Chapter 1: Independent expert report, *An Evaluation of WSDOT's Cable Median Barrier Policy*, prepared by Malcolm H. Ray, P.E., Ph.D.

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Mr. Douglas MacDonald
Secretary of Transportation
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P.O. Box 47365
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Chief John R. Batiste
Washington State Patrol
General Administration Building
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RE: **An Evaluation WSDOT's Cable Median Barrier Policy**

Dear Secretary MacDonald and Chief Batiste:

I am pleased to present this letter report containing my evaluation of WSDOT's cable median barrier policy.

SCOPE OF WORK

WSDOT requested that I perform an independent third party review of its Cable Median Barrier policy and program. The objective of this work was to provide a critical review of WSDOT policy on the use and placement of cable median barrier, discuss the merits of use of the system and its applicability as compared to other types of median crossover protection and median barrier policies in other states. The review was completed with the goal of assessing the effectiveness of the cable median barrier system and providing opinions regarding whether WSDOT's use of cable barrier is the best solution for providing reduced crossover accidents, fatalities and severity reduction as compared to concrete or other types of barriers. I have evaluated WSDOT's policy, crash statistics provided by WSDOT, the performance of cable median barriers in other states, the policy regarding cable median barriers in other States as well as some evidence from recent crashes.

BACKGROUND

Median cross-over crashes are some of the most hazardous and difficult to predict types of crashes that occur on highways. When vehicles cross-over to opposing lanes of traffic, the risk of catastrophic injuries is very high since vehicles are often striking head-on and drivers in the opposing lanes have little or no warning that a vehicle is coming from such an unexpected direction. This is often little time for evasive actions. Protecting motorists from vehicle crossing over the medians is, therefore, a high priority in providing safe highways.

On February 13, 2007 an SUV driving southbound on I-5 in Marysville entered the 40-foot wide median and struck a high-tension cable median barrier installed on the west side

of the median. The SUV penetrated the high-tension system, crossed the depressed median and then struck a low-tension cable median barrier on the other side. The SUV penetrated the low-tension cable median barrier and entered the northbound lanes of traffic where it struck a charter bus. The SUV gas tank was ruptured upon impact with the bus and the SUV burst into flames. The driver of the SUV was killed and the driver of the bus was seriously injured in the crash.[1] [2]

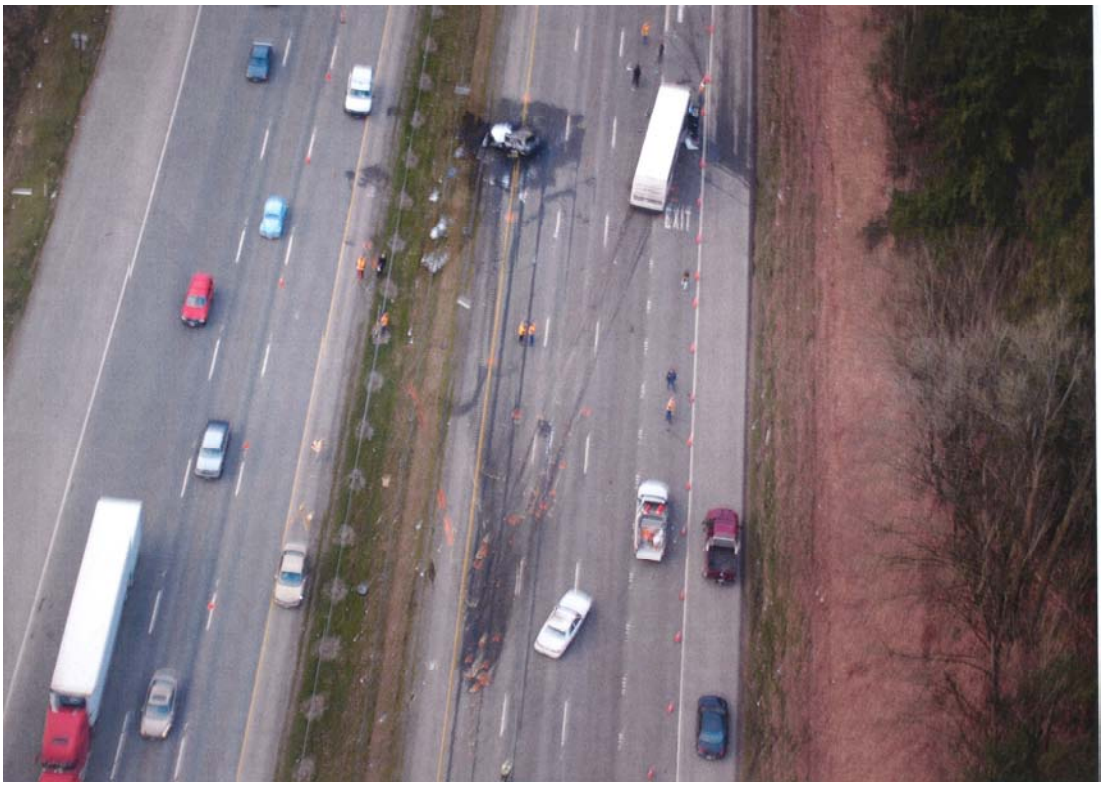

Figure 1. Photograph of the February 13, 2007 crash on I-5 in Marysville.

As reported by media, the February 13 crash was the latest in a series of median cross-over crashes that have resulted in the deaths of eight people along a 10-miles section of I-5 in Marysville since 2000.[3] Four of these crashes and seven of the deaths (including the most recent crash) involved penetrating cable median barriers. Public concern over the number and frequency of such catastrophic crashes resulted in the Governor requesting an evaluation of the crash and the Department of Transportation's cable median barrier policy.[4] [5] This report is a part of that evaluation.

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[1] Diana Hefley and Lukas Velush, "Fiery fatal crossover accident closes northbound I-5 at Marysville," HeraldNet, http://www.heraldnet.com/stories/07/02/13/100loc_i5fatalWART2.cfm, 13 February 2007.
[2] Jerry Cornfield, "Fatal crash proves cable barriers don't work, 2 lawmakers say," HeraldNet, http://www.heraldnet.com/stories/07/02/14/100loc_cablexgr.cfm , February 14, 2007.
[3] Diana Hefley and Lukas Velush, "Talk targets I-5 safety: Police plan to talk about the cables dividing I-5 and a recent death in a crossover crash," HeraldNet, http://www.heraldnet.com/stories/07/02/23/100loc_b1i5talk001.cfm , February 23, 2007.
[4] Lukas Velush, "Gregoire orders independent probe of cable barrier use," HeraldNet, http://www.heraldnet.com/stories/07/02/24/100loc_a1gregoire001.cfm , February 24, 2007.
[5] Lukas Velush and Jerry Cornfield, "State hires outside expert to investigate use of cable barriers," HeraldNet, http://www.heraldnet.com/stories/07/03/20/100loc_a1barriers001.cfm , March 20, 2007.

THE HISTORY OF CABLE MEDIAN BARRIERS

Development of the Cable Median Barrier

The modern low-tension cable guardrail and median barrier were first developed and crash tested by New York DOT in the 1960's. [6] These first systems were low-tension three cable barriers with bottom cable heights of 21 inches and top cable height of 27 inches. A typical low-tension cable median barrier is shown in Figure 1. The cable guardrail and median barriers developed by New York DOT were some of the first crash tested barriers developed using what might be called modern techniques. New York DOT changed cable heights at various times in the past four decades, generally in response to particular crash problems. While the bottom cable height has always been at 21 inches, the top cable has been positioned variously at 27, 30 and 33 inches.

Figure 2. Typical low-tension cable median barrier.

Over the years, the height of the top cable has varied in response to the changing vehicle fleet. Generally, 27-inch tall barriers were used on the roadside but a higher top cable height was used in medians because installations in the median generally involve traversing some sloped terrain. A higher top-cable height makes the system more forgiving of changes in bumper height. As large passenger cars disappeared and were replaced by pickup trucks and SUVs, the height was again raised in order to provide protection for these vehicles with higher bumpers.

Missouri DOT is thought to be the first State to widely adopt the 33-inch high low tension cable median barrier which is considered a crashworthy test level three barrier by FHWA.[7 8 9] When North Carolina began to install cable median barrier in the mid-1990's, the only available alternative was the 33-inch high cable median barrier so they adopted it in their first installations. At about the same time (i.e., the mid-1990's), Washington DOT sponsored full-scale crash tests of a 30-inch high low-tension cable median barrier based on the tried-and-true New York designs.[10] The tests, which involved a small car and a pickup truck, were both successful and many States began to adopt the WSDOT version of the low-tension cable median barrier.

In 2001, the British company Brifen received approval from the FHWA to begin marketing and installing a four-cable high-tension wire-rope safety fence as a cable median barrier in the U.S.[11] Unlike the low-tension cable median barriers, the Brifen system uses cables with a tension of between 2500 and 8100 lbs and four cables that are interweaved

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[6] M. D. Graham et al, "New Highway Barriers: Practical Application of Theoretical Design," Transportation Research Record 174, Washington, D.C., 1967.

[7] Dwight Horne (FHWA), "Nonproprietary guardrails and median barriers," Memorandum to Resource Centers, Federal Highway Administration, U.S., Department of Transportation, Washington D.C., 14 February 2000.

[8] Richard Powers (FHWA), Letter to Mary Viparina, Assistant State Engineering, Arizona Department of Transportation, August, 2005.

[9] John Baxter (FHWA), "Generic cable barriers," Memorandum to Resource Centers, Federal Highway Administration, U.S., Department of Transportation, Washington D.C., 12 September 2005.

[10] R. B. Albin, D. L. Bullard and W. L. Menges, "Washington State Cable Median Barrier," Transportation Research Record No. 1743, Transportation Research Board, Washington, D.C., 2001.

[11] F.G. Wright (FHWA), Letter to Graham Sharp, FHWA Approval Letter HS10-B82, Brifen LTD, 10 April 2001.

through the posts. The Brifen system was developed and tested in the UK and had been used there for many years prior to its FHWA approval in the US. Since the Brifen system was approved, a number of other high-tension systems have been approved for use by the FHWA including the Safence, a system from Blue Systems AB in Sweden, CASS by Trinity Industries, the Gibraltar System and the Saferoads Cable Barrier System by Nucor. [12] [13] [14] [15] Coon *et al* has written a review of cable barrier testing from the early days until the present that provides details on several of these systems and full details can be obtained in the cited approval letters.[16] The Brifen, CASS and Gibralter systems are also available in test level four configurations that can redirect a 18,000-lb single-unit truck striking the barrier at 50 mi/hr at a 15 degree angle.[17] There are, therefore, a variety of crash tested and approved cable median barrier systems available that meet the requirements for both test level three and four. WSDOT has played an important role in this: sponsoring crash tests of the 30-inch low-tension system and examining the various high-tension systems. While a successful full-scale crash test is not a guarantee of satisfactory performance in every real-world crash, it is the best available method for judging the impact performance of roadside safety hardware today. The cable median barrier options available today have been tested and evaluated as thoroughly as any roadside safety hardware appurtenance.

Use of Cable Median Barrier

The State of New York began using a low-tension cable median barrier in some limited situations in 1978 and a five-mile section was installed on the Palisades Parkway in 1984.[18] For the next twenty years, cable median barriers were relatively uncommon and most roadside safety engineers thought the best way of preventing cross-median crashes was to provide wide medians. This has been reflected in the various editions of the Roadside Design Guide where median barriers were generally not considered necessary in medians wider than 30 feet unless there was a particular cross-median crash problem.[19]

This began to change in the late 1980's when States like California, Missouri and North Carolina began to observe an increase in the number and severity of cross-median crashes. Often, these crashes occurred on medians much wider than 30 feet. Often, the cross-median crash problems occurred on suburban and urban highway sections which are typically characterized by high speeds, large volumes, numerous interchanges and other factors that promote traffic conflicts. Median cross-over crashes are often initiated by a traffic conflict on the road. For example, one vehicle cuts another off causing it to lose control and enter the median or a fast-moving vehicle suddenly encounters a line of stopped traffic resulting from congestion and in an attempt to avoid a collision the vehicle enters the median.

In North Carolina 105 people died between 1988 and 1991 in cross-median crashes where there was no median barrier installed. The North Carolina DOT analyzed across-median accident data from April 1988 through October 1991 and used the results to identify

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[12] F. G. Wright (FHWA), Letter to Matts Heinevik, FHWA Approval Letter HS10-B88, Blue Systems AB, 13 July 2001.
[13] Micheal Griffin (FHWA), Letter to Rodney Boyd, FHWA Approval Letter HS10-B113, Trinity Industries, 13 May 2003.
[14] John R. Baxter (FHWA), Letter to Bill Neusch, FHWA Approval Letter HS10-B137, Gibraltar, 13 June 2005.
[15] John R. Baxter (FHWA), Letter to Rick Mauer, FHWA Approval Letter HS10-B96A, Gibraltar, 12 October 2005.
[16] B.A. Coon, R.A. Faller, J.D. Reid, "Cable Barrier Literature Review," Report TRP-03-119-02, Midwest Roadside Safety Facility, University of Nebraska, Lincoln, Nebraska 10 July 2002.
[17] See http://safety.fhwa.dot.gov/roadway_dept/road_hardware/listing.cfm.
[18] Tyrell, Ashley B. and Bryden, James E., "Performance of Cable Median Barrier on the Palisades Interstate Parkway," Client Report 37, Jan 1989.
[19] Technical Committee for Roadside Safety, Roadside Design Guide, American Association of State Highway and Transportation Officials, Washington, D.C., 2006.

24 specific locations where the installation of median barriers was recommended.[20] During the 3.5 years of the study, there were 751 across-median crashes at locations with no median barrier, of which 71 involved at least one fatality. Cross-median crashes represent just three percent of all interstate crashes but 32 percent of all interstate fatalities. Forty percent of the across-median accidents resulted in serious or fatal injuries. Crashes occurred most frequently at sections with a median width of 20 to 39 feet.

While the study showed that cross-median crashes were a significant safety problem, it was unclear how to deal with the problem so several pilot studies were initiated to explore alternatives. One such study evaluated the performance of an installation of low-tension three-cable median barrier on a segment of I-40 in North Carolina.[21] [22] The particular segments of I-40 where the barrier was installed had experienced a history of cross-median head-on collisions. On the 8.5-mile segment, 6.8 miles of double-run median barrier (i.e., one roadside cable barrier on each side of the median) and one mile of single-run barrier (i.e., one median barrier in the center of the median) were installed. The posted speed limit was 65 mph, and the AADT ranged from 106,000 to 119,000 vehicles per day over the segment. In addition, data were collected for a four-mile section of single-run barrier (i.e., cable median barrier in the center of the median) on I-40 and a three-mile section of double-run cable barrier on US 1. The top cables were mounted at a nominal height of 27 inches. During four years of monitoring, there were 71 collisions with the barriers, resulting in no fatalities and only one serious injury.

At about the same time, other States were also beginning to experience an increase in serious cross-median crashes. States like Arizona, Washington and Oregon began to use low-tension cable median barriers in locations where cross-median crashes were being observed.[23] [24] [25] Today, at least 25 States use cable median barriers to some extent and there are close to 3,000 miles of cable median barrier installed with more planned for installation in the next few years.[26] [27] Every State that has performed a pilot study of the use of cable median barriers has expanded its use of cable median barriers with the single exception of New Jersey.

The in-service performance of cable median barriers has been studied more frequently than any other type of roadside hardware. At least 10 studies are available in the literature and typical reductions in cross-median fatalities have been in the range of 40 to 100 percent. States that have performed longer term studies with a large amount of installed barriers report fatal cross-median crash reductions of 50 percent or more with many above 90 percent. Some of the same studies report that the cable median barrier contains the vehicle in between 88 and 100 percent of the crashes, the longer-term studies suggesting 93 to 95 percent effectiveness. There is no question, therefore, that cable median barriers are effective and that they have been used across the nation to reduce the number of cross-median crashes.

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[20] NCDOT, "Interstate Across Median Accident Study," North Carolina Department of Transportation, July 1993.

[21] W. W. Hunter, J. R. Stewart, K. A. Krull, H. F. Huang, F. M. Council and D. L. Harkey, "Crash Evaluation of Three-Strand Cable Median Barrier in North Carolina," Highway Safety Research Center, University of North Carolina, Chapel Hill, N.C.,1999.

[22] W. W. Hunter *et al*, "Three-Strand Cable Median Barrier in North Carolina: In-Service Evaluation," Transportation Research Record No. 1743, Transportation Research Board, Washington, D.C., 2001.

[23] ADOT, "Median Barrier Summary Report," Arizona Department of Transportation , Phoenix, Arizona, 1999.

[24] R. W. Glad, R. B. Albin, D. M. McIntosh and D. K. Olson, "Median Treatment Study on Washington State Highways," Washington Department of Transportation, Report WA-RD-516.1, March 2002.

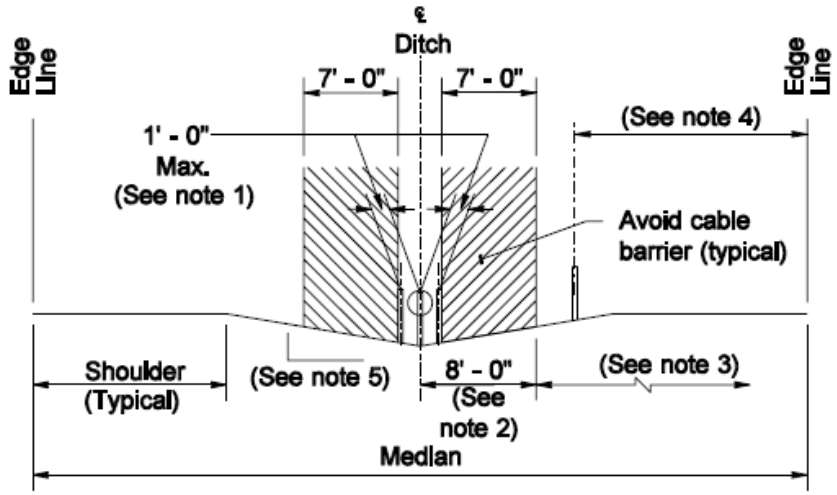
[25] Sposito, Brett and Johnston, Sam for Oregon Department of Transportation, Three-Cable Median Barrier Final Report, Report #OR-RD-99-03, July 1998.

[26] Dean Alberson, "Update on Guidelines for the Selection of Cable Median Barriers," NCHRP Project 20-7(210), AASHTO Subcommittee on Design Annual Meeting, June 14, 2006.

[27] M. H. Ray, "Experience with Cable Median Barrier in Other States," Prepared for WSDOT, 1 May 2007.

CABLE MEDIAN BARRIER POLICY IN THE STATE OF WASHINGTON

Washington State installed its first two-mile long pilot installation of cable median barrier in 1995. WSDOT has been one of the leaders in cable median barrier research and policy development since the early 1990's. WSDOT sponsored crash tests of a 30-inch high low-tension cable median barrier in 1996 and this barrier has been adopted by a number of States and was also included in the 2002 RDG.[28] Cable median barrier policy in Washington State has developed as understanding about cable median barrier performance has improved based on its own experience and the experiences in other states. Today, WSDOT's policy is reflected in Chapter 710 of the "Design Manual."[29] The current policy allows for the use of both the 30-inch low tension cable median barrier and the newer proprietary high-tension systems (see Section 710.07). The policy recommends that median barriers, including cable median barrier be placed at least 14 feet from the edge of the nearest traveled lane where site conditions permits (see Section 710.07(3)). In depressed medians with relatively flat slopes (i.e., 10:1 or flatter), the median barriers should be placed in the center of the median to minimize the chance of collisions with vehicles (see Section 710.05). Cable median barriers are recommended for medians 30 to 50 feet wide and can be used in depressed medians as steep as 6:1. In depressed medians, the cable median barrier should be placed either within one foot of the centerline of the median or ditch or at least eight feet away from the center line of the ditch (see Figure 710-14) as shown in Figure 2.



Notes:

(1) Cable barrier may be installed in the center of the ditch. The cable barrier may be offset from the ditch centerline a maximum of 1 foot in either direction.
(2) Avoid installing cable barrier within a 1 foot to 8 foot offset from the ditch centerline.
(3) Cable barrier may be installed a distance of 8 feet or greater from the ditch centerline.
(4) Depending on the system used and post spacing, this distance varies from 6 feet 8 inches to 12 feet.
(5) Applies to slopes between 6H:1V to 10H:1V.

Figure 3. Placement of cable median barriers in depressed medians.[29]

These policy recommendations have evolved as the roadside safety community's understanding of cross-median crashes have improved. When it was apparent that no cable median barrier had been crash tested according to the current crash testing guidelines,

[28] R. B. Albin, D. L. Bullard and W. L. Menges, "Washington State Cable Median Barrier," Transportation Research Record No. 1743, Transportation Research Board, Washington, D.C., 2001.
[29] WSDOT, "Design Manual," Chapter 710 – Traffic Barriers, Washington Department of Transportation, November 2006.

WSDOT sponsored testing to verify the impact performance of the low-tension system.[30] When new proprietary high-tension cable median barriers became available, WSDOT examined their safety, maintenance and repair performance and began to install the newly available technology. When crash tests at the Federal Highway Administration's Federal Outdoor Impact Facility showed that passenger cars can underride cable median barriers installed four-feet from the centerline of a ditch, WSDOT changed its policy to avoid placing cable median barriers in such locations.[31] WSDOT has been at the forefront of developing better cable median barriers and better cable median barrier policy for nearly a decade. Many States derive aspects of their standards from WSDOT's experience with cable median barriers.

CABLE MEDIAN BARRIER PERFORMANCE IN THE STATE OF WASHINGTON

One of the problems with comparing performance from State to State is that each State collects and reports its data differently. Many States do not have good information about the amount and location of their roadside hardware inventory and often it can be difficult to correctly identify cross-over and potential cross-over median crashes based on police reported crash data. Often, States simply resort to reporting the number and percent of cross-median crashes and fatal cross-median crashes without addressing important aspects like traffic growth and installed barrier volume. While the performance statistics for cable median barriers reported by other States have been consistently good (i.e., cable median barrier effectiveness measure around 95 percent) the data reported in this way is sometimes difficult to interpret.

Figure 4. Passenger car underriding a low-tension cable median barrier positioned four feet from the bottom of a 6:1 ditch.

The best way to compare the performance of traffic barriers is to use crash rates as described in NCHRP Report 490.[32] A crash rate is calculated by determining the number of crashes in a particular category (e.g., crashes with cable median barriers, cross-median crashes, fatal cross-median crashes, etc.), and dividing by the average yearly traffic volume in the study area and the length of barrier installed in the study area. The resulting crash rate is usually reported in units of crashes per 100 million vehicle miles traveled (100 MVMT). The crash rate is a direct measure of the risk inherent in driving on the road segment. If, for example, the crash rate on a particular one-mile long road segment is 1.00 crashes/100 MVMT, it means that on average one crash occurs for every 100 million vehicles that pass through the segment. Put another way, an individual's average risk of being involved in a crash is one in 100 million. Reporting crash statistics in this way allows data from different

[30] R. B. Albin, D. L. Bullard and W. L. Menges, "Washington State Cable Median Barrier," Transportation Research Record No. 1743, Transportation Research Board, Washington, D.C., 2001.
[31] FOIL Crash tests.
[32] M. H. Ray, J. A. Weir, J. A. Hopp, In-Service Performance of Traffic Barriers, National Cooperative Highway Research Program Report No. 490, ISBN 0-309-08762-7, National Academy of Sciences, Washington, D.C., 2003.

sites with different traffic volumes and lengths of barriers to be compared directly to each other.

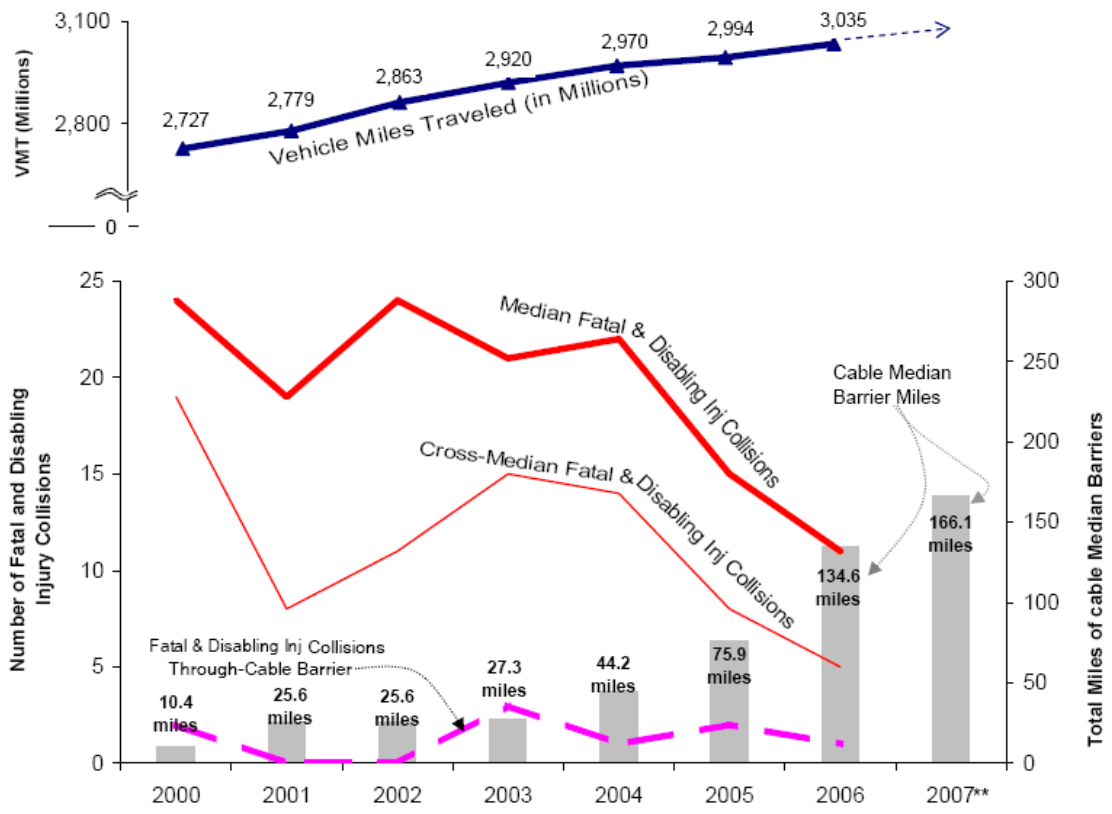
Fortunately, WSDOT has very good traffic, inventory and crash records so it is one of the few States where it is possible to calculate crash rates that give an accurate picture of the performance of cable median barriers. WSDOT performed such an analysis in March of 2007 and a summary of the results is shown in Table 1. Table 1 shows the crash rates for crashes of all severities, disabling crashes, fatal crashes and disabling and fatal crashes for the periods before cable median barrier was installed and the period after cable median barrier was installed.

As shown in Table 1, prior to the installation of cable median barrier, the average cross-over fatal and disabling crash rate in the sections where cable barrier was installed was 0.464 per 100 MVMT whereas after the installation of cable median barriers the rate dropped to 0.118 per 100 MVMT. For fatal crashes, the statewide crash rate prior to the installation of cable median barriers was 0.213 per 100 MVMT and the after rate was 0.044 per 100 MVMT. These rates show that fatal crashes have been reduced by nearly 80 percent and fatal and disabling crashes have been reduced by 75 percent, an impressive improvement in safety.

Table 1. Median cross-over crash rates per 100 MVMT in the State of Washington before and after the installation of cable median barriers.

	Total Crashes		Disabling Crashes		Fatal Crashes		Fatal and Disabling Crashes	
Segment	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Statewide	2.009	0.607	0.251	0.074	0.213	0.044	0.464	0.118
I-5 Vancouver	1.238	0.176	0.146	0.117	0.291	0.000	0.437	0.117
I-5 Lewis County	2.983	0.351	0.213	0.000	0.426	0.000	0.639	0.000
I-5 Nisqually	1.126	0.000	0.000	0.000	0.375	0.000	0.375	0.000
I-5 Fife	0.991	0.807	0.000	0.000	0.270	0.000	0.270	0.000
I-5 Marysville	2.319	0.841	0.357	0.080	0.089	0.120	0.446	0.200
I-5 Mt Vernon	0.861	0.000	0.287	0.000	0.287	0.000	0.574	0.000
I-5 Burlington	4.243	0.000	1.306	0.000	0.653	0.000	1.958	0.000
I-5 So. Bellingham	2.780	0.000	0.214	0.000	0.428	0.000	0.642	0.000
I-5 Ferndale	3.355	0.000	0.419	0.000	0.000	0.000	0.419	0.000
I-5 Blaine	2.256	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SR 12 Montesano	1.682	0.000	0.420	0.000	0.000	0.000	0.420	0.000
SR 16 Purdy	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SR 18 Covington	2.727	0.000	0.000	0.000	0.000	0.000	0.000	0.000
I-90 Issaquah	1.778	0.000	0.000	0.000	0.000	0.000	0.000	0.000
I-90 George	3.592	0.000	0.000	0.000	0.000	0.000	0.000	0.000
I-90 Moses Lake	4.989	3.648	0.000	1.216	0.454	0.000	0.454	1.216
I-90 E. Moses Lake	3.838	1.856	0.426	0.000	0.000	0.000	0.426	0.000
I-90 Spokane	3.595	1.151	0.938	0.000	0.156	0.000	1.094	0.000
SR 99 Tukwila	1.291	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SR 167 Sumner	0.319	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SR 410 Sumner	1.489	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SR 522 Bothell	3.989	0.000	0.000	0.000	0.000	0.000	0.000	0.000

This trend of reduced cross-median crashes is shown graphically in Figure 5 where the number of fatal and fatal and disabling crashes are plotted by year with the vehicle miles traveled and the miles of cable median barrier installed. In 2000, only about 10 miles of cable median barrier were installed and 18 fatal and disabling crashes occurred, all involving unprotected medians. By 2006 almost 135 miles of cable median barrier had been installed and the number of fatal and disabling collisions had been reduced to five.



*The data shown within the segments where cable median barriers were installed/planned as of March 2007. Collision data is available through 2006. Vehicle Miles Traveled (VMT) is based on estimated ADT for the segments where cable median barriers were installed as of March 2007.

**166.1 miles of segments where Cable Barriers were installed or in contract as of March 2007

Figure 5. Total miles of cable median barriers installed and cross-median collisions in the State of Washington, 2000-2007.

The cable median barrier program in Washington State has clearly been effective on a statewide basis. The fatal and disabling crash rate has been reduced by 75 percent, the barriers are about 95 percent effective in containing errant vehicles in the median. The median barrier program on the whole is a success but, as will be discussed below, there are still problem sections where cross-median crashes persist.

I-5 in Marysville

There have been four fatal cross-median crashes where seven people died involving cable median barriers in Washington State since 2000 and all of them have been on the five-mile section of I-5 in Marysville between mile posts 200 and 206. As shown in Table 1,

Marysville has the highest fatal cross-median crash rate (i.e., 0.12 fatal crashes/100 MVMT) and second highest fatal and disabling cross-median crash rate (i.e., 0.20 fatal and disabling crashes/100 MVMT) in the state for areas where cable median barriers are installed (Note: I-90 near Moses Lake also has a very high fatal and disabling median cross-over crash rate but these are relatively low volume sections of barrier than has not been in place very long. A few crashes have distorted the rate. The rate should approach other values in the state once the number of vehicle miles traveled through the segments increases). While cable median barriers are highly effective in the rest of the state, there is clearly something unusual about I-5 in Marysville.

While it is not the intention of this report to reconstruct or analyze in detail the crashes on I-5 in Marysville, it is instructive to review the crashes and look for common threads that might explain why the cable median barrier less effective in this location than the rest of the State.

A two-mile section of low-tension cable median barrier was installed in Marysville near milepost 202 at the end of 1995, the first installations in the State of Washington. The first reported crash was on February 15, 1996. While the crash resulted in an injury the median barrier contained the vehicle and likely prevented a serious cross-over crash. The cable median barriers reduced the number of cross-median crashes and WSDOT was pleased with results such that nearly 10 miles of cable median barrier had been installed between mileposts 199 and 209 by 2000.

On October 31, 2003 a southbound Subaru Legacy entered the median near milepost 205, under-rode the low-tension cable median barrier and entered the northbound traffic lanes striking three other vehicles and resulting in two deaths.[33]

Approximately one year later, on December 15, 2004 a southbound Ford Explorer traveling over 70 mi/hr left the right side of the road and over-steered across the southbound lanes of traffic, entered the median without braking near milepost 205, penetrated the low-tension cable median barrier and vaulted into the northbound traffic lanes striking a Suburban and a Toyota pickup truck and bursting into flames. The crash resulted in the death of a passenger in one of the northbound vehicles.[34] [35]

About six months later, on May 30, 2005 a southbound Ford F350 pickup truck illegally towing a 37-foot long fifth-wheel trailer in the left-hand lane entered the median near milepost 203, struck the cable median barrier and overturned into the northbound travel lanes. Three northbound vehicles struck the overturned truck and trailer resulting in the deaths of a family of three people in one of the northbound vehicle.[36] [37] [38]

Most recently, a 2001 Infinity QX4 SUV driving southbound on I-5 in Marysville on February 13, 2007entered the 40-foot wide median near milepost 200 and struck a high-tension cable median barrier installed on the west side of the median. The SUV penetrated the high-tension system, crossed the depressed median and then struck a low-tension cable median barrier on the other side. The SUV penetrated the low-tension cable median barrier and entered the northbound lanes of traffic where it struck a charter bus. The SUV gas tank

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[33] Detective Cunningham, "Criminal Investigative Report: No. 03-012374," Washington State Patrol, December 1, 2003.

[34] Katherine Schiffner, "Fatal wreck prompts review of I-5 barrier," HeraldNet, http://www.heraldnet.com/stories/04/12/18/100loc_wreck001.cfm , December 18, 2004.

[35] Detective Sergeant Jerry Copper, "Major Accident Investigation Team Case Summary: Case No. 04-015857," Washington State Highway Patrol, December 15, 2004.

[36] Diana Hefley, " Steel cable barricades focus of deadly I-5 crash," HeraldNet, http://www.heraldnet.com/stories/05/06/01/100loc_steel001.cfm, June 1, 2005

[37] Diana Hefle , "Driver in fatal crash was in wrong lane," HeraldNet, http://www.heraldnet.com/stories/05/06/21/100loc_crash001.cfm , June 21, 2005.

[38] Detective Greg Wilcoxson, "Major Accident Investigation Team: Case No. 05-006178," Washington State Highway Patrol, May 30, 2005.

ruptured upon impact with the bus and the SUV burst into flames. The driver of the SUV was killed and the driver of the bus was seriously injured in the crash.[39 40 41]

There have also been three other crashes involving cable median barriers that resulted in fatalities but were not median cross-over events. In one of these cases, the passengers in the bed of a pickup were ejected and killed, in another the vehicle was rolling over and a passenger was partially ejected and in the third, a vehicle was traveling the wrong way (i.e., northbound in the southbound lanes) when it struck another vehicle and one of the vehicles then struck the median barrier. In these three cases, the fatalities can not fairly be attributed to the cable median barrier since the fatality producing event occurred prior to the collision with the barrier such that the barrier was simply the last object struck in a chain of crash events. There was another fatal crash that involved a vehicle crossing the median at a location where there was not a cable median barrier installed. Interestingly, however, all four of these crashes occurred in the same general area as the three cross-over fatal crashes (i.e., between milepost 202 and 206).

The median in the area of all four fatal median cross-over crashes described above is 40 feet wide between the edges of the north and southbound traveled lanes. There are six-foot wide paved median shoulders with rumble strips. A relatively flat gravel and grass slope extends to a slope breakpoint. The slope changes to a 1:6 grassy slope that ends in the center of the median on a ditch line. The median is symmetric from the other direction. The first cable median barrier (i.e., the low-tension cable median barrier) was installed on the northbound side about 16 feet from the edge of the southbound lane. The second cable median barrier (i.e., the high-tension system) was installed in 2006 about 12 feet from the southbound lanes and about two feet past the slope breakpoint.

One issue regards where to place the cable median barrier. Deciding on the proper placement is a balance between minimizing the number of collisions by putting the barrier as far away from traffic as possible and minimizing the chance of vehicles penetrating the barrier due to trajectory and stability problems as the vehicle crosses the un-level median terrain. Regardless of the type of barrier, as barriers are positioned farther from the road, the chance of the vehicle bumper being either too high or too low are increased, the chance of striking the barrier at a large impact angle increase, the chance of rolling over during the approach increases and the chance of yawing or sliding sideways increases. Many States (e.g, Arizona) install cable median barriers almost exclusively at the center of the median but this presents problems in many locations in Washington and particular Snohomish County where the center of the drainage ditch is frequently either filled with water or very wet. WSDOT, therefore, often chooses not to place the barrier in the centerline of the ditch since the soft soil conditions could detract from the barrier performance.

The importance of placement on slopes for cable median barrier was not appreciated prior to 2004 when the Federal Highway Administration performed two crash tests involving mid-size passenger vehicles striking low-tension cable median barriers in 6:1 V-ditches. In one test, the barrier was located one-foot from the center line of the ditch. The vehicle, which struck the barrier at 60 mi/hr and 25 degrees, was contained and smoothly redirected in accordance with the design of the cable median barrier. In the other test, however, the vehicle under-rode a cable median barrier that was positioned four-feet from the centerline of the ditch. The reason was, that as the vehicle crosses the ditch line, the suspension bottoms out effectively lowering the bumper height such that the bumper strikes below the bottom

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[39] Diana Hefley and Lukas Velush, "Fiery fatal crossover accident closes northbound I-5 at Marysville," HeraldNet, http://www.heraldnet.com/stories/07/02/13/100loc_i5fatalWART2.cfm, 13 February 2007.

[40] Jerry Cornfield, "Fatal crash proves cable barriers don't work, 2 lawmakers say," HeraldNet, http://www.heraldnet.com/stories/07/02/14/100loc_cablexgr.cfm , February 14, 2007.

[41] "State of Washington Police Traffic Collision Report," Report No. 2808176, Washington State Highway Patrol, February 13, 2007.

cable. Once this happens, the vehicle can wedge itself under the cables and penetrate the system. Unfortunately, the FHWA research was never completed so there are no crash test reports and no finding about the relevance of these crash tests to median design.

After the FHWA crash test, WSDOT engineers modified their placement recommendations as shown earlier in Figure 3 such that cable median barrier generally would not be placed in an area between one and eight feet from the bottom of the ditch. This would appear to be a contributing cause for the October 13, 2003 crash involving the Subaru Legacy where the vehicle crossed through the 6:1 ditch and struck the low-tension cable median from behind resulting in an under-ride of the barrier.

In the latest crash on February 13, 2007, a different placement issue may have played a role in the crash. The Infinity QX4 first struck the high-tension median barrier. The impact conditions have been estimated by the Highway Patrol as being roughly 65-70 mi/hr and 25 degrees. The vehicle did not appear to be braking or yawing (i.e., spinning or sliding sideways) prior to impact so the impact conditions are nearly identical to a typical full-scale crash test. This latest crash is particularly troubling to roadside safety engineers since the vehicle struck the barrier in a manner that is consistent with our standard crash tests for this type of barrier and the barrier was placed in agreement with RDG.

One detail that may have contributed is the placement of the high-tension barrier two feet past the breakpoint to the 6:1 slope. While cable median barriers are effective in crash tests on 6:1 slope, placing the barrier this close to the breakpoint effectively lowers the cable height by about 1.6 inches because the vehicle tires are still on the 10:1 slope but the bumper is protruding out over the 6:1 slope. (i.e., at 6:1 the elevation drops four inches in two feet whereas at 10:1 the elevation drops 2.4 inches in two feet for a difference of 1.6 inches). The distance from the front of the bumper to the center of the front axle for the Infinity QX4 is 30 inches and the corresponding distance in pickup trucks used in crash tests is 35 inches.[42] When the front tires reach the slope breakpoint, the bumper is hanging out over the slope 35 inches. The nominal height of the high-tension cable median barrier is 30 inches and it appears to have been installed correctly. The height, however, of the barrier with respect to the breakpoint in the slope would be approximately 28.4 inches making it easier for the vehicle to override the barrier as happened in the February 13 crash.

The vehicle itself also may have played a role in this particular crash. Bullard has reported that the top of the Infinity QX4 bumper is normally 27 inches above the ground.[43] The pickup truck vehicles normally used in full-scale crash tests have bumper heights of about 24 inches, three inches lower than the Infinity QX4. This illustrates that as SUV and light trucks have gotten more popular and larger, bumper heights have been creeping higher and higher to the point where they may not be effective with some of the roadside hardware that has been tested and approved by FHWA. The roadside safety community has recognized this fact and is in the process of updating its crash test and evaluation procedures but the procedures have still not been formally approved and few crash tests have been performed with the newer pickup trucks with higher bumpers. It appears, therefore, that the combination of the higher bumper height of the Infinity QX4 with respect to the crash test vehicles and the lower effective height of the high-tension cable median barrier due to its placement behind the slope breakpoint may have contributed to the vehicle going over the barrier.

The May 2005 crash involving an F350 pickup truck and fifth-wheel trailer may have simply exceeded the capacity of the barrier since the combined weight of the truck and trailer were on the order of 12,000 lbs, much greater than the 4400-lbs pickup truck used in crash

[42] Lance Bullard, "Warren cable guardrail accident on I-5," Letter to Richard Albin (WSDOT), SafetyQuest, Inc., April 17, 2007.
[43] Ibid.

testing. The dynamics of trucks towing large trailers are also difficult for any barrier to control so this crash may well have resulted in a similar outcome regardless of the barrier type selected.

Another issue is the integrity of the cable wedge-and-socket. In the February 13, 2007 crash, the wedge-and-socket that attach the cable to the anchoring system appears to have failed for the top and middle cables at the north anchor due to contact with the Infinity QX4 and the low cable anchor failed at the south anchor due to contact with the bus.[44] The cable is secured in place by inserting a wedge between the cable strands and passing the cable through a specially designed socket. As the cable is pulled, the wedge, cable and socket are jammed together creating a strong connection. Unfortunately, it appears that sometimes the wedge is not firmly or correctly seated in the socket and this can allow the cable to pull out. This issue is dealt with more completely in other reports but it is mentioned here because the failure of the wedges-and-sockets in the latest crash are a likely reason that the Infinity QX4 was able to penetrate the system.[45] Since the cables were loaded enough to pull through the socket, it shows that the Infinity QX4 was in good contact with the cable barrier and probably would have been contained had the cable not come free. This is probably not an issue with the high-tension systems since placing the cables in tension serves to pull the wedge into the socket and make a good connection. WSDOT should develop a procedure for field-checking and fixing the wedge-and-socket connections on low-tension cable median barriers to ensure this type of mechanical failure does not occur again.

The final issue is the particular nature of this portion of highway. It is significant that all the fatal crashes have been initiated in the southbound direction. Drivers approaching the Smokey Point Rest Area from the north are driving in a rural environment with relatively few interchanges and few traffic conflicts. When these drivers proceed south of SR 531 they enter the outer edges of the Seattle urban area. Quite suddenly, there is more traffic, there are more vehicles entering and exiting the highway at more numerous interchanges. They may suddenly encounter congestion, slower moving traffic and vehicles trying to merge onto the highway. This type of situation is what creates conflicts between vehicles that sometimes results in a vehicle entering the median. The Infinity QX4 in the February 13, 2007 crash had just merged onto the highway at the 88th Street ramp, within sight of the crash site, and quickly crossed all the southbound with their busy afternoon traffic where it entered the median. The driver of the pickup truck and trailer in the May 30, 2005 crash was reported as speeding and making "aggressive lane changes" which caused him to lose control.[46] These types of in-stream traffic conflicts are almost always the precipitating events in median cross-over crashes.

According to WSDOT traffic data, the traffic volume increases from 79,000 vehicles/day to 111,000 vehicles/day as drivers pass SR 531, an increase of traffic of 40 percent. In the years since installing the first cable median barrier, traffic has increased by about one third. The area is home to numerous residential neighborhoods, manufacturing facilities, large shopping malls and a casino. The area has experienced rapid growth in the past decade and this is reflected in the increased amount of traffic. In this 10-mile section, there are five on-off interchanges and one rest area resulting in an average of one interchange every 1.7 miles. Table 2 shows an estimate of the traffic volumes at each interchange based on a 2006 mid-week ramp volume count and the approximate AADT for the areas north and south of SR 531. The volume flowing southbound doubles between milepost 209 and 199 whereas it is cut in half going northbound. In this one ten-mile section, 191,000 vehicles each day are

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[44] Lance Bullard, "Warren cable guardrail accident on I-5," Letter to Richard Albin (WSDOT), SafetyQuest, Inc., April 17, 2007.
[45] Ibid.
[46] Detective Greg Wilcoxson, "Major Accident Investigation Team: Case No. 05-006178," Washington State Highway Patrol, May 30, 2005.

either entering or exiting I-5. The percentage of vehicles merging into the traffic stream is shown in Table 2. Some interchanges have very high percentages of merging vehicles. For example, at the southbound SR531 interchange over half (i.e., 51 percent) of the vehicles are either exiting or entering the highway at that location. All the interchanges southbound, with the exception of the rest area, are above 35 percent. The percentage of vehicles entering and leaving is a measure of how much traffic mixing is occurring. When vehicles are mixing they are merging on-to or off-of the highway, changing lanes, repositioning themselves to accommodate merges and making other lane change maneuvers. A large amount of traffic mixing will result in a corresponding increase in traffic conflicts, some of which will progress into cross-median crashes. After the 2005 crash, WSDOT reduced the speed limit in this area from 70 to 60 and the Washington State Highway Patrol increased speed enforcement activities. While enforcement activities are highly effective when police officers on visible on the road, conditions revert back to their previous condition when the officers are not visible. The high degree of traffic mixing, high speeds and urban/rural transition suggest that Marysville is prone to more than the usual number of traffic conflicts which may become cross-median crashes. The traffic conditions in this segment of I-5 seem to promote cross-median crashes so the barriers are more frequently tested than in other parts of the State where traffic conditions are less demanding.

Table 2. Estimated ramp and highway volumes in vehicles per day on I-5 in Marysville.

	Southbound					Northbound					Total ADT
Interchange	In	Out	Merge Events	Estimated ADT	Merges	In	Out	Merge Events	Estimated ADT	Merges	
MP 209				32,000					39,553		71,553
SR 530	8,832	6,001	14,833	33,000	45%	6,242	8,575	14,817	40,720	36%	73,720
				34,831					41,886		76,717
Rest Area	757	757	1,514	34,831	4%	745	745	1,490	41,886	4%	76,717
				34,831					41,886		76,717
SR 531	13,946	5,772	19,718	38,918	51%	6,855	14,998	21,853	45,958	48%	84,876
				43,005					50,029		93,034
116th St	12,020	4,478	16,498	46,776	35%	5,040	10,926	15,966	52,972	30%	99,748
				50,547					55,915		106,462
88th St	14,259	6,013	20,272	54,670	37%	5,387	13,200	18,587	59,822	31%	114,492
				58,793					63,728		122,521
SR 528	16,069	6,644	22,713	63,506	36%	6,967	16,239	23,206	68,364	34%	131,870
MP 199				68,218					73,000		141,218
Total Merges			95,548					95,919			

Clearly there is a problem with cross-median crashes on I-5 in Marysville that has persisted even with the installation of one and even two runs of cable median barrier. As described above, there is no single feature of the site that explains all four of the fatal crashes: barrier placement, mechanical failure of the wedge-and-socket, vehicle type and traffic conditions have all played a role. As often happens in serious crashes, the results are a combination of factors that affect the performance of vehicles, drivers and barriers. While

some of these factors are nearly impossible to predict or control (i.e., aggressive driver behavior, speed, traffic congestion, etc.) some can be treated with engineering solutions to try and minimize the consequences of entering the median but it should be recognized that the development and traffic characteristics of I-5 in Marysville make this an area that may be prone to cross-median crashes.

CROSS-OVER ALTERNATIVES

All roadside safety design involves finding the best compromise. No system is 100 percent safe, all systems involve trade-offs and every system will fail in some types of impacts. For example, cable median barriers are an attractive alternative because many miles of highway can be effectively treated with a device that has a good track record for safety. The trade-off is that occasionally vehicles may penetrate the barrier and cross-over to the opposing lanes. Concrete barriers, on the other hand, can virtually eliminate cross-over crash but other types of severe crashes will occur since vehicles will be redirected back into the traffic stream. The added expense of concrete barriers limits the amount of miles that can be installed so the net affect on safety can be limited since appropriations for safety are limited. The question to be answered whenever a highway is designed is what alternative results in the lowest net fatal and disabling injury rate?

Table 3. Crash rates per 100 MVMT for concrete median barriers based on crashes at four locations between 2002 and 2006.

Crash Type	All severities	Disabling	Fatal	Fatal and Disabling
All	13.15	0.200	0.088	0.288
Cross median	0.276	0.025	0.0000	0.025
Overturn	0.676	0.025	0.0000	0.025

Locations evaluated:
- I-5, Lewis County
- I-5, Tacoma Vicinity
- I-5, Everett to Marysville
- I-90, West of Spokane

Table 3 shows crash rates based on crash data from four locations collected for the years 2002 through 2006. Rates were calculated for all median related crashes, cross-median crashes and crashes resulting in an overturn. As shown in Table 3, the fatal and disabling cross-median crash rate is 0.025 crashes/100 MVMT, a rate almost five times smaller than the corresponding cable median barrier crash rate. Concrete median barriers are clearly effective at reducing cross-median crashes. The counter-point to their effectiveness in cross-median protection is that the fatal and disabling crash rate for all types of concrete median barrier related crashes is 0.288 crashes/100 MVMT. This means that improved cross-median protection comes at the price of more fatal and disabling crashes in the same direction of travel. This may be acceptable in some situations where the likelihood of a cross-median event resulting in a collision is high as would be the case where there are high traffic volumes in the opposing lanes.

One of the advantages of cable median barriers are their low cost in comparison to concrete median barriers. Unfortunately, the funds allocated for highway safety construction projects are not limitless so often choices have to be made about how best to spend a fixed amount of funding. Concrete median barriers cost about from two to six times more than cable median barriers depending on the grading requirements, so it is possible to treat two to six times more sites if cable median barrier is used. Choosing between cable and concrete

median barriers involving balancing the effectiveness of preventing cross-over crashes with the over-all likelihood of fatal and disabling crashes and the amount of funds available for safety improvements. In cases like I-90 near George or Issaquah the cable median barrier was an effective solution since it was low cost and highly effective in eliminating cross-median fatal and disabling crashes but concrete median barriers may be a better solution for problematic sites like I-5 in Marysville where vehicles continue to penetrate the cable median barrier on occasion.

CONCLUSIONS AND RECOMMENDATIONS

I have several recommendations to make regarding median cross-over protection in Washington State. First, I have specific recommendations for the 10-mile section of I-5 in Marysville and second, I have specific recommendations for changing WSDOT's policy for median cross-over protection and third, I have recommendations for research that needs to be performed to improve the roadside safety community's understanding of cable median barrier crashes.

Marysville

As described above, the section of I-5 in Marysville is problematic. While cable median barrier has resulted in a large decrease in cross-median fatalities, four fatal cross-median crashes resulting in seven deaths within the past four years is unacceptable. Marysville, especially the southbound sections of I-5, are a transitional highway: drivers are transitioning from rural to urban surrounds, low congestion to higher congestion, higher speeds to lower speeds and widely spaced interchanges to closely spaced interchanges with relatively high ramp traffic. These conditions promote on-road vehicle-to-vehicle conflicts and these conflicts are the initiators of cross-median events. While there are some improvements that could be made in both the placement of cable median barriers and their performance in Marysville, it is probably better to focus on finding a solution that will make cross-over crashes very unlikely given the high probability that a large number of median incursions will continue to occur.

I recommend that WSDOT install a concrete median barrier approximately 10 to 12-feet from the inside edge of the northbound traveled lanes. The concrete barrier should nearly eliminate cross-median crashes. Placing it closer to the northbound lanes will help minimize the number of serious median related crashes since most of the serious median events seem to be associated with southbound traffic. Southbound vehicles that enter the median will have more room to stop or recover but the concrete median barrier will be a last wall of protection for northbound vehicle occupants. The concrete barrier should be placed such that sufficient room is available for an emergency lane since police, fire, rescue and maintenance personnel will still need access to the far left shoulder of the highway and not providing an adequate shoulder will place these personnel in danger. WSDOT may also want to consider leaving the high-tension cable median barrier in place on the southbound side. This would provide some of the benefits of a more flexible and forgiving barrier system (i.e., the cable median barrier) while preventing cross-median crashes with the more rigid system (i.e., the concrete median barrier).

While I firmly believe that cable median barriers are highly effective and an appropriate choice in many locations, we simply cannot risk another fatal cross-median crash on this section of roadway.

Policy Recommendations

First, WSDOT has been a leader in median cross-over crash protection in the US and I commend them for their efforts and the success they have had in reducing cross-median crashes. WSDOT has accomplished this by sponsoring its own research, collaborating with other States, keeping informed about developments in research and operations in other States and, perhaps most important, carefully observing the situation in Washington State.

Median protection policy, like all good policy, must not be static and policy makers must be willing to modify and adapt policy as problems are observed in the field. Policy makers can sometimes resist change because it points out short-comings in earlier policy decisions but I believe WSDOT has made a good-faith effort to improve their standard designs and policies as soon as they have observed problems or become aware of research on better design alternatives. The following specific policy recommendations are provided in the spirit of assisting WSDOT to continue to improve their median cross-over protection policy and thereby create the safest possible traveling environment in the State of Washington.

1) I recommend that WSDOT continue its use of cable median barrier. The cable median barrier program has been very effective statewide in reducing the number and severity of median cross-over crashes and has doubtless saved many lives.
2) When cable median barriers must be placed near the breakpoint between a nominal 10:1 and nominal 6:1 slope in the median, the following options should be considered:
    a. For single-runs of cable median barrier, if there is at least 13 feet from edge of the nearest traveled lane to the slope breakpoint, the cable median barrier should be placed at least one foot in front of (i.e., between the breakpoint and the traveled lane) the slope breakpoint. Any crash tested cable median barrier can be used in this situation (i.e., low-tension or high-tension). This arrangement will allow 12 feet of dynamic deflection distance for back-side hits, provide an adequate emergency lane, minimize the chance of bumper height problems associated with SUV's and pickup trucks traversing slopes prior to contacting the barrier and provide some recovery space for vehicles leaving the near lanes of travel.
    b. For double-runs of cable median barrier, if there is at least 11 feet from edge of the nearest traveled lane to the slope breakpoint, the cable median barrier should be placed at least one foot in front of the slope breakpoint. Any crash tested cable median barrier can be used in this situation (i.e., low-tension or high-tension). This arrangement will provide an adequate emergency lane, minimize the chance of bumper height problems associated with SUV's and pickup trucks traversing slopes prior to contacting the barrier and provide some recovery room for vehicles leaving the near lanes of travel. Deflection distance for back-side hits are not as much of a concern in this situation since the back of one barrier is shielded by the barrier on the other side of the median.
    c. When there is not sufficient space to position the barrier in front of the slope breakpoint, a cable median barrier with a wider window of protection should be used to minimize the chance of newer SUV and pickup trucks from over-riding the barrier. Other types of cable median barriers that can be used behind the slope break point are:
        i. Any test level four cable median barrier or

ii. A cable median barrier that is designed and crash tested such that its successful performance with newer SUVs and pickup trucks on terrains with typical slope breakpoints has been established.

While I do not believe that test level four barriers are appropriate for general highway conditions, the higher rail height of typical test level four barriers should provide additional protection for SUV's in the interim period between the new full-scale crash testing guidelines being adopted and the development of new test level three hardware. I also encourage WSDOT to perform full-scale crash testing of cable median barriers on typical median cross-sections to develop barrier options with established performance on typical median cross-sections.

3) WSDOT should develop a field inspection procedure to ensure that all wedge-and-socket connections are sound and the wedges are firmly seated into the sockets. All such connections on the low-tension cable median barriers should be field checked in a reasonable period of time to ensure that the cable forces are correctly transmitted to the foundation. It may be advisable to also check a representative sample of high-tension cable median barrier connections as well to be sure that there are no problems with these systems.

Table 4. Median barrier installation recommendations based on historical crash rates.

Crash Rate † Cross-median crashes of all severities per 100 MVMT	**Site Characteristics**	**Action**
Greater than 1.00	• No median barrier, • 30-ft or wider median and • 6:1 or flatter slopes.	Evaluate cost benefit of using a cable median barrier.
Greater than 2.00	• No median barrier, • 30 to 50 ft wide median, • 6:1 or flatter slopes, • ADT > 75,000 vpd and • In rural/urban transition area.‡	Evaluate cost benefit of using a double-run of cable, w-beam, thrie-beam or concrete median barriers.
Greater than 0.75	• 30 to 50 ft wide median, • Cable median barrier, • 6:1 or flatter slopes, • ADT > 75,000 vpd and • In rural/urban transition area.‡	Evaluate cost benefit of replacing a cable median barrier with w-beam, thrie-beam or concrete median barriers.

† Crash rates should be calculated on sections that are at least two miles long and where data is available such that the section has experienced at least 100 MVMT. Crash rates calculated in shorter segments or where there has not yet been sufficient traffic are liable to be inaccurate and overly sensitive to a few early crashes.

‡ Rural/urban transition areas are areas that are characterized by several of the following characteristics:

- Interchanges spaced closer than two miles apart,
- A change in speed limit,
- A large change in ADT (e.g., 30 percent) in a relatively short distance or
- High ramp volumes in proportion to the mainline ADT.

4) WSDOT should develop install recommendations based on a periodic review of crash history for installing both cable median barrier and concrete median barrier. Currently, installation recommendations are based primarily on the median characteristics such as median width and traffic volume. Engineering judgment and installation recommendations based on highway geometry should be the first criteria in deciding on locations for median barrier but crash history should also play a role for locations like Marysville where the site geometry are simply not accurate predictors of the magnitude of the cross-median problem. I suggest the installation recommendations summarized in Table 4 based on the crash rate histories reported earlier in Table 1. I have based these recommendations on cross-median crashes of all severities because we should not wait until someone is killed in a crash to make a decision. Any median cross-over is a potential fatal crash and crash data can be collected more quickly based on crashes of all severities. The installation recommendations shown below would have identified Marysville as a candidate for the use of concrete median barrier both now (i.e., with cable median barrier in place) but also prior to the installation of any median barrier. Missouri uses a rate of 0.8 cross-median crashes per 100 MVMT as an installation recommendation so there is some support in the practice of other states to use historical crash data in making barrier installation decisions.[47]

Research Recommendations

Some of the aspects of the cable median barrier failures in Washington point out a need for additional research. These problems are general in nature and affect every State that uses cable median barriers. There are a number of already initiated or soon-to-be initiated NCHRP research projects that should provide valuable answers in five or so years. I recommend that WSDOT continue to take an active role in monitoring and participating in research to improve cable median barrier policy. I have three recommendations regarding research.

1) *Placement in the median* – Research on the proper placement of cable median barriers is desperately needed. The only guidance in this area is either outdated or never completed. Recently some crash tests of high-tension cable median barriers have been performed on 4:1 slopes but a comprehensive study of vehicle behavior when traversing typical depressed medians is needed to determine exactly where barriers should and should not be located. A new NCHRP project is programmed for this year that will look at the issue of guardrail and median barrier placement on slopes. NCHRP 22-22, Placement of Traffic Barriers on Roadside and Median Slopes," will examine a variety of types of guardrails and median barriers placed on slopes so it should be possible for WSDOT personnel to encourage the project team to include the issues of cable median barrier placement in the project scope. NCHRP 22-17, "Identification of Vehicular Impact Conditions Associated with Serious Ran-Off-Road Crashes," is examining real-world impact conditions to try and re-examine the most relevant crash test conditions. This project has been active since 2001 and has recently been expanded.

2) *Higher bumper heights of pickups and SUVs* – As discussed earlier, pickup trucks and SUVs have continued to become larger resulting in increasing bumper heights.

[47] MoDOT, "Engineering Policy Guide," Section 606.2.3, http://epg.modot.org, Missouri Department of Transportation, 2007.

Newer pickup trucks and SUVs may not perform well in impacts with some types of roadside hardware due to the miss-match between the barrier heights and bumpers. NCHRP 22-14(3), Evaluation of Existing Roadside Safety Hardware Using Updated Criteria, is a new project that will perform crash tests of existing hardware like cable median barriers using the new proposed updated crash test procedures. Since the new crash test procedures recommend the use of newer pickup trucks with higher bumpers, some of the questions regarding bumper and barrier compatibility should be resolved. The Midwest Roadside Safety Facility at the University of Nebraska is also developing a new four-cable median barrier system that may provide some insight into the interaction of newer pickups and SUVs and cable median barriers.

3) *Traffic conditions that promote median cross-overs* – The conditions that promote cross-median crashes are not well understood. Traffic conflicts and impaired drivers seem to initiate most cross-median crashes but it has been difficult to predict which sites will respond well to treatment with cable median barriers and which should use concrete median barriers. Traffic conditions like volume, mixing, interchange spacing, land use and speed limits appear to be related to the likelihood of cross-median crashes. Research should be performed to find good ways of predicting locations where cross-median crashes will be a problem. Such research would enable engineers to be pro-active and create designs that address a problem before fatal and disabling crashes occur.

I am hopeful that the foregoing analysis has helped to answer some of your questions about WSDOT's cable median barrier policy, its effectiveness and ways that it might be improved. If you should have any questions or comments, please contact me. I appreciate the opportunity to be of service to the WSDOT and the people of the State of Washington.

Sincerely,

Malcolm H. Ray, P.E., Ph.D.