Safety Evaluation of Sinusoidal Centerline Rumble Strips

Task 7: Summary of "After" Period Data

Prepared by:

Eric T. Donnell
Professor

Vikash V. Gayah
Professor

Prakash Poudel
Doctoral student

Department of Civil and Environmental Engineering
The Pennsylvania State University
208 Engineering Collaborative and Research and Education Building (ECoRE)
University Park, PA 16802

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The Montana Department of Transportation

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BACKGROUND

The objective of the Task 7 deliverable is to summarize the data collection activities and protocols that were used to develop the "after" period data to be used in the safety evaluation of sinusoidal centerline rumble strips. The "before" data collection efforts took place during Tasks 4 and 5 of the project, which involved compiling crash data, electronic roadway data, and supplemental data for the treatment and reference group sites. These activities were described in the Task 6 memorandum submitted to MDT for review.

The current memorandum summarizes after period crash/roadway data and provides a preliminary statistical model to predict crash frequencies on roadway segments without centerline rumble strips.

SUMMARY OF ROADWAY AND CRASH DATA

The dataset for this study consisted of 10,785 segments of two-lane, undivided rural roads with posted speed limits greater than 45 mph, representing a total length of 7,565.7 miles. In 2021, sinusoidal centerline rumble strips were installed on 490.4 miles (about 6.5%) of these roads. Thus, for the purposes of this project, the period from 2016 to 2020 (inclusive) is considered the "before" period and the period from 2022 to 2024 (inclusive) is considered the after period.

After period roadway and traffic data obtained from the Montana Department of Transportation (MDT) were merged with the segmented before-period dataset. The additional roadway and traffic variables included the presence of shoulder rumble strips, annual average daily traffic (AADT), and crash counts for the after period (2022–2024). All other roadway attributes—such as surface width, paved shoulder width, and geometric characteristics (e.g., horizontal curve radius, vertical grade)—were assumed to remain unchanged between the before and after periods. The research team confirmed that sites at which sinusoidal rumble strips were installed did not previously have centerline rumble strips during the before period. For certain segments, AADT values were missing for 2023 and 2024. These values were estimated by applying the average annual growth rate to the most recent year of AADT data found in the Montana DOT data files. Crash data for the years 2016–2024 were then merged with the roadway data using crash location information. Table 1 provides descriptive summary statistics of the annual crash frequencies for each target crash type during the before and after periods.

Table 1. Summary of reported crash frequencies

Description	Year	Mean	Standard Deviation	Min	Max	Average for respective before/after period
Total Crash Frequency	2016	0.355	0.84	0	14	0.373
	2017	0.386	0.898	0	13	
	2018	0.387	0.905	0	17	
	2019	0.357	0.84	0	13	
	2020	0.381	0.877	0	11	
	2022	0.369	0.899	0	15	0.355
	2023	0.342	0.849	0	14	
	2024	0.353	0.852	0	13	
Fatal and Injury Crash Frequency	2016	0.097	0.344	0	5	0.091
	2017	0.092	0.335	0	5	
	2018	0.088	0.332	0	5	
	2019	0.084	0.319	0	5	
	2020	0.093	0.333	0	4	
	2022	0.089	0.339	0	5	0.088
	2023	0.086	0.333	0	5	
	2024	0.089	0.331	0	5	
Head On Crash, Total Frequency	2016	0.005	0.071	0	2	0.005
	2017	0.005	0.075	0	2	
	2018	0.004	0.068	0	2	
	2019	0.004	0.065	0	1	
	2020	0.005	0.07	0	1	
	2022	0.005	0.071	0	2	0.005
	2023	0.006	0.08	0	2	
	2024	0.004	0.065	0	1	
Head On Crash, Fatal and Injury Frequency	2016	0.004	0.061	0	2	0.004
	2017	0.004	0.066	0	2	
	2018	0.003	0.06	0	2	
	2019	0.004	0.06	0	1	
	2020	0.004	0.065	0	1	
	2022	0.004	0.06	0	1	0.004
	2023	0.004	0.067	0	1	
	2024	0.003	0.054	0	1	

Description	Year	Mean	Standard Deviation	Min	Max	Average for respective before/after period
Opposite Direction Sideswipe, Total Frequency	2016	0.008	0.091	0	1	0.007
	2017	0.006	0.078	0	1	
	2018	0.006	0.08	0	2	
	2019	0.006	0.079	0	1	
	2020	0.007	0.084	0	2	
	2022	0.007	0.086	0	2	0.007
	2023	0.008	0.092	0	2	
	2024	0.007	0.086	0	3	
Opposite Direction Sideswipe, Fatal and Injury Frequency	2016	0.005	0.067	0	1	0.003
	2017	0.002	0.048	0	1	
	2018	0.003	0.054	0	2	
	2019	0.003	0.053	0	1	
	2020	0.002	0.042	0	1	
	2022	0.003	0.053	0	1	0.003
	2023	0.003	0.058	0	2	
	2024	0.002	0.042	0	1	
Off Road Left, Total Frequency	2016	0.042	0.22	0	4	0.045
	2017	0.05	0.242	0	3	
	2018	0.045	0.224	0	3	
	2019	0.042	0.217	0	3	
	2020	0.045	0.226	0	3	
	2022	0.045	0.228	0	5	0.041
	2023	0.04	0.214	0	3	
	2024	0.039	0.216	0	5	
Off Road Left, Fatal and Injury Frequency	2016	0.019	0.142	0	2	0.017
	2017	0.02	0.148	0	2	
	2018	0.014	0.12	0	2	
	2019	0.015	0.127	0	2	
	2020	0.018	0.136	0	2	
	2022	0.017	0.132	0	2	0.017
	2023	0.016	0.13	0	2	
	2024	0.017	0.133	0	3	

Description	Year	Mean	Standard Deviation	Min	Max	Average for respective before/after period
Single Vehicle Run Off Road, Total Frequency	2016	0.104	0.363	0	4	0.116
	2017	0.123	0.422	0	8	
	2018	0.124	0.411	0	8	
	2019	0.111	0.383	0	5	
	2020	0.117	0.392	0	6	
	2022	0.12	0.417	0	8	0.109
	2023	0.103	0.378	0	8	
	2024	0.103	0.369	0	6	
Single Vehicle Run Off Road, Fatal and Injury Frequency	2016	0.045	0.221	0	4	0.043
	2017	0.045	0.223	0	4	
	2018	0.039	0.207	0	3	
	2019	0.039	0.207	0	4	
	2020	0.046	0.225	0	3	
	2022	0.042	0.215	0	3	0.04
	2023	0.038	0.205	0	3	
	2024	0.04	0.207	0	3	

Tables 2 presents the summary of target crash types separately for sites treated with SCLRS, sites having conventional CLRS, and sites having no CLRS (reference sites). The average crash frequencies for total crash and fatal and injury crashes are higher in the before-period than in the after-period across all three site categories, although the differences are relatively small. Further analysis will be carried out to evaluate whether the SCLRS treatment had a significant effect with respect to the reference sites and CLRS sites.

Table 2. Summary of reported crash frequencies for sites treated with SCLRS, conventional CLRS sites, and reference sites

Description	Period	SCLRS sites (N = 6,488)				conventional CLRS sites (N = 36,256)				Reference sites (N = 47,591)			
		Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max	Mean	Standard Deviation	Min	Max
Total crash frequency	2016 – 2020	0.853	1.257	0	11	0.438	0.888	0	12	0.326	0.858	0	17
	2022 – 2024	0.823	1.245	0	15	0.396	0.863	0	13	0.250	0.77	0	14
Fatal and injury crash frequency	2016 – 2020	0.196	0.475	0	3	0.103	0.351	0	5	0.081	0.319	0	5
	2022 – 2024	0.189	0.463	0	4	0.093	0.337	0	4	0.068	0.304	0	5
Head-on crash - Total frequency	2016 – 2020	0.010	0.103	0	2	0.006	0.076	0	2	0.004	0.065	0	2
	2022 – 2024	0.009	0.093	0	1	0.006	0.081	0	2	0.004	0.059	0	1
Head-on crash - Fatal and injury frequency	2016 – 2020	0.008	0.091	0	2	0.005	0.069	0	2	0.003	0.057	0	2
	2022 – 2024	0.006	0.078	0	1	0.005	0.068	0	1	0.002	0.049	0	1
Opposite direction sideswipe - Total frequency	2016 – 2020	0.015	0.124	0	2	0.008	0.087	0	2	0.006	0.079	0	2
	2022 – 2024	0.014	0.117	0	1	0.008	0.089	0	2	0.006	0.081	0	3
Opposite direction sideswipe - Fatal and injury frequency	2016 – 2020	0.008	0.094	0	2	0.003	0.051	0	1	0.003	0.055	0	2
	2022 – 2024	0.005	0.073	0	1	0.003	0.053	0	1	0.002	0.046	0	2
Off-road left - Total frequency	2016 – 2020	0.091	0.314	0	3	0.052	0.246	0	4	0.040	0.21	0	3
	2022 – 2024	0.086	0.326	0	5	0.045	0.226	0	3	0.032	0.192	0	5
Off-road left - Fatal and injury frequency	2016 – 2020	0.035	0.195	0	2	0.020	0.143	0	2	0.016	0.129	0	2
	2022 – 2024	0.034	0.190	0	2	0.017	0.132	0	3	0.014	0.12	0	2
Single vehicle run-off-road - Total frequency	2016 – 2020	0.232	0.532	0	4	0.135	0.432	0	8	0.102	0.365	0	5
	2022 – 2024	0.226	0.556	0	5	0.121	0.411	0	8	0.082	0.331	0	6
Single vehicle run-off-road - Fatal and injury frequency	2016 – 2020	0.087	0.306	0	3	0.049	0.231	0	4	0.038	0.206	0	4
	2022 – 2024	0.085	0.304	0	3	0.042	0.214	0	3	0.032	0.186	0	3

Tables 3 and 4 provide descriptive summaries of the AADT and shoulder rumble strip variables indicating their changes during the study period (2016 to 2024). The data indicates increases in the mean values of AADT and mileage of shoulder rumble strips between the before and after periods. Tables 5 and 6 present summaries of the continuous and categorical variables that were assumed to remain constant throughout the study period. For example, the surface width was assumed to remain the same throughout the analysis period.

Table 3. Summary of AADT

Description	Year	Mean	Standard Deviation	Min	Max	Average for before/after period
Average Annual Daily Traffic (AADT)	2016	1272.8	1516.0	21	29017	1276.4
	2017	1270.1	1563.3	21	30978	
	2018	1285.4	1553.3	14	31412	
	2019	1311.3	1608.8	14	30509	
	2020	1242.1	1537.8	1	13837	
	2022	1342.6	1696.1	1	14969	1385.4
	2023	1389.4	1754.5	16	16058	
	2024	1424.2	1799.7	1	15962	

Table 4. Summary of shoulder rumble strip presence by year

Shoulder rumble strips	Year	Mileage	Percentage	Average for before/after period
No rumble strip	2016	5877.9 mi	77.70%	76.34%
	2017	5860.1 mi	77.50%	
	2018	5877.9 mi	77.70%	
	2019	5720.4 mi	75.60%	
	2020	5535.8 mi	73.20%	
	2022	5269.9 mi	69.70%	69.30%
	2023	5221.5 mi	69.00%	
	2024	5233.5 mi	69.20%	
Shoulder RS	2016	1687.8 mi	22.30%	23.66%
	2017	1705.6 mi	22.50%	
	2018	1687.8 mi	22.30%	
	2019	1845.3 mi	24.40%	
	2020	2029.9 mi	26.80%	
	2022	2295.8 mi	30.30%	30.70%
	2023	2344.2 mi	31.00%	
	2024	2332.2 mi	30.80%	

Table 5. Summary of continuous variables in the dataset

Description	Mean	Standard Deviation	Min	Max
Surface Width, ft	29.54	5.72	19	74
Segment Length, mi	0.7	0.29	0.1	1
Paved shoulder width, ft	2.68	2.53	0	17
Posted speed limit, mph	68.04	4.87	50	70
No. of access points per mile	3.86	4.85	0	80
No. of intersections per mile	0.53	1.53	0	40
No. of horizontal curves per mile	1.02	1.91	0	20
Curve proportion, % (ratio of curve length to segment length)	12.82	22.3	0	100
Degree of curvature per mile	3.59	10.08	0	256.06
Average gradient (%)	0.6	0.5	0	6.56

Table 6. Summary of continuous variables in the dataset

Category	Mileage	Percentage
Functional classification		
Principal Arterial	2437.5	32.22%
Minor Arterial	2604.9	34.43%
Collectors	2516	33.26%
Local	7.3	0.10%
Centerline rumble strips		
No Rumble Strip	4138.6	54.70%
Centerline RS	3427.1	45.30%
Sinusoidal centerline rumble strips		
No Sinusoidal Rumble Strip	7075.3	93.52%
Sinusoidal RS	490.4	6.48%
Presence of curve type		
Reverse and compound curves [1]	37.1	0.49%
Reverse curve only	330.9	4.37%
Compound curve only	100.3	1.33%
Simple curve	2364.3	31.25%
No curve	4733.1	62.56%
Presence of curve warning sign		
No curve warning sign	7266.8	96.05%
Curve warning sign	298.9	3.95%
Posted speed limit (mph)		
50	96.3	1.27%
55	367.9	4.86%
60	342	4.52%
65	357.5	4.73%
70	6402	84.62%

PRELIMINARY CRASH FREQUENCY MODEL

A negative binomial model for expected total crash frequency was estimated for reference segments (i.e., those without centerline rumble strips) using crash data from 2016–2024. Table 7 presents the model results.

[1] To identify reverse and compound curves, spacing criteria between successive curves used was 300 ft or less

Table 7. Coefficients from the negative binomial model for total crashes for reference group

Variable	Coefficient	Std.error	p.value
(Intercept)	-8.111	0.078	<0.001
Natural logarithm of AADT	1.069	0.011	<0.001
Natural logarithm of segment length in miles	0.926	0.02	<0.001
Presence of shoulder RS (1 if true, 0 otherwise)	-0.223	0.026	<0.001
No. of intersections per mile	0.026	0.005	<0.001
No. of access points per mile	0.022	0.002	<0.001
Average vertical grade, %	0.049	0.022	0.025
Degree of curvature per mile	0.01	0.001	<0.001
Minimum radius 1000 ft or less (1 if true, 0 otherwise)	0.247	0.055	<0.001
Presence of reverse or compound curve (1 if true, 0 otherwise)	0.068	0.041	0.096
Presence of curve warning sign (1 if true, 0 otherwise)	0.213	0.042	<0.001
Surface width greater than 24 ft (1 if true, 0 otherwise)	-0.272	0.024	<0.001
Observation in year 2017 (reference year 2016)	0.032	0.037	0.378
Observation in year 2018 (reference year 2016)	0.043	0.037	0.242
Observation in year 2019 (reference year 2016)	-0.067	0.037	0.07
Observation in year 2020 (reference year 2016)	0.058	0.037	0.115
Observation in year 2022 (reference year 2016)	-0.067	0.041	0.099
Observation in year 2023 (reference year 2016)	-0.142	0.041	<0.001
Observation in year 2024 (reference year 2016)	-0.115	0.041	0.005

The results suggest that for the reference sites – with no centerline rumble strips - there were higher expected crash frequencies on segments with greater AADT, longer segment lengths, more intersections, more access points, steeper vertical grades, sharper curves (higher curvature per mile), and segments with curves having a minimum radius of 1,000 ft or less. On the other hand, expected crashes were lower on segments with shoulder rumble strips present, and surface width greater than 24 ft. These results are consistent with findings from existing roadway safety literature. Furthermore, for these reference sites, the expected crash frequencies for the before-period years (2017-2020) were generally not significantly different from the reference year 2016, with only 2019 and 2020 showing marginal significance. However, in the after period, significant differences in expected crash frequencies were observed from the baseline year 2016.