

Analysis of Run-Off-Road Crashes in Relation to Roadway Features and Driver Behavior

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ABSTRACT

The state of Wisconsin has been collecting crash information for the entire state trunk highway system that covers over 11,000 miles of roadways. This study examined crashes that occurred between 1998 and 2002, located based on a state-developed linear referencing system. A method (PRÈCIS), originally developed to systematically identify crashes on undivided state trunk highways (STH) and compute crash rates, crash densities (crashes/mile), and other safety statistics at any given point along a STH using a floating highway segment, was utilized. The study expanded the PRÈCIS application to divided highways and established relationships between driver actions that lead to a run-off-road crash and roadway information collected from the State Trunk Network log database. Information such as shoulder width, pavement condition, and roadside features indexed by mile point was examined. The crash database houses over 250,000 crashes that occurred over the analyzed five years, allowing a meaningful analysis of rural low-frequency crash types such as run-off-road crashes. The study merged crash and roadway databases and provided results on a linear highway- and mile point-indexed tabulation system. The results were also transferable to Geographical Information Systems for presentation.

The present analysis describes three tasks that demonstrate applications of the PRÈCIS algorithm and database: (1) development of average and 95th percentile crash rates for targeted crash subsets (e.g., rural, undivided, two-lane highways with 10 ft. shoulders); (2) identification of highway sections for safety improvements where crash rates exceed a set threshold value; (3) identification of the point of diminishing safety returns for highway improvements.

Key words: crash rate—safety improvement—shoulder width—state-wide safety

PROBLEM STATEMENT

The Wisconsin state trunk highway (STH) system covers approximately 12,000 highway miles, of which approximately 10,000 miles are classified as rural highways. The extent of the rural highway system and the relatively lower traffic volumes on these highways contribute to a wide scatter of crashes. It is, thus, a challenging job to identify “unsafe” highway segments using manual or even simple database searches, if a comprehensive state-wide safety evaluation based on crash rates is desired.

The Wisconsin Department of Transportation addressed this challenge and sponsored the development of an automated procedure (PRÈCIS) to analyze widely scattered crashes, based on a floating highway segment analysis method: crash rates are established for the entire STH system, using a one-mile highway length that is “floated” or moved over every highway in the system in small, even, increments at a time—establishing a crash rate for every 1/100th of a mile (point), based on the number of crashes and traffic volumes on short segments of the highway on either side of each point.

Because a number of highway features (such as shoulder widths, number of lanes, lane widths, median information, light posts and bridges) are indexed using a linear referencing system that can be correlated with PRÈCIS, it is possible to develop crash rates just for highway segments where a specific feature is present, for example segments with guardrail, or even contrast crash rates between segments with guardrail versus those using cable guard.

RESEARCH OBJECTIVES

The present effort demonstrates three types of statewide tasks that can be performed using the extensive PRÈCIS database. The first task presents crash rates developed for a targeted subset of crashes (driver intent of negotiating a curve was used as an example) and their relation to a specific geometric feature (right shoulder paved width was chosen here) for a variety of conditions (divided and undivided urban and rural highways with various lane configurations). The same principle can be applied to quantify crash risks posed by light posts or bridges, various types of barriers (concrete, guardrail, cable guard, curb and gutter, etc.), or median types (paved, rumble strip, barrier curb, etc.) Any number of crash rate statistics can be calculated (mean, median, standard deviation, etc.); the 99th percentile crash rates were used for this task in order to facilitate the second task, described below.

The second task demonstrates how the 99th percentile crash rate for a targeted subset of crashes developed under the first task can be used to identify the total length of highways that exceed this criterion and are therefore in need of safety upgrades. Furthermore, the termini of specific highway segments exceeding the 99th percentile crash rate are produced in tabular form (PRÈCIS capability to display results on color-coded geographic information systems [GIS] maps was presented in a 2006 Mid-Continent Symposium paper).

If the criterion for safety upgrades is set at a lower percentile, a larger number of highway miles will meet this new criterion. Safety program administrators can adjust the statewide length of high-risk highway segments targeted for safety upgrades to match available funding by choosing an appropriate crash rate percentile.

The third task demonstrates how benefit-cost analysis data can be developed for a targeted safety upgrade measure, for example provision of a shoulder (or shoulder widening). Paved and unpaved right shoulder widths are analyzed in relation to statewide run-off-road (ROR) crash rates on two-lane highways. The

point of diminishing (safety) returns for additional paved and/or unpaved shoulder width can be determined.

RESEARCH METHODOLOGY

The PRÈCIS database, consisting of records containing roadway feature, crash, and traffic volume information for each 1/100th of a mile along the entire Wisconsin STH system was used to develop crash rates. Separate crash rates were produced for all and ROR crashes for urban and rural, divided and undivided highways, segregated into cells representing combinations of number of lanes and right shoulder width. For the first task, mean and 99th percentile crash rates were calculated for each above-described cell; this information was used in the second task to identify the total length of highway segments meeting or exceeding a threshold value; specific highway segments were identified for targeted safety improvements. The third task required the development of regression models, using average crash rates as the dependent variables and paved, unpaved, and total right shoulder width as the dependent variable. A variety of regression models (linear, quadratic, polynomial) were fit to the data; the best-fitting models are presented herein.

KEY FINDINGS

Lengths of STH segments with right shoulder paved width within a given range are summarized in Table 1. The table provides a breakdown of information by highway classification (divided or undivided highway) and population density (urban or rural) for the most common numbers of lanes in each category. It should be noted that this information is provided as a demonstration of PRÈCIS capabilities. It is not intended to provide definitive crash rates for each presented category, given that about a third of the categories do not have adequate mileage.

Table 1. Right shoulder length (miles) for STH

		Rural population density				Urban population density			
		Divided hwy		Undivided hwy		Divided hwy		Undivided hwy	
		# of Lanes		# of Lanes		# of Lanes		# of Lanes	
		4	6	2	4	4	6	2	4
R Shoulder	1–3 ft.	118.42	4.45	6078.20	24.98	115.86	9.83	565.69	81.09
	4–8 ft.	790.53	12.20	1520.22	21.78	286.68	54.40	279.15	59.17
	9–12 ft.	650.49	87.81	223.88	1.62	183.36	101.93	100.87	14.38

Note: Cells shaded in light grey have very limited mileage—their information may not be reliable

Task 1. Statewide Crash Rate Statistics for Targeted Crash Subsets

The extensive crash rate database created by PRÈCIS was used to provide crash rate statistics corresponding to each category (cell) of Table 1. Table 2 provides average crash rates for Table 1 cells. In general, as expected, for identical numbers of lanes, crash rates for undivided highways are higher than for divided highways, and urban crash rates are higher than rural crash rates.

Table 2. Average crash rates, crashes per 100 MVMT, all crashes

		Rural population density				Urban population density			
		Divided hwy		Undivided hwy		Divided hwy		Undivided hwy	
		# of Lanes		# of Lanes		# of Lanes		# of Lanes	
		4	6	4	6	4	6	2	4
R Shoulder	1–3 ft.	99.30	195.02	143.19	121.50	125.27	191.83	137.38	155.05
	4–8 ft.	72.88	59.46	151.16	129.50	93.76	134.32	138.39	190.33
	9–12 ft.	56.81	78.98	193.52	126.55	79.56	94.34	136.31	176.38

A variety of statistics (median, standard deviation, different percentiles etc.) can also be produced for Table 1 cells. The 99th percentile crash rates in crashes per 100 million vehicle miles of travel (MVMT) for all types of crashes are displayed in sample Tables 3 through 6, in order to demonstrate possible cells for which statewide crash rate statistics can be calculated using PRÉCIS. The 99th percentile was chosen because it is used to demonstrate Task 2, presented later. It should be noted in Table 3 that the extreme values for the 99th percentile for six-lane divided and two-lane undivided rural highways (1533.73 and 1291.71 crashes per 100 MVMT, respectively) are due to large crash rate standard deviations within these two categories, multiples of which are added to the average crash rates in order to find the given percentiles.

Table 3. 99th percentile crash rates, crashes per 100 MVMT, all crashes

		Rural population density				Urban population density			
		Divided hwy		Undivided hwy		Divided hwy		Undivided hwy	
		# of Lanes		# of Lanes		# of Lanes		# of Lanes	
		4	6	4	6	4	6	4	6
R Shoulder	1–3 ft.	329.04	450.91	719.67	272.09	513.57	508.52	558.13	471.03
	4–8 ft.	245.65	267.50	701.77	258.00	318.05	449.17	659.24	474.92
	9–12 ft.	226.29	1533.73	1291.71	215.49	301.25	286.67	551.17	487.33

Table 4 displays run-off-road 99th percentile crash rates for Table 1 cells.

Table 4. 99th percentile crash rates, crashes per 100 MVMT, ROR crashes

		Rural population density				Urban population density			
		Divided hwy		Undivided hwy		Divided hwy		Undivided hwy	
		# of Lanes		# of Lanes		# of Lanes		# of Lanes	
		4	6	2	4	4	6	2	4
R Shoulder	1–3 ft.	146.46	65.88	388.52	152.53	119.04	72.84	247.70	137.85
	4–8 ft.	96.77	68.91	440.19	124.04	104.15	94.06	239.27	160.84
	9–12 ft.	98.41	842.05	468.18	57.04	93.52	106.05	179.40	142.00

Table 5 displays the 99th percentile crash rates for crashes where the driver was negotiating a curve at the time of the accident.

Table 5. 99th percentile crash rates, crashes per 100 MVMT, driver negotiating curve

		Rural population density				Urban population density			
		Divided hwy		Undivided hwy		Divided hwy		Undivided hwy	
		# of Lanes		# of Lanes		# of Lanes		# of Lanes	
		4	6	4	6	4	6	4	6
R Shoulder	1–3 ft.	72.83	15.59	252.33	24.04	24.68	15.23	115.37	23.47
	4–8 ft.	34.41	10.97	265.29	16.25	24.09	17.05	91.15	30.34
	9–12 ft.	16.65	90.22	328.80	4.99	23.72	23.72	106.74	24.99

Table 6 displays the 99th percentile crash rates by driver age for four-lane divided highways.

Table 6. 99th percentile crash rates, crashes per 100 million vehicle miles of travel, driver age group

Hwy classification: divided; # of Lanes: 4.00		Rural population density				Urban population density			
		16–24	25–34	35–44	45–64	16–24	25–34	35–44	45–64
R Shoulder	1–3 ft.	65.62	44.16	27.92	30.75	46.69	36.40	30.93	24.94
	4–8 ft.	36.61	29.03	26.88	30.11	47.83	28.90	25.33	20.09
	9–12 ft.	33.65	26.75	20.62	25.58	31.13	23.18	21.51	21.34

Task 2. Crash Rate Percentiles Used to Identify Highway Segments for Safety Upgrades

Once the 99th crash rate percentile values for a particular combination of highway type, right shoulder width range and crash category have been identified, the crash rate database can be queried again in order to identify the total length of highway segments that meet or exceed this crash rate. The query also provides the specific highway and highway segment(s) that meet or exceed this criterion.

Findings in Table 3 will then be used to identify segments meeting or exceeding the calculated 99th percentile crash rate. For example, a data base query indicated that there were a total of 9.38 STH miles exceeding a crash rate of 226.29 crashes per 100 MVMT (identified as the 99th percentile value for four-lane divided highways with shoulders 9–12 ft. in Table 3). A partial listing of identified segments is shown in Table 7 below, organized by right shoulder width, the sum of daily volumes in the analyzed five years, a highway reference point that provides highway, direction and milepost and the crash rate for the segment, based on five years of crashes and traffic information.

Table 7. STH rural divided four-lane highway segments targeted for treatment

R. shoulder (ft.)	5 YR ADT	Reference	Rate
9.00	2070	078N124 115	262.09
		078N124 121	262.09
	31700	002W022D000	273.83
		002W023D040	273.83
	160500	164N133K000	231.91
164N134D020		228.33	
10.00	2070	078N124 146	262.09
		078N124 150	284.63

Table 7 indicates, for example, that crash rates in the northbound direction of State Trunk Highway 78 between reference point 078N124 115 and reference point 078N124 121 (these codes provide the exact termini of a specific segment, approximately 320 ft. long) exceeded the 99th percentile value for similar divided four-lane rural highways with 9–12 ft. right shoulders since the segment had a crash rate of 262.09 crashes per 100 MVMT. The sum of ADTs during the five-year analysis period was 2070 vpd; the segment had 9 ft. shoulders.

If sufficient funds are available to treat more highway miles, the criterion for safety upgrades can be set at a lower percentile, so that a larger number of highway miles will meet this new criterion. For example, the 95th percentile crash rate value could have been used in the place of the 99th percentile to increase the number of miles identified for treatment. Safety program administrators can adjust the statewide length of high-risk highway segments targeted for safety upgrades to match available funding by choosing an appropriate crash rate percentile.

Task3. Identifying the Point of Diminishing Returns for a Targeted Safety Upgrade Measure

This section will demonstrate how PRÉCIS can be used to support a decision for a statewide policy on appropriate paved and unpaved right shoulder widths if it is desired to lower ROR crash rates on two-lane, two-way rural highways. Average crash rates are used throughout the section.

Between 1998 and 2002, 61,787 ROR crashes occurred on the Wisconsin STH system. The average ROR crash rate on rural roadways was approximately 30% higher than on urban roadways.

Table 8. ROR avg. crash rates, crashes per 100 MVMT, population density

	Rate	Length (miles)
Rural	51.0	10222
Urban	39.1	2195

ROR crash rates on rural highways were much higher for undivided roadways (Table 9), mainly due to two-lane pavements that comprised approximately 80% of the rural mileage (Table 10).

Table 9. Rural ROR avg. crash rates, crashes per 100 MVMT, highway classification

	Rate	Length (miles)
Divided	26.83	1997.85
Undivided	56.82	8215.93

Table 10. Rural ROR avg. crash rates, crashes per 100 MVMT, highway classification

Divided/Undivided	No. of Lanes	Crash rate	Length (miles)
D	4	25.0	1784.98
D	6	31.8	135.47
U	1	21.5	75.79
U	2	57.2	8046.62
U	4	36.8	62.60

Average ROR crash rates for two-lane rural highways were used as the dependent variable and paved right shoulder width as the independent variable in regression models (linear, quadratic, other polynomial) calibrated on the PRÈCIS database. Figure 1 is a graphical representation of the best fit, a third-degree polynomial model, with an R^2 value of 0.753. The model is based on a total of 8,038 miles of rural two-lane undivided highways. The diameters of the cross-hatched circles indicate the mileage for each given shoulder width value (exact mileage shown on the table accompanying Figure 1).

ROR crash rates drop rapidly as right paved shoulder width increases from zero to three ft.; this effect seems to taper off as the width of the paved shoulder increases to values greater than three ft.

The majority of rural two-lane mileage (5,792 miles) in the Wisconsin STH system has three ft. paved shoulders. These sections had a ROR crash rate of 50.3 crashes/100MVMT. A quadratic regression model (ROR crash rate independent variable; additional unpaved shoulder width dependent variable) was calibrated on this population of two-lane rural highways with paved three ft. shoulders. A graphical representation of the model is shown in Figure 2.

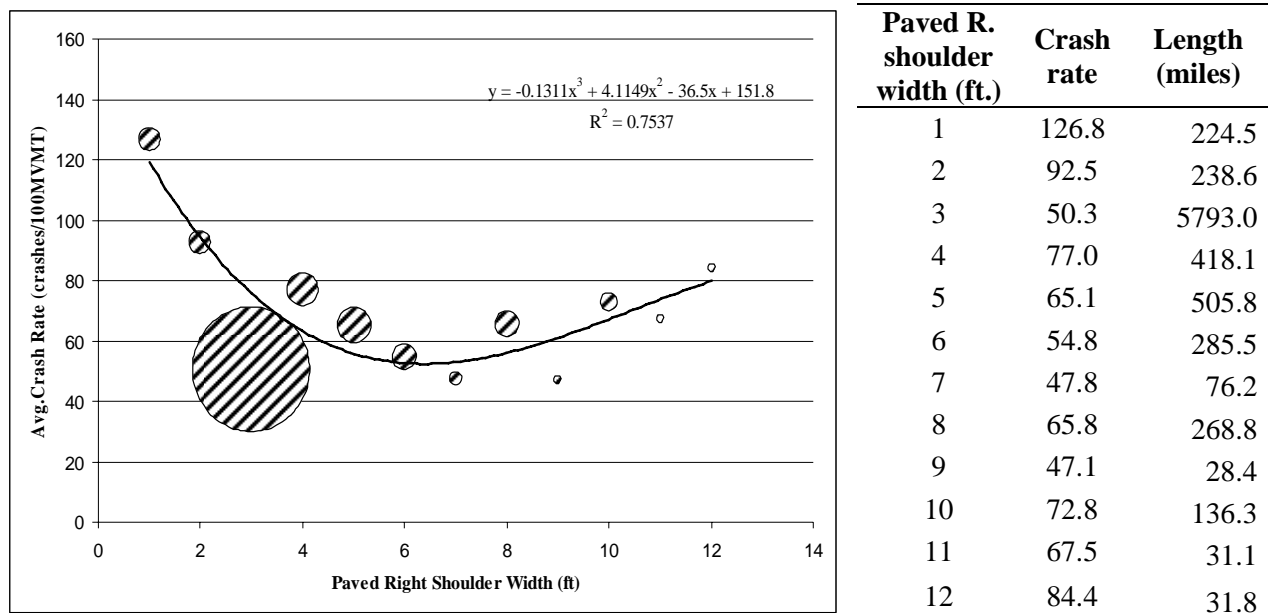
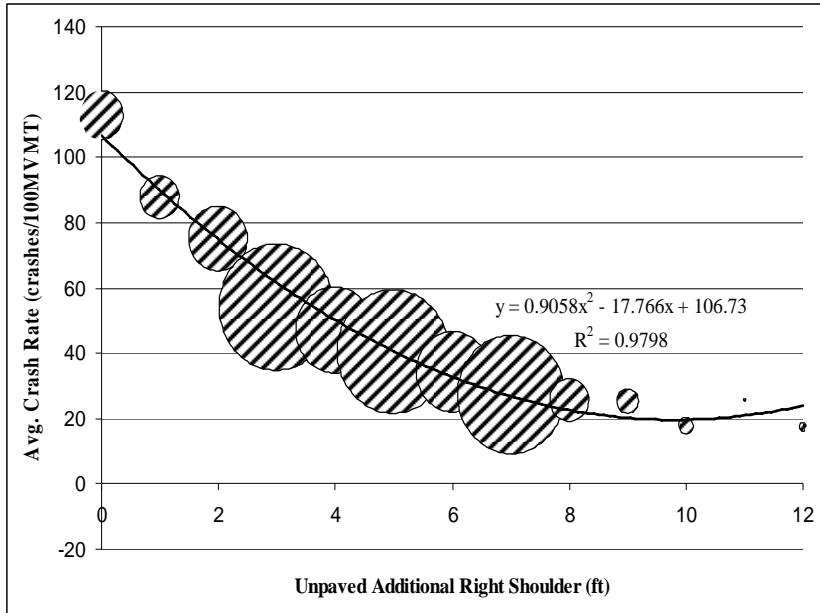


Figure 1. Effect of paved right shoulder width on average ROR crash rate



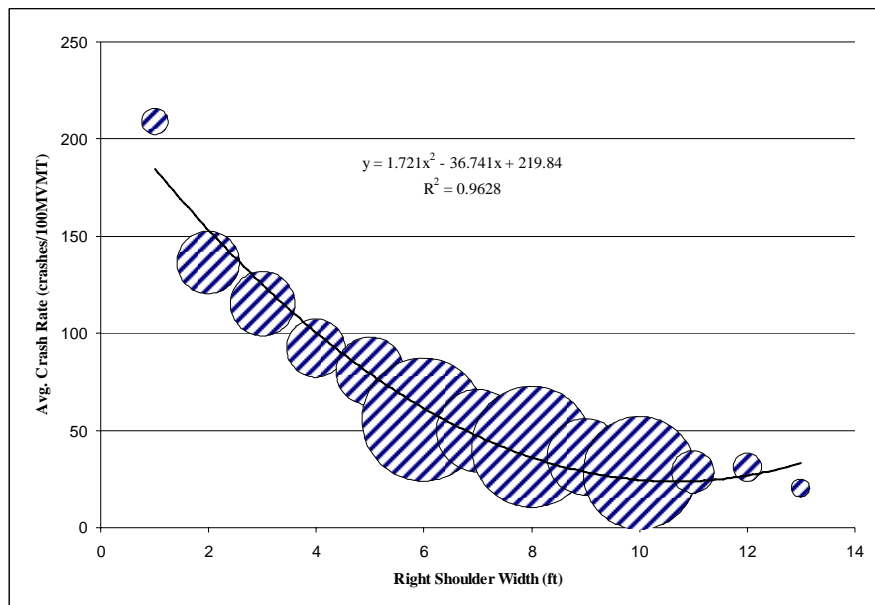
Unpaved R. shoulder width (ft.)	Crash rate	Length (miles)
0	112.9	184.8
1	87.8	149.7
2	74.9	339.7
3	54.2	1284.9
4	47	589.2
5	40.3	1207.1
6	34.3	507.0
7	27.5	1092.1
8	25.6	152.5
9	25.1	53.7

Figure 2. Effect of additional unpaved right shoulder width on average ROR crash rate

Figure 2 shows ROR crash rate reductions for two-lane rural highways with three ft. shoulders when additional unpaved shoulder width is provided. Crash rate reductions taper off for additional unpaved shoulder widths in excess of seven ft.; however, very limited mileage is available with wider unpaved shoulders, thus this width limit is a tentative finding.

When a quadratic regression model is calibrated using total right shoulder width (paved plus unpaved width) as the independent variable, it is shown that a crash rates become lower as the width increases from one to ten ft. (Figure 3); additional shoulder width does not reduce crash rates any farther. Here, again, there is limited mileage with a total right shoulder width greater than ten ft. for statistically sound findings.

PRÈCIS helped determine that, when it comes to ROR crashes on rural two-lane highways, crash rates decrease in direct relation to the available right shoulder width, up to a width of 10 ft. An optimal paved shoulder width is three ft.; additional safety benefits correlate well with the width of any available additional unpaved shoulder.



Unpaved R. shoulder width (ft.)	Crash rate	Length (miles)
1	208.8	78.8
2	136.5	426.5
3	115.2	437.6
4	92.5	380.0
5	80.3	494.8
6	55.7	1598.2
7	49.8	740.2
8	41.4	1542.5
9	36.2	625.0
10	27.9	1358.8
11	28.3	197.7
12	31.0	94.3

Figure 3. Effect of total paved right shoulder width on average ROR crash rate

CONCLUSIONS

PRÈCIS was shown to be suitable to provide statewide crash rate statistics for a variety of targeted crash types (e.g., driver negotiating a curve) or crashes associated with specific driver characteristics (e.g., driver age) on targeted highway subsets (e.g., rural four-lane undivided highways) that exhibit specific characteristics (e.g., a given shoulder width).

Furthermore, PRÈCIS was used to identify specific highway segments that exceed a certain crash rate threshold (based on statewide information) for a targeted type of safety problem. Adjusting the crash rate threshold upward (or downward) allows safety administrators to target a smaller (or larger) number of highway miles for safety treatment.

The PRÈCIS database provides the opportunity to identify the point of diminishing safety returns for various roadway features. For rural two-lane undivided highways, three ft. paved shoulders and seven ft unpaved shoulders were found to be associated with the lowest ROR crash rates, based on available statewide information.

PRÈCIS is a flexible method to analyze statewide safety information in a consistent and labor-efficient manner.

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