WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON

Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

RETROFIT MEDIAN BARRIER WARRANT FOR CROSS MEDIAN CRASHES

INTRODUCTION

Cross median crashes (CMC) in which a vehicle leaves a divided highway to the left and crosses completely through the median into oncoming roadway, are one of the most severe types of crashes due to high speeds and risk of collision with an opposing vehicle. Sideswipe collisions, overcorrecting after leaving the roadway to the right, and adverse roadway conditions are typical occurrences that initiate the loss of control and contribute to CMCs. Vehicles crossing the median commonly roll over, hit guardrails or other fixed objects, or collide with oncoming vehicles.

CMC are classified as one of two types; namely multi- and single-vehicle cross median crashes. CMC where the crossing vehicle collides with a vehicle in the opposing lanes are classified as multi-vehicle CMC. The severities of these crashes are typically high due to the high rates of speed and head-on or opposing sideswipe crash types. Additionally, as more vehicles are involved in a crash, more injuries and fatalities often result. Due to the catastrophic nature of multi-vehicle CMC, many agencies have made them the primary focus of safety improvements mitigating CMC.

In a vast majority of CMC observed in Wisconsin, the crossing vehicle entered or crossed the opposing travel lanes without colliding with an oncoming vehicle (*1*). These crashes, referred to as single-vehicle CMCs, are typically less severe and have fewer injuries than multi-vehicle crashes, but can still be severe as they often involve rollovers or collisions with roadside objects. Single-vehicle CMCs are expected to have contributing factors and crash dynamics that are similar to multiple-vehicle CMCs and would thus have similar treatments. Additionally, single-vehicle CMC incidents have the potential to become the more severe multi-vehicle crashes, but the crossing vehicle found a gap in the opposing traffic stream. Single-vehicle CMC frequency is an important factor in predicting safety performance on divided highways as they act as an indicator to highlight potential problem areas.

In 1978, California Department of Transportation (Caltrans) adopted the crash rate warrants of 0.50 CMC per mile per year and 0.12 fatal CMC per mile per year, with at least three CMC over a five year period, to determine sites that warrant additional analysis on the basis of crash history. The crash rate warrants were reviewed in 1991 by Seamons and Smith and again in 1997 by Nystrom et al. (*2*, *3*). Seamons and Smith concluded that the median width/traffic volume

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

warrant and the crash rate warrants (identified above) be retained as guidelines for identifying sites requiring additional analysis (*2*). Sites meeting the warrant with three to four crashes over a five year period "frequently lost their warrants before construction" due to the random nature of crashes. Although one of the suggestions was that the warrant be increased to require five rather than three crashes observed in a five year period, the crash frequency requirement was not changed so as not to "preclude valid projects from being identified and constructed." In 1997, Nystrom et al. concluded that the crash rate warrant was appropriate (*3*). This crash-rate warrant and CMC definition have been adopted as guidelines by Wisconsin Department of Transportation (WisDOT).

Currently, there is no flag in the Wisconsin crash report form (MV4000) to readily identify CMC in Wisconsin. The Traffic Operations and Safety Laboratory (TOPS Lab) at the University of Wisconsin-Madison had been identifying CMC and using the crash rate warrant to identify CMC hotspots for WisDOT. TOPS Lab used the 2001-07 CMC data and concrete median barrier crash (MBC) data to develop a predictive median barrier warrant for Wisconsin (*1*). For developing the predictive warrant TOPS Lab developed frequency models for CMC and MBC using the 2001-07 dataset and performed a benefit-cost analysis considering installation and maintenance costs for a barrier as well as savings from crash costs. This memo summarizes the research completed to develop a retrofit or crash-rate warrant for cable median barriers.

RETROFIT WARRANT DEVELOPMENT

Methodology

In order to evaluate the efficacy of constructing a median barrier, economic analysis using present worth of benefits and costs was performed. The benefit-cost framework formulated by the research team for developing predictive median barrier warrants was utilized for retrofit warrant development as well. Details of the framework are presented in the predictive median barrier warrant report (*1*). While the benefit-cost formulation is the same for both predictive and retrofit warrants, there is a fundamental difference between them. In the "Predictive" warrant, the number of CMC (multi or all) one can expect to see on the average in a year (given the influence of bridges, ramps, curves etc.) are predicted. In retrofit warrants the observed crashes (or crash rates) are used. A summary of the methodology is presented here along with the resultant rate thresholds and mileages of hotspots.

Net benefits include reduced crash costs due to elimination of CMC and increased crash costs due to MBC costs. The National Safety Council crash costs were used. The MBC frequency model developed as part of the predictive median barrier warrant development was used to

WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON

Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

estimate the number of MBC for a segment. In order to be conservative in estimating MBC frequency, bridges, ramps and curves were assumed to be absent in the segment. Costs include installation and maintenance costs of the cable barrier. Based on a previous cable barrier crash analysis performed for WisDOT, installations costs of $100,000 per mile and maintenance costs of $1,000 per cable barrier hit were used in the analysis (*4*). Salvage value for the barrier at the end of service life was assumed to be zero. Rate thresholds were computed for 10 year and 25 year service lives and a 3 percent discount rate was used for the analysis. Equations 1 and 2 are used to compute the present value of benefits and costs respectively for a 10 year service life.

$$PV_{benefits} = \sum_{t=0}^{9} \frac{E(crash\ cost_{cross\ median}) - E(crash\ cost_{median\ barrier})}{(1+i)^t} \quad (1)$$

$$PV_{costs} = 100000 + \sum_{t=0}^{9} \frac{number\ of\ crashes\ \times maintenance\ cost\ per\ crash}{(1+i)^t} \quad (2)$$

CMC rate thresholds were computed for different combinations of directional ADT and benefit cost ratios (B/C ratios). Results for the 25 year service life are presented in the appendix.

Warrant Thresholds

Tables 1 and 2 present the CMC rate thresholds (in per mile per year) for different combinations of directional ADT and B/C ratios for only multi-vehicle CMC and all CMC, respectively, for a 10 year service life.

TABLE 1. Multi-vehicle CMC Thresholds (per mi per year)

Directional ADT	B/C ratio		
	1	5	10
20000	0.05	0.10	0.17
30000	0.06	0.11	0.18
40000	0.07	0.12	0.19
50000	0.07	0.13	0.20

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

TABLE 2. All-CMC Thresholds (per mi per year)

Directional ADT	B/C ratio		
	1	5	10
20000	0.14	0.29	0.48
30000	0.17	0.32	0.52
40000	0.19	0.35	0.55
50000	0.21	0.38	0.58

COMPUTATION OF HOTSPOT MILEAGE

CMC thresholds (only multi and all-CMC) for various combinations of directional ADT and B/C ratios were presented in the previous section. In order to understand the impact of various thresholds, mileage of segments that would satisfy them were computed. Details of the hotspot mileage computation and the results are presented in this section.

CMC Data

As mentioned before, there is no flag in the MV4000 to readily identify CMC. Therefore, crash report forms of non-deer, non-intersection related crashes that occurred on all divided highways without barriers were reviewed manually. Over 52,000 crash report forms were manually reviewed to identify CMC from 2001-10. Between 2001 and 2010, 2,229 CMC (single and multi) occurred in Wisconsin of which 374 (17%) were multi-vehicle and 1,855 (83%) were single-vehicle CMC. Figures 1 and 2 show maps of multi-vehicle and single-vehicle CMC, respectively. Crash severity of single and multi-vehicle CMC are shown in Table 3. As one would expect multi-vehicle CMC are much more severe than single-vehicle CMC. About 21% of multi-vehicle CMC turned out to be fatal while 3% of single-vehicle CMC were fatal. About 78% of multi-vehicle CMC were fatal or injury while 54% of single-vehicle CMC were fatal or injury crashes.

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706
Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

TABLE 3. Crash Severity of Single and Multi-vehicle CMC

Crash Severity	Single-vehicle CMC	Multi-vehicle CMC
FAT	55 (3%)	79 (21%)
INJ	937 (51%)	214 (57%)
PDO	863 (46%)	81 (22%)

Current Wisconsin (and nationally) definition of CMC considers only multi-vehicle CMC and does not include single-vehicle CMC. Consequently, about 83% of CMC are not being considered for any safety analysis. In both the cases, a vehicle traverses the median and reaches opposing lanes. The only difference is that in the case of a single-vehicle CMC, there is no collision with a vehicle(s) in the opposing lanes because either there were no vehicles in opposing lanes or the vehicle was lucky enough to find a gap in opposing traffic. One may surmise that single-vehicle CMC occur in lower volume roadways while the converse holds for multi-vehicle CMC. Figure 3 shows a histogram of CMC (based on 2001-07 data) versus ADT. Figure 3 illustrates that about a quarter of single-vehicle CMC occur on roadways with ADT greater than 40,000. Conversely, multi-vehicle CMC occur on roadways with ADT lower than 10,000. Therefore, CMC single or multi can occur in any volume roadways and both should be considered in addressing CMC.

To illustrate the point further that single-vehicle CMC can be due to luckily finding a gap in opposing traffic, two CMC from 2011 are presented. Figure 4 shows a fatal single-vehicle CMC on U.S. 12 (Beltline highway) in Madison, with an ADT over 100,000 vehicles. A total of five vehicles (one semi-trailer) were involved in the crash, of which two were in opposing lanes. There was debris impact in the opposing lanes, but no collision with a vehicle. Therefore this crash would be classified as a single-vehicle CMC. Another single-vehicle CMC (shown in Figure 5) occurred on I-94 in Jefferson County, east of Madison. Two vehicles were involved in the crash, but no collision in opposing lanes. The witness was within one hundred yards of the crossed over vehicle in the opposing lanes, according to the police narrative in the crash report form, showing that the gap the driver snuck through was less than 100 yards. All these examples reiterate the need to consider single-vehicle CMC also as CMC and include them in safety analysis.

WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON

Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

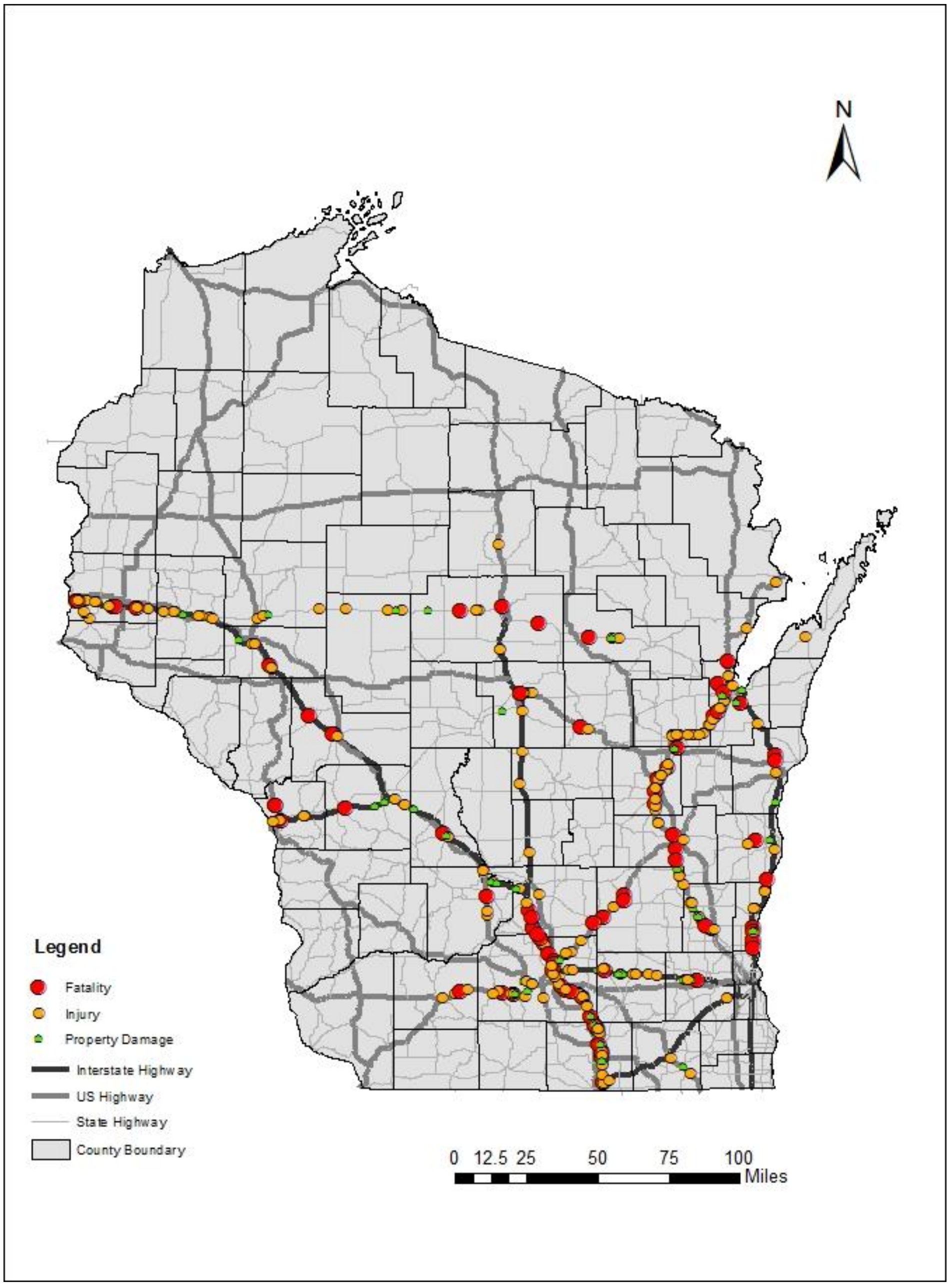

FIGURE 1. Multi-vehicle CMC in Wisconsin 2001-10.

WISCONSIN TRAFFIC OPERATIONS & SAFETY LABORATORY

UNIVERSITY OF WISCONSIN-MADISON

Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

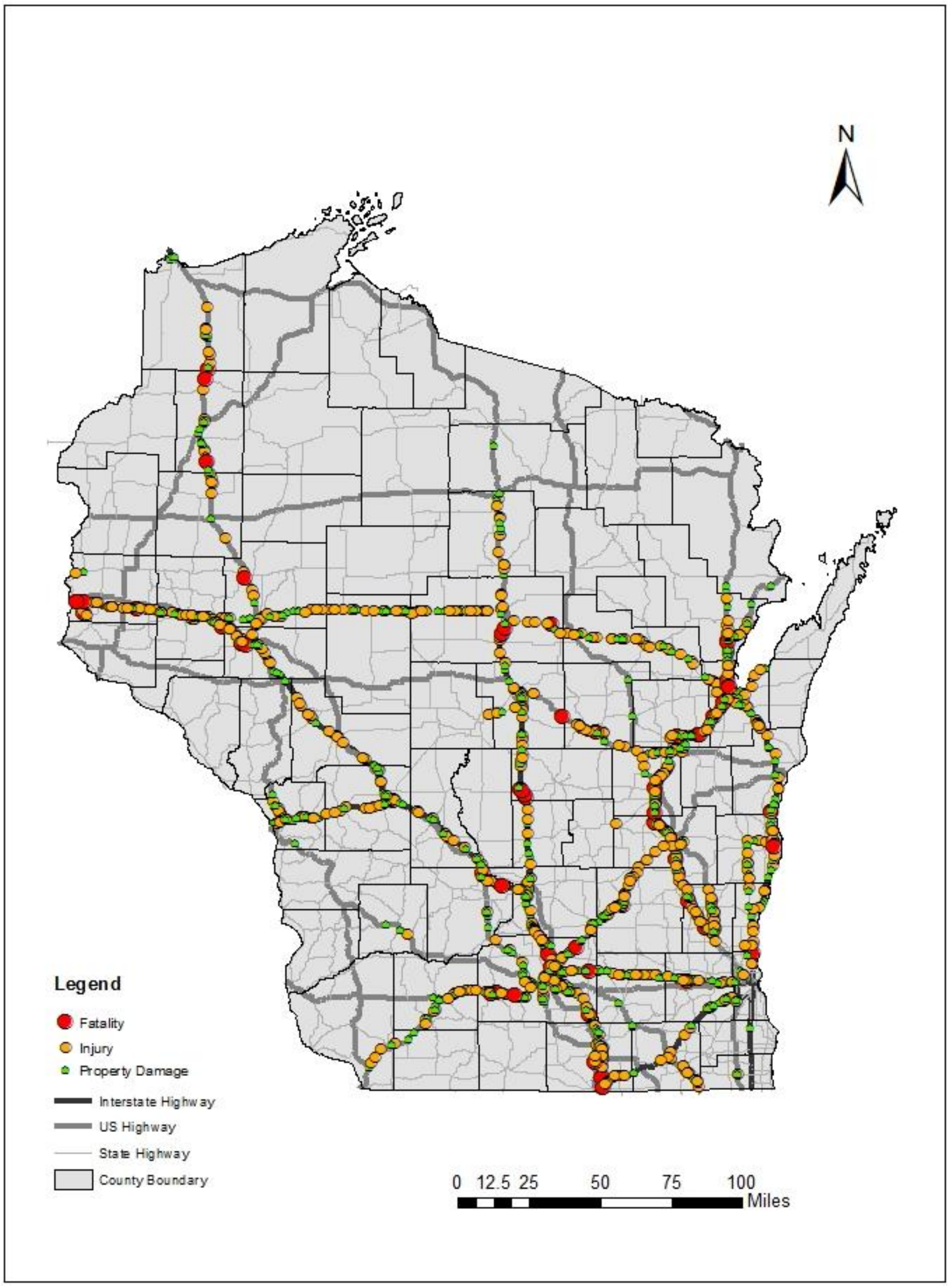

FIGURE 2. Single-vehicle CMC in Wisconsin 2001-10.

WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON
Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

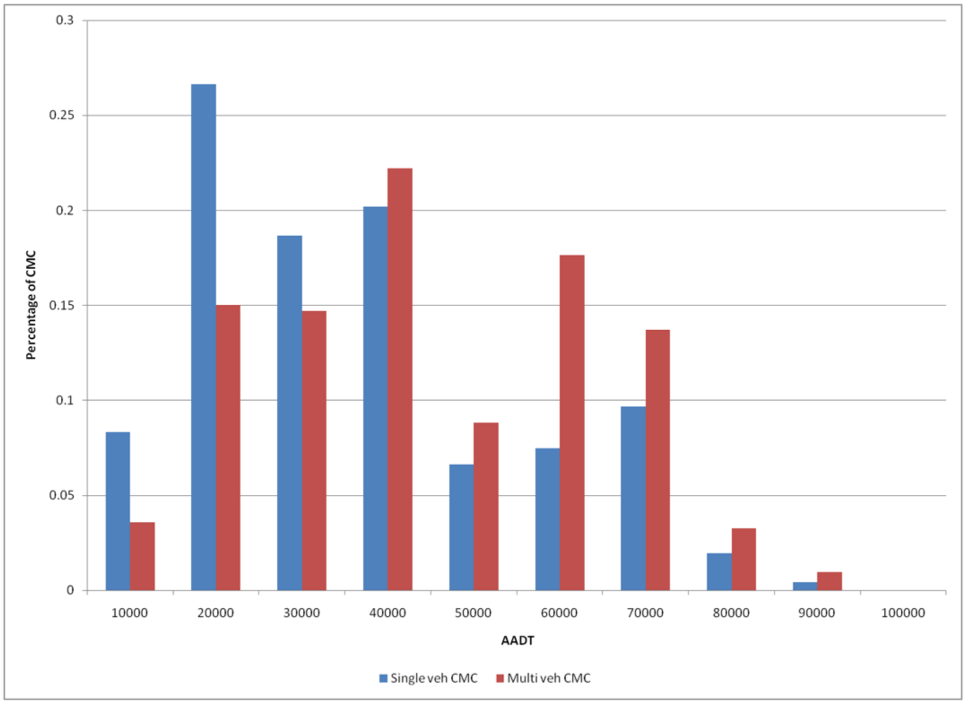

FIGURE 3. Histogram of CMC with AADT.

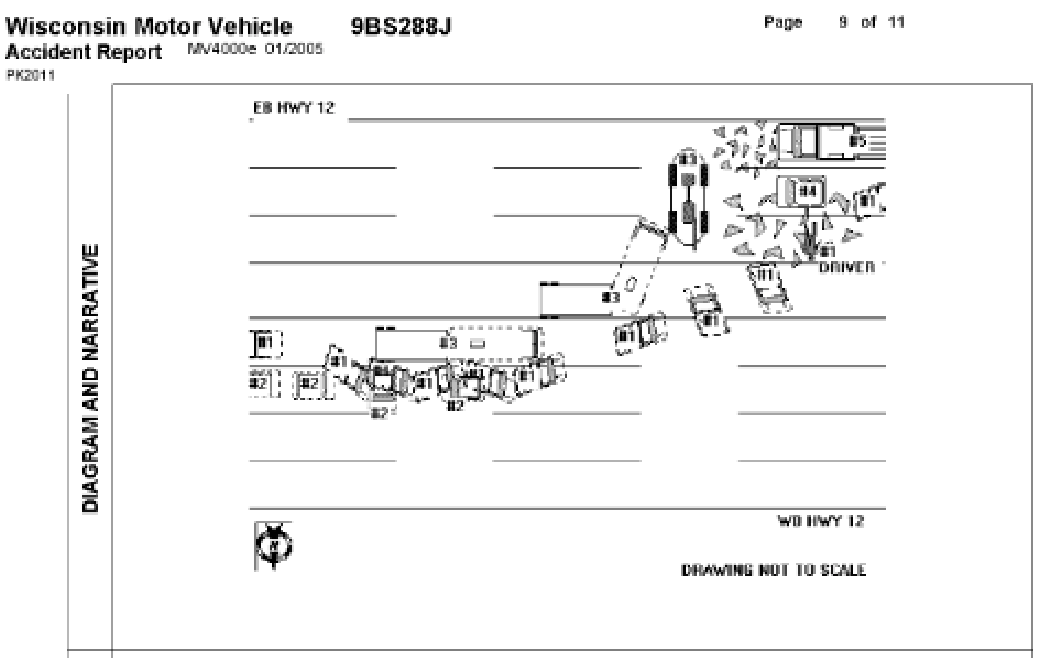

FIGURE 4. Single-vehicle CMC on Beltline Highway in Madison.

WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON
Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

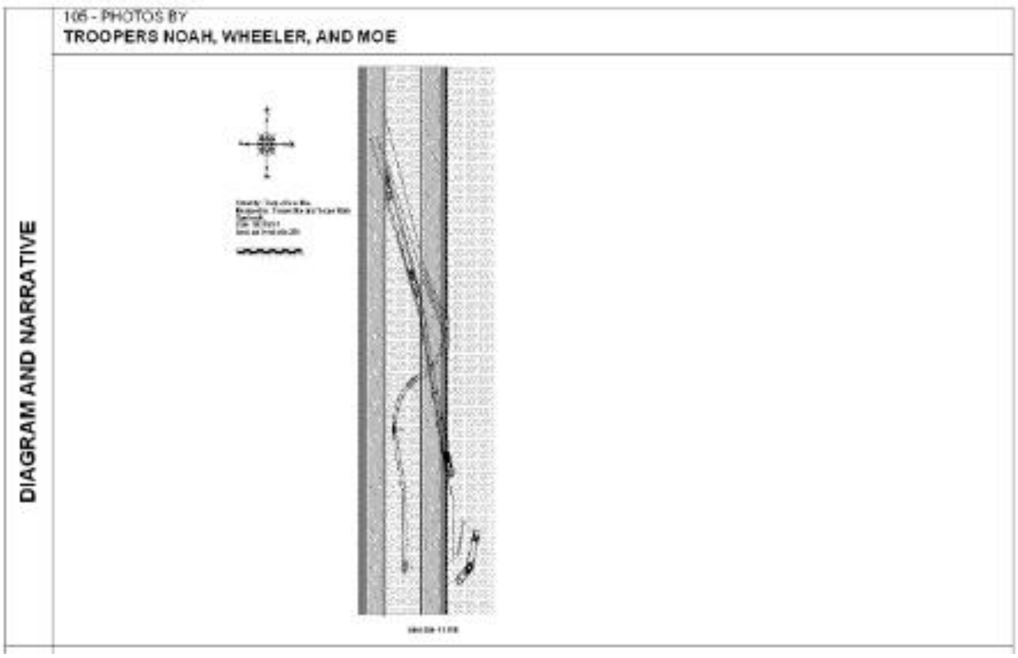

FIGURE 5. Single-vehicle CMC on I-94 in Jefferson County, East of Madison.

Data Processing

In order to compute the mileage that satisfies the computed retrofit warrants, WisDOT crash maps from 2001-10 were used. Past hotspot analysis involved manually computing the mile markers of each CMC and identifying the hotspots. Considering that there are over 2,200 CMC the manual approach was unfeasible and an automated method was developed in ArcGIS to compute the hotspots. Crash map for each year is generated using STN map of that year. In order to perform the analysis all the crashes are required to be on a single map. Therefore, all the CMC were snapped to 2010 STN. In order to avoid snapping the crashes to the wrong highways, every highway of interest was extracted from the STN separately and all the crashes that occurred on that highway (as indicated by the ONHWY field in crash data) were snapped to it. Forty one (of 2,229) were not located on the WisDOT crash maps. Furthermore, four crashes were off the highway by more than 1,000 m. Consequently, 2,184 CMC (368 multi and 1,816 single-vehicle) were used for computing the mileage that satisfies the warrant.

For each highway, CMC rates were computed for consecutive crashes. A series of CMC constitute a potential hotspot when the CMC rate exceeds the threshold. If there were at least three crashes in any given five year period (2001-05 or 02-06 or 03-07 or 04-08 or 05-09 or 06-

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

10) then that segment is a hotspot. Occasionally, hotspots may overlap and the crash rate for the combined hotspot may be smaller than the CMC rate threshold. An example of is illustrated in Figure 6.

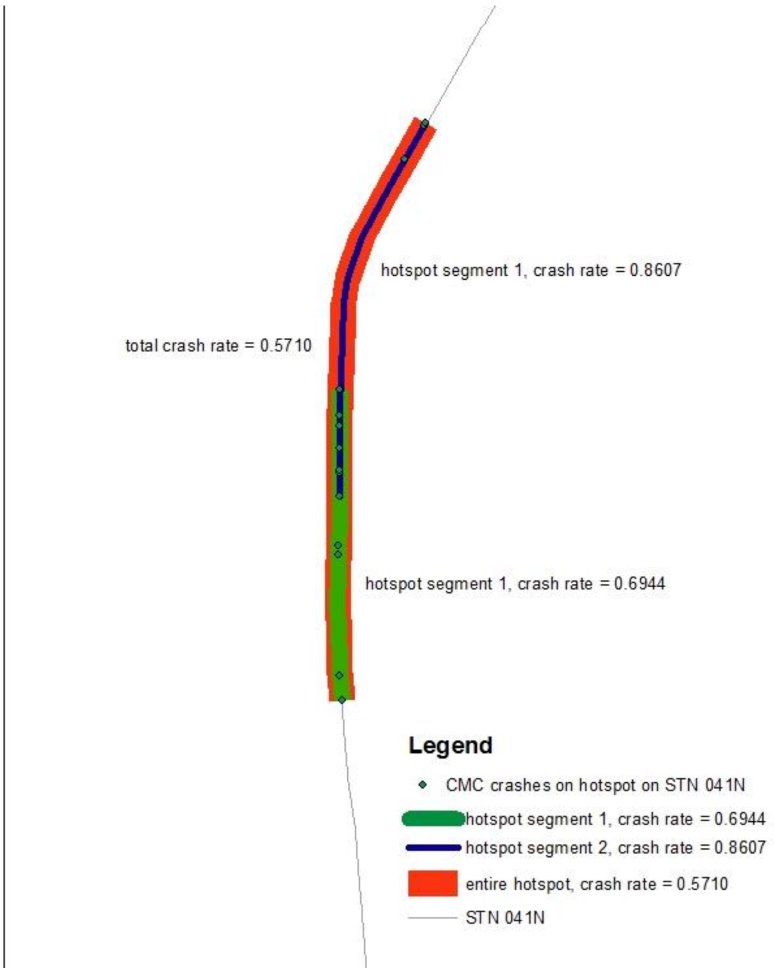

FIGURE 6. Overlapping Hotspots.

Hotspot Mileage

Hotspot mileages were computed for the lowest (20,000) and highest (50,000) directional ADTs and three benefit-cost ratios (1, 5, and 10) because these would be bounds on the hotspot mileage. While computing the mileage a single threshold (corresponding to a directional ADT and a benefit-cost ratio) was used for the entire state. Using a different threshold based on ADT would make the analysis much more complicated because segments can span over sections of

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706
Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

highways with very different ADTs. Tables 4 and 5 show the mileages of hotspots for only multi-vehicle CMC and all-CMC corresponding to a 10-year service life assumption. Similar tables for 25-year service life are presented in the Appendix. Figures 7 and 8 show maps of hotspots corresponding to 20,000 directional ADT and B/C ratio of 10 for multi-vehicle CMC (0.17 CMC/mi/yr) and all-CMC (0.48 CMC/mi/yr). After this analysis was completed, 2011 CMC were identified. Using the CMC dataset from 2002-2011, hotspot mileage for all CMC threshold of 0.48 CMC/mi/yr was found to be 225.89 miles.

TABLE 4. Hotspot Mileage for Multi-vehicle CMC Thresholds

Directional ADT	B/C ratio		
	1	5	10
20000	420.62	204.71	85.52
30000			
40000			
50000	315.92	148.12	71.41

TABLE 5. Hotspot Mileage for All-CMC Thresholds

Directional ADT	B/C ratio		
	1	5	10
20000	1010.52	491.13	242
30000			
40000			
50000	710.23	344.05	177.35

Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

FIGURE 7. Hotspot Map for 0.17 Multi-vehicle CMC/mi/yr Threshold

WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON

Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

FIGURE 8. Hotspot Map for 0.48 All-CMC/mi/yr Threshold

CONCLUSIONS

The objective of this research was to develop retrofit median barrier warrants for cross median crashes using Wisconsin data. The research methodology, CMC rate thresholds and hotspot mileage corresponding to various thresholds are presented in the memo. Literature does not suggest a benefit-cost ratio to be used. Therefore, CMC rate thresholds were computed for three

WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON

Department of Civil and Environmental Engineering

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

different benefit-cost ratios (1, 5, 10) to provide sensitivity analysis. The thresholds ranged from 0.05 to 0.20 multi-vehicle CMC/mile/year for only multi-vehicle CMC and 0.14 to 0.58 CMC/mile/year for all CMC. Over 80% of CMC were single-vehicle CMC and their occurrence is not limited to low volume roadways. Single-vehicle CMC are strongly recommended to be included in safety analysis. Following an ongoing cable barrier evaluation in Wisconsin, this warrant may be revisited.

REFERENCES

1. Chitturi M.V, A.R. Bill, D.A. Noyce, and A.W. Ooms. A Predictive Median Barrier Warrant to Reduce Cross Median Crashes. Dec 2011.

2. Seamons, L.L. and R.N. Smith. *Past and Current Median Barrier Practice in California.* California Department of Transportation, Sacramento, California, 1991.

3. Nystrom, K. et al. *Median Barrier Study Warrant Reviews – 1997.* California Department of Transportation, Sacramento, California, 1997.

4. Qin X, F. Wang, A.R. Bill and D.A. Noyce. Evaluation of High-tension Cable Barriers in Wisconsin. August, 2009.

1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706

Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

APPENDIX

TABLE A-1. Multi-vehicle CMC Thresholds (per mi per year) for 25 Year Service Life

Directional ADT	B/C ratio		
	1	5	10
20000	0.04	0.07	0.11
30000	0.05	0.08	0.12
40000	0.06	0.09	0.13
50000	0.07	0.10	0.14

TABLE A-2. All-CMC Thresholds (per mi per year) for 25 Year Service Life

Directional ADT	B/C ratio		
	1	5	10
20000	0.12	0.21	0.31
30000	0.15	0.24	0.34
40000	0.17	0.26	0.37
50000	0.20	0.29	0.40

WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON
Department of Civil and Environmental Engineering
1204 Engineering Hall
1415 Engineering Drive
Madison, WI 53706
Phone: (608) 890-3425
Fax: (608) 262-5199
E-mail: bill@wisc.edu
http://www.topslab.wisc.edu

TABLE A-3. Hotspot Mileage for Multi-vehicle CMC Thresholds for 25 Year Service Life

Directional ADT	B/C ratio		
	1	5	10
20000	548.5	315.92	187.62
30000			
40000			
50000	315.92	204.71	137.67

TABLE A-4. Hotspot Mileage for All-CMC Thresholds for 25 Year Service Life

Directional ADT	B/C ratio		
	1	5	10
20000	1110.62	710.23	454.71
30000			
40000			
50000	739.04	491.13	319.1