.4		4.1	2.9	3.0	3.0	2.8	2.1	4.2		3.4	

Figure 10. Total Roadway Departures and Overturns per Segment under Different Lighting Conditions Before Construction

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
AFTER	Dawn	N								1.0				2.0		3.0
		Min								7.0				10.0		7.0
		Max								7.0				11.0		11.0
		Mean								7.0				10.5		
		Std. Dev.												0.7		
	Daylight	N	5.0	8.0	7.0		17.0	8.0	3.0	1.0	5.0	3.0	2.0	21.0	7.0	87.0
		Min	6.0	4.0	2.0		4.0	3.0	4.0	4.0	4.0	3.0	12.0	1.0	5.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	4.0	12.0	11.0	12.0	12.0	11.0	12.0
		Mean	8.6	8.1	8.4		8.3	7.4	7.7	4.0	9.4	7.7	12.0	6.6	7.1	
		Std. Dev.	2.2	3.4	3.4		2.7	3.2	4.0		3.7	4.2	0.0	3.3	2.1	
	Dusk	N														0.0
		Min														0.0
		Max														0.0
		Mean														
		Std. Dev.														
	Dark-Lit	N	1.0											2.0		3.0
		Min	6.0											9.0		6.0
		Max	6.0											12.0		12.0
		Mean	6.0											10.5		
		Std. Dev.												2.1		
	Dark-Unlit	N	2.0	7.0	3.0		14.0	1.0				4.0		5.0	5.0	41.0
		Min	10.0	2.0	10.0		3.0	9.0				9.0		1.0	6.0	1.0
		Max	12.0	12.0	12.0		12.0	9.0				11.0		12.0	11.0	12.0
		Mean	11.0	9.0	10.7		8.9	9.0				10.5		8.6	9.2	
		Std. Dev.	1.4	3.5	1.2		2.9					1.0		4.4	2.2	

Figure 11. Total Roadway Departures and Overturns per Segment under Different Lighting Conditions After Construction

f - Total Crashes per Segment under Different Road Conditions Before and After Construction

The data was also analyzed to understand the impact of different road conditions before and after construction. Figures 12 and 13 show the total crashes per segment under different road conditions before construction on the studied road segments. Each segment has information regarding three road conditions: Dry, Wet, and Snow. For each road condition, the following information is provided: Number of Months with crashes (N), minimum number of crashes reported in any month (Min), maximum number of crashes reported in any month (Max), mean number of crashes reported for the months (Mean) and standard deviation (Std. Dev.).

Based on the results of this analysis summarized in Figure 12 and 13, it was determined that different road conditions have a definite impact on the number of crashes. This occurs both before and after construction. It is also important to highlight that, while there are fewer crashes in wet and snow conditions, the number of hours per year of wet and snow on the studied road segments are significantly less. The specific analysis regarding the distribution of hours of dry, wet and snow conditions was beyond the scope of this project.

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
BEFORE	Dry	N	40	43	46		96	47	35	40	53	32	54		39	525
		Min	1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	12.0	12.0		12.0	12.0
		Mean	5.9	6.4	6.6		5.9	6.3	6.4	6.1	5.6	6.1	7.1		5.6	
		Std. Dev.	3.3	3.6	4.0		3.1	3.4	3.7	3.1	3.3	3.6	3.2		3.8	
	Wet	N			1.0				3				2			6
		Min			3.0				2.0				2.0			2.0
		Max			3.0				8.0				6.0			8.0
		Mean			3.0				4.0				4.0			
		Std. Dev.							3.5				2.8			
	Snow	N	4	3	6						6	3				22
		Min	3.0	9.0	2.0						2.0	7.0				2.0
		Max	7.0	10.0	10.0						10.0	11.0				11.0
		Mean	6.0	9.7	7.0						6.0	8.7				
		Std. Dev.	2.0	0.6	3.9						3.5	3.6				

Figure 12. Total Crashes per Segment under
Different Road Conditions Before Construction

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
AFTER	Dry	N	33	34	78		130	54	54	27	47	50	30	107	62	706
		Min	1.0	2.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	12.0	12.0	11.0	12.0	12.0	12.0	12.0
		Mean	7.2	7.2	7.0		7.9	7.8	7.5	6.8	6.3	6.9	7.1	6.6	7.4	
		Std. Dev.	3.2	3.5	3.5		3.4	3.7	3.4	3.6	4.0	3.2	3.7	3.5	3.1	
	Wet	N	1	12	9		16	6	8	1	8	1	6		6	74
		Min	10.0	1.0	1.0		1.0	3.0	1.0	4.0	2.0	12.0	7.0		1.0	1.0
		Max	10.0	12.0	12.0		12.0	11.0	12.0	4.0	12.0	12.0	12.0		11.0	12.0
		Mean	10.0	8.6	5.2		5.6	6.7	6.5	4.0	7.1	12.0	8.8		7.3	
		Std. Dev.		3.1	3.7		4.2	3.4	5.6		5.2		1.9		4	
	Snow	N					3							1	1	
		Min					4.0							6.0	6.0	
		Max					11.0							6.0	6.0	
		Mean					7.0							6.0	6.0	
		Std. Dev.					3.6									

Figure 13. Total Crashes per Segment under
Different Road Conditions After Construction

g - Roadway Departures and Overturn Crashes per Segment under Different Road Conditions Before and After Construction

Similarly to the previous analysis, the roadway departures and overturn crashes data was also analyzed to understand the impact of different road conditions before and after construction. Figures 11 and 12 show the roadway departures and overturn crashes per segment under different road conditions before and after construction for the studied road segments. Each segment has information regarding three road conditions: Dry, Wet, and Snow. For each road condition, the following information is provided: Number of Months with roadway departures and overturn crashes (N), minimum number of roadway departures and overturn crashes reported in any month (Min), maximum number of roadway departures and overturn crashes (Max), mean number of roadway departures and overturn crashes reported for the months (Mean) and standard deviation (Std. Dev.).

Based on the results of this analysis summarized in Figure 14 and 15, it was determined that different road conditions have a definite impact on the number of roadway departures and overturn crashes. This occurs both before and after construction.

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
BEFORE	Dry	N	15	35	14		31	20	14	21	30	7	15	29	24	255
		Min	2.0	1.0	3.0		1.0	1.0	1.0	2.0	1.0	2.0	4.0	1.0	1.0	1.0
		Max	12.0	12.0	12.0		12.0	12.0	12.0	10.0	12.0	8.0	12.0	12.0	12.0	12.0
		Mean	6.7	6.6	6.8		5.7	6.4	7.1	6.2	5.8	4.4	7.9	7.5	5.7	
		Std. Dev.	2.9	3.6	3.3		3.4	3.4	3.3	2.7	3.4	2.4	2.9	3.6	3.9	
	Wet	N			1											1
		Min			3.0											3.0
		Max			3.0											3.0
		Mean			3.0											
		Std. Dev.														
	Snow	N	4	3	5						4	1				17
		Min	3.0	9.0	2.0						2.0	8.0				2.0
		Max	7.0	10.0	10.0						10.0	8.0				10.0
		Mean	6.0	9.7	8.0						7.3	8.0				
		Std. Dev.	2.0	0.6	3.4						3.8					

Figure 14. Total Roadway Departures and Overturns per Segment under Different Road Conditions Before Construction

		Segment	1	2	3	4	5	6	7	8	9	10	11	12	13	Overall
AFTER	Dry	N	8	12	6		25	13	2	2	3	7	2		10	
		Min	6.0	2.0	10.0		3.0	1.0	4.0	4.0	4.0	3.0	12.0		5.0	
		Max	12.0	12.0	12.0		12.0	12.0	7.0	7.0	12.0	11.0	12.0		11.0	
		Mean	8.9	7.8	10.8		8.6	7.6	5.5	5.5	7.7	9.3	12.0		8.1	
		Std. Dev.	2.4	3.3	1.0		2.7	4.0	2.1	2.1	4.0	2.9	0.0		2.4	
	Wet	N		3	3		2	1	1		2				1	
		Min		10.0	2.0		11.0	6.0	12.0		12.0				9.0	
		Max		12.0	7.0		12.0	6.0	12.0		12.0				9.0	
		Mean		11.3	5.3		11.5	6.0	12.0		12.0				9.0	
		Std. Dev.		1.2	2.9		0.7				0.0					
	Snow	N					3								1	
		Min					4.0								6.0	
		Max					11.0								6.0	
		Mean					7.0								6.0	
		Std. Dev.					3.6									

Figure 15. Total Roadway Departures and Overturns per Segment under Different Road Conditions After Construction

FROM RESEARCH TO THE STUDENTS LEARNING EXPERIENCE

It is worth noting that this first project from the MDOT to quantitatively document the effectiveness of rumble stripes on highway safety was a success. It provided quantitative evidences of the program effectiveness which had not been done before for multiple reasons including that the data is normally dispersed in many different places in several formats. For this study, all Divisions and Districts were very willing to collaborate and made possible the data consolidation.

The consolidated data has great value to the MDOT and also to student. The students now have the ability to learn through meaningful real world scenarios. The real world scenario for the students begins with the professor presenting two simple questions to the class 1-"What is the effectiveness of rumble stripes on highway safety?" and 2-"How could it be measured?" The students are encouraged to perform quick literature review and establish a possible research methodology. Based on the literature review, the students are requested to create more specific research questions (framed by the two simple questions above). The students are also requested identify all data needed to answer their specific questions. Then a debate-like activity is performed in the classroom, where the students' ideas are challenged by their peers and the specific research questions are fined tuned. The professor then provides part of the thousands of data points that were consolidated as part of the original research. The student then are required to understand the data and identify what other data will be needed to answer the two original questions (guided by their specific questions). The professor then provides the remaining data and the students must derive their conclusion from the data using the statistical methods of their choice.

SUMMARY

One of the special measures implemented by numerous departments of transportation around the United States, to reduce the number and severity of crashes and roadway departures is the placement of rumble stripes during the construction. This paper focused on the descriptive analysis to quantify the impact of the placement of rumble stripes during the construction. The results presented in this paper indicate that the placement of rumble stripes during construction of the roadway segments in the studied area significantly improved safety in terms of the number and severity of crashes and roadway departures.

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