Safety Effectiveness and Operating Performance of a Three-Cable Median Barrier on Interstate 5 in Oregon

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ABSTRACT

On interstate-type facilities, median crossover crashes are typically severe and often result in fatality or severe injury. Given the limited resources of most agencies, many transportation departments are interested in mitigating these crash types with the most cost-effective, proven countermeasure in the appropriate location. As a result, some states have installed a lower-cost solution, the three-cable median barrier, in areas with available median width and high crash potential.

A literature review indicates there is limited information concerning the safety effectiveness and operating performance (maintenance and repair costs) of the cable barrier system. This paper presents the evaluation results of approximately 21.9 miles (35.2 kilometers) of cable barrier. The safety evaluation compared the before-and-after crash experience in the study location using three years of before-and-after computerized crash records. A statistically valid subset of similar interstate facilities in Oregon for use as a comparison group could not be identified for use in the study. As a result, this paper only reports a simple before-after study and economic comparison of the cost of the barrier system based on the crash severity. In addition, cable barrier impacts, under-rides, and penetrations were studied using maintenance records and police crash reports. The repair costs were also studied for the evaluation period. The study indicates that the cable barrier system has been effective in reducing the severity of crashes but, as expected, has resulted in an increase of reportable minor injury and property damage crashes.

INTRODUCTION

Following an August 1996 median crossover crash on Interstate 5 (I-5) between Portland and Salem that resulted in three fatalities, public attention was focused on median crossover safety. Although the targeted section had relatively low historical crash rates, the accidents that did occur were catastrophic. From 1987 through 1996, there were nine fatalities and thirty-eight injuries related to median crossover crashes. The Oregon DOT (ODOT) considered various median treatments as a potential countermeasures and a three-cable median barrier was selected as the most attractive option. The three-cable guardrail is a flexible barrier system that can be used as a roadside or median barrier. The weak-post guardrail system gradually redirects an impacting vehicle by elastically stretching the cables, minimizing forces on the vehicle occupants. During an impact, the kinetic energy of the vehicle is dissipated by breaking and bending the posts and stretching the cables (*1*).

Weak-post cable guardrails have been used in many northern states for over 40 years since they allow plowed snow to pass through the cable system instead of building up in front. Weak-post cable guardrails and median barriers are intended to be used in locations where there is enough room for lateral deflection as cable guardrails may have a deflection of up to 3.5 m (11.5 ft.) (*1*). Therefore, the width of the median needs to be at least 7 m (23 ft.) for a cable barrier system centered in the median. The American Association of State Highway and Transportation Officials (AASHTO) Roadside Design Guide advocates the use of cable guardrail “on irregular terrain and on wider medians where the need is only to prevent infrequent potentially catastrophic cross-median accidents (*2*)".

In December 1996, ODOT installed the initial cable barrier test sections in the median of I-5. After seeing the effects of this installation, ODOT installed additional sections in April 1998, creating a total of 35.2 km (21.9 mi.) of continuous cable barrier from milepost 260.20 to 282.10. This paper presents an analysis of the state's reported crashes to determine the effectiveness of the barrier at reducing cross-median crashes. Since the barrier increased the number of reported collisions while reducing the severity of crashes, an economic analysis was conducted to compare the cost of these crashes on an annual basis. In addition, maintenance logs and Oregon State Police reports were examined to provide further information on crashes where vehicles under-rode or penetrated the cable barrier. Much of the work presented here is a summary of two other ODOT reports on the performance and costs of the three-cable median barrier (*3, 4*).

REVIEW OF PUBLISHED CABLE BARRIER STUDIES

The cable system is less expensive than other median barrier options but it must be repaired after an impact to remain effective. Therefore, the use of the cable system in areas where it is likely to be hit frequently is not recommended (*2*). When hit, a relatively long section of the barrier will become non-functional and will need repair. Three-cable guardrail has met the National Cooperative Highway Research Program (NCHRP) Report 350 TL-3 crash test requirements (*5, 6*). *NCHRP Synthesis 244 - Guardrail and Median Barrier Crashworthiness* documented some of the advantages and disadvantages of cable guardrail (*1*). Some advantages are: cost of installation is inexpensive compared with other barrier systems; forces on the occupants of the vehicles during a crash are low compared with other types of barriers; cable barriers have good crash test performance (up to a 2000 kg (4409.2 lb.) pick-up); system is aesthetically appealing; and sight distance problems are minimized. Some disadvantages are barrier damage is increased in a typical accident, when compared to other systems; damaged installations need to be repaired or replaced quickly since the damaged run may be ineffective until repaired; a minimum clear space is required behind the barrier for cable deflection; and periodic retensioning of the cables is required. All of the numbers presented in the following paragraphs have been adjusted to 2001 dollars using an assumed inflation rate of 4%.

The North Carolina Department of Transportation performed a study to find the maintenance and repair costs for the 13.7 km (8.5 mi.) of cable barrier installed on Interstate 40. All maintenance and repair was accomplished by Wake county maintenance personnel. From January 1994 through September 1995, there were 71 repairs per year. There were no fatality accidents, but there were 21.1 injury accidents per year. The estimated repair cost per post was $86 for the subject section, which is 73% less than the repair cost per post in Oregon (Table 1) (*7*). More recently, Hunter et. al studied the effectiveness of the cable barrier system in North Carolina. The researchers developed negative binomial regression models and used a reference population of all North Carolina interstates to predict the expected number of crashes. They found that the barrier did indeed reduce cross median collisions but there was an increase in some ran-off-the-road left crashes. They concluded that overall safety was enhanced (*8*).

Iowa studied cable barrier effectiveness in the years 1977 and 1978. There were 16 police-reported accidents per year. In 23% of the accidents, the cable system was penetrated. It was reported that there were 29 repairs per year to the cable barrier with an average repair cost per accident is $543 ($90 per post), which is 62% less than the average repair cost per accident for Oregon. The study concluded cable barrier impacts were less costly and less severe than impacts with other barriers, and the cable system was performing adequately (*1*).

The study of cable barriers in use on New York State roads found for a three-year period, 1967-1969, there were 125 police-reported cable barrier related accidents per year. In 27% of the accidents, the cable system was penetrated. There were 1.3 fatalities and 6.0 injury accidents per year. For the three-year period, two of the fatalities involved penetrating the barrier. The average repair cost per accident is $328, which is 77% less than the average repair cost per accident for Oregon. New York's study concluded the weak-post cable barrier resulted in less severe crashes than strong post W-beam guardrail systems (*1*).

The Washington State Department of Transportation (WsDOT) conducted crash tests with a small 820 kg (1808 lb.) car, as well as with a 2000 kg (4409 lb.) pickup truck (9). The median barrier was configured with the top cable height at 770 mm (30.3 in.), the middle cable height at 650 mm (25.6 in.) and the bottom cable height at 530 mm (20.9 in.). The barrier had two cables on one side and the middle cable on the opposite side. In both tests, the vehicle was contained and brought to a stop, with relatively minor vehicle damage.

Table 1: Crash Comparisons with Other States

	Oregon	**North Carolina**	**Iowa**	**New York**
Study Period in Years	4.1	1.8	2.0	3.0
Km Cable Median Barrier (mi.)	35.2 (21.9)	13.7 (8.5)	NA	NA
Repairs/Year	44	71	29	NA
Repair Cost/Accident ($)	$1,419	NA	$543	$328
Repair Cost/Post ($)	$320	$86	$90	NA

NA: Not available
Costs adjusted to 2001 assuming 4% inflation.

SITE CONDITIONS

The cross section of I-5 treated with the cable median barrier has three 3.6 meter (12 ft) lanes in each direction. The treated section has an average median width from the edge of pavement to edge of pavement of 15.2 m (50 ft.) and has relatively wide inside paved shoulder at an average of 3.1 m (10 ft.). Milled shoulder rumble strips were installed on both the left and right shoulders in the fall of 1998. The median is grass-covered and rose bushes have been planted to act as a glare-guard. These rose bushes generally alternate from one side of the median to the other approximately every 0.5 mile. The posted speed limit is 65 mph. Volume data was obtained from the state's database. Over the analysis period, the ADT has increased from 66,000 to 82,600 vehicles per day. The volume trends are presented in Figure 5 and 6. The section has a high percentage of Portland to Salem commuter traffic and is one of the more traveled sections in the state. Images from the state's digital video log are shown in Figure 1.

For most of the treated section, the median slopes down at a flat slope from the edge of pavement to the center of the median. The cable barrier is typically centered in the median and installed in the bottom point. The barrier is nearly continuous but there are some small gaps in the barrier sections at emergency vehicle median crossovers and near bridge abutments. The cable barrier system used consists of three steel 19 mm (.75 in.) diameter cables with steel supporting posts a maximum of 5 m (16.4 ft.) apart. The bottom cable height is 540 mm (21.3 in.); the top cable height is 840 mm (33.1 in.) (Figure 1). The foundation detail is shown in Figure 2. Anchor post brackets and breakaway anchor angles secure the ends of the cable run. The cable tension is controlled by the spring turnbuckles located near both ends of the cable run. The maximum distance between anchors is 600 m (0.4 mi.). The installation cost for cable barrier was $26,357 per kilometer ($42,417 per mile).

In December of 1996, two sections totaling nearly 7 miles were installed. In April 1998 an additional 18 miles were installed for continuous installation over 21.9 miles. The locations and installation date of the cable barrier are shown in Figure 4.

Northbound *Southbound*

Figure 1 - Video Log Images of Treated Sections

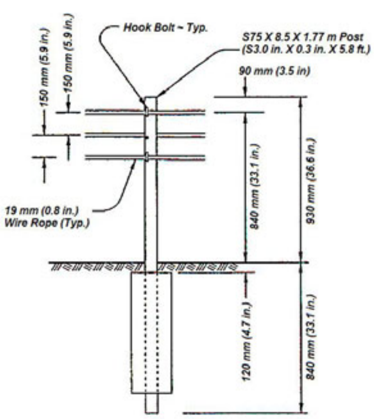


Figure 2: Post and Cable Assembly

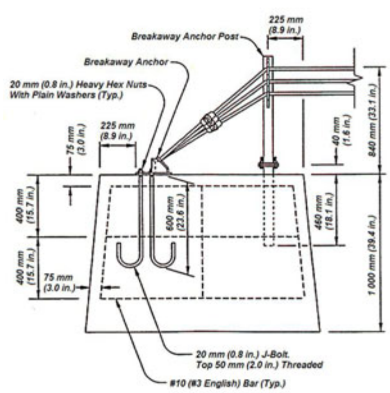
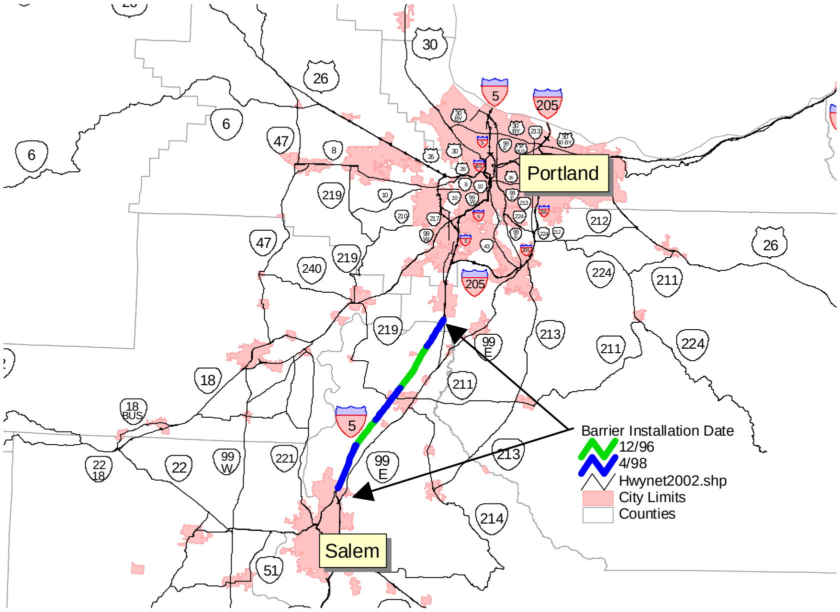


Figure 3: Footing Elevation



Beg. Milepost	Ending Milepost	Install Date
260.20	265.24	4/98
265.25	268.81	12/96
268.82	273.20	4/98
273.21	278.67	12/96
278.67	282.10	4/98

Figure 4 - Location of Cable Barrier Installation

CRASH ANALYSIS

For this analysis, two primary sets of data were used to generate the results. The first source was reported crashes in the state's computerized crash record system. The second source was maintenance logs documenting cable barrier impacts and Oregon State Police (OSP) reports for some crashes. These data were reviewed for additional information about barrier under-ride and penetration events.

Analysis of State Reported Crash Data

The original intent of the analysis was to conduct a before-and-after evaluation using a comparison group as outlined in Hauer's *Observational Before-After Studies in Road Safety* (10). Unfortunately, once the targeted crashes were identified, a suitable comparison group of similar highways with statistically acceptable odds ratio (ω) could not be identified. For the comparison group analysis to be valid, the time series of the sample odds ratio for the treated and comparison groups should have a mean sufficiently close to one. In other words, the historical crash performance of comparison group should be very similar to the crash performance of the treated section; otherwise, the primary assumption of the comparison group study is invalid. The geometric configurations and volumes on the treated site are fairly unique to the state and given the small sample of possible target crashes perhaps this was to be expected since, in terms of total crashes, median crossover crashes that result in a collision are a relatively rare occurrence. For 1993-2001, only 70 out of 17,600 (0.4%) crashes on I-5 were coded as one vehicle crossing a grass median or plunging through an existing median barrier.

Instead, a simple before and after crash performance of the treated section is presented. The crash performance in terms of severity was equated using comprehensive crash costs in order to gauge the effectiveness of the barrier. Readers should be aware that the section was chosen for treatment because of the occurrence of median crossover crashes and is likely to exhibit some regression-to-the-mean, which was not adjusted or accounted for in the analysis. For this reason and others related to the difference in the before and after conditions that were not accounted for (rumble strips, volume, weather, etc.), no estimate has been made of the safety effectiveness in terms of percent reduction of the treatment or a crash reduction factor.

Before-after time periods

The first section of barrier was installed in December of 1996 and additional sections were installed in April of 1998. Three years of crash data for both before and after period were considered for the analysis period. Rather than conduct two analyses, crashes that occurred during the transition (January 1997-April 1998) are not included in the before-after comparison.

Target Crashes

The first step in the analysis was to identify the target crashes (those crashes that were to be treated by the barrier installation). Identifying these cross-median collisions was not a straightforward task. The Oregon crash data does not indicate which direction, left or right, vehicles leave the roadway, so in order to identify target crashes a variety of crash factors were used to identify the target crashes. Given the entire treated section is a divided, access control freeway; it was simple enough to construct a set of crash factors to query to identify crashes involving the median. Some factors were included to exclude a crash as barrier or median related. A preliminary list of target crashes for both the before and after periods were identified by meeting any one of criteria specified in the following table:

Table 3 - Crash Factors Queried to Develop Preliminary List

Crash Field	Related codes
Crash Type	Head-on; Sideswipe-Meeting; Fixed Object; Non-collision
Driver error	Driving thru median, Driving on wrong side of road, Driving wrong-way
Driver action	Crossed earth or grass median
Object struck	Guard rail, median barrier

All crashes meeting the preliminary set of criteria were reviewed manually to separate them into three types: 1) reported median crossover crash; 2) reported crashes striking barrier; and 3) crashes unrelated to the barrier treatment. In some instances, the original crash report was reviewed to verify if the crash was related to the median barrier. For example, there was a head-on crash where it was not clear from the crash record if the vehicles had crossed the median. A review of the report revealed that one vehicle had entered the freeway in the wrong direction. This procedure for identifying median crossover crashes is likely to miss some crashes that did involve the median or cable barrier. For some crashes, the barrier is a minor part of the collision and is not coded. A better procedure would have been to review the detailed crash reports to clearly identify those collisions to be considered "target" but this was not possible because of time constraints. Crash types 1) and 2) were considered in the analysis and were summarized by severity. ODOT uses the KABCO scale where a severe injury is coded "A", moderate injury coded "B", and minor injury coded "C". Crashes in category "3" were not considered in the analysis.

Results of the analysis

In the three year period prior to the installation of the cable barrier, there were 11 crashes (2 fatal and 1 injury A) crashes as a result of a vehicle crossing the median. The remaining crashes were minor injury B or C or property damage. In the three years after the barrier treatment, there has not been a reported crash involving a vehicle crossing over the median. This trend is shown in Figure 5

In the three-year period prior to the installation of the cable barrier, there were 7 reported collisions (2 injury B, 1 injury C, 4 PDO) in which a vehicle hit a guardrail or median barrier. Since there was no median barrier during this period, these crashes may involve a guardrail in the median or on the right shoulder. These crashes were considered in both the before and after period since the direction of road departure was not available in the data. In the three years after, there was a substantial increase in the number of collision, mostly those coded as striking "median barrier". There were a total of 60 crashes (2 injury A, 4 injury B, 13 injury C, and 41 PDO). This information is presented in Figure 6.

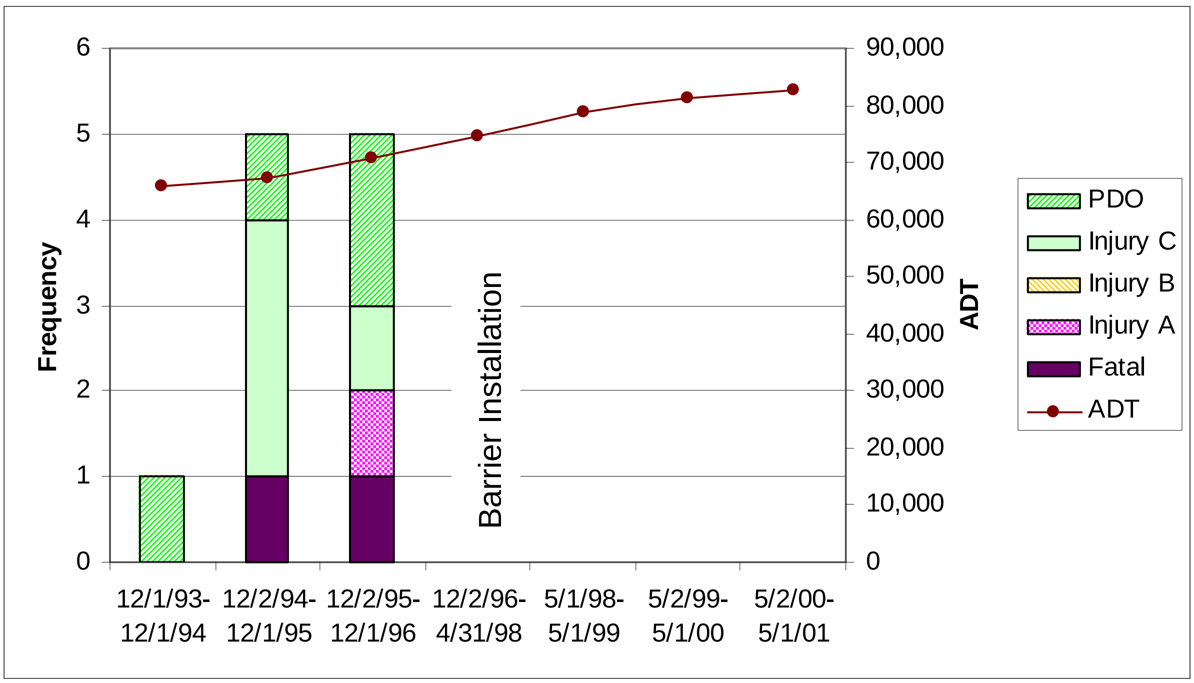


Figure 5 - Reported Cross Median Crashes

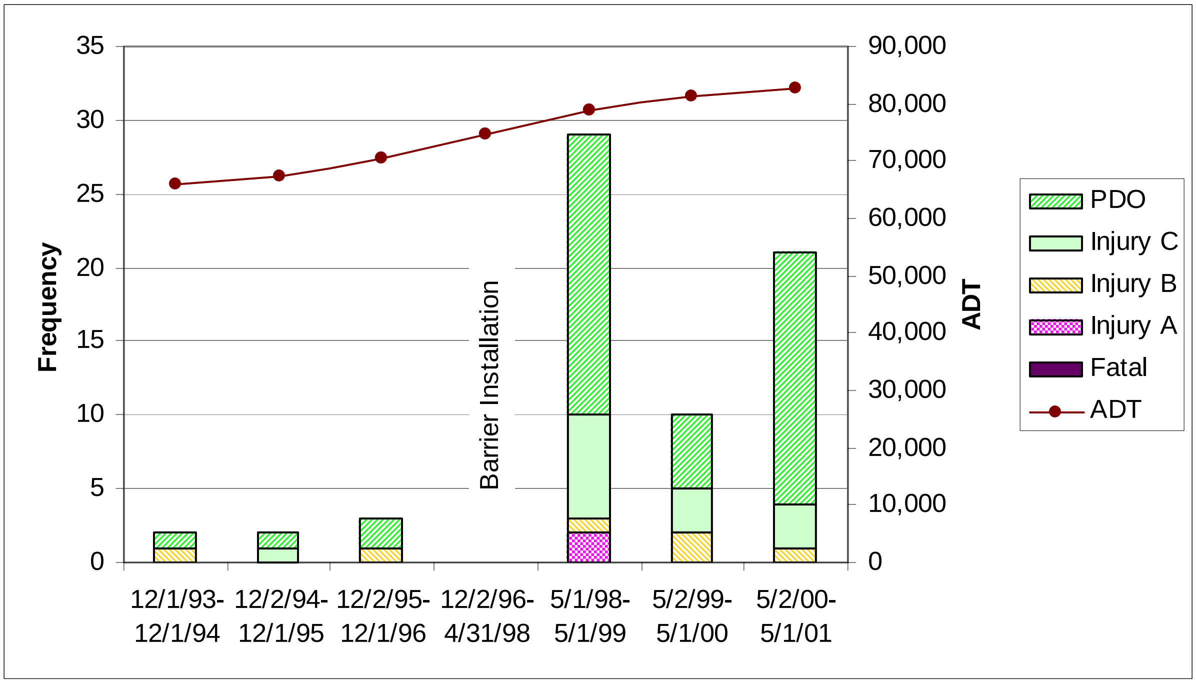


Figure 6 - Reported Crashes Striking Barrier

Analysis of Maintenance Logs and State Police Reports

ODOT personnel, the traveling public, police, and contractor employees can report damage to the cable system. Once identified, ODOT notifies a contractor who makes the necessary repairs. Coral Construction accomplished all cable barrier repairs under an ODOT contract. Based on data collected, the average time before a damaged barrier was repaired was 17 days. According to the maintenance logs, there were 231 impacts to the cable median barrier between December 1996 and April 2002.

The total cost for cable barrier maintenance and repair was $252,600 for the period from April 1998 through April 2002. Consequently, the average annual maintenance and repair cost is $62,129, or $1,766/km/year ($2,842/mi./year). Because of the wide shoulders along the median of the interstate, no lane closures were required for repairing the cable barrier. When possible, ODOT recovers costs for repairing the system from the parties responsible for the damage as allowed by statute. So far, no routine maintenance has been required for the system. The expected periodic retensioning of the cables seems to be accomplished as part of the repairs, since the cable system is retaining tension.

Potential Crossover Events

To estimate the effectiveness of the barrier in reducing crossovers using the maintenance data, collisions with the barrier that resulted in damage to four or more line posts were considered a potential crossover. Although subjective, this estimate is based on analysis of the crash report descriptions and the number of line and anchor posts damaged. Increased damage to the system should correlate to increased momentum, which would carry the vehicle into opposing traffic lanes. In addition, all under-ride and rollover events were considered potential crossovers. Using this assumption, there were 105 potential crossovers contained by the cable median barrier, which is 45% of the total number of impacts. The under-rides and penetration events are discussed in more detail in the following sections.

Cable Barrier Under-ride Events

Of the 231 impacts to the cable median barrier between December 1996 and April 2002, only five vehicles were reported to have under-ridden the cables and none of these crossed over into the opposing traffic lanes. In addition to the police reports, weather information was examined for the day of and the week prior to the collision to see if saturated, soft ground could have played a part in the under-rides. The data summarizing these under-rides is shown in Table 4. For all but one of the five crashes, soft ground can be ruled out as a contributing factor to the under-ride event due to lack of precipitation surrounding the event.

Table 4 - Cable Barrier Under-ride Events

Date	Vehicle	Milepost	Precip. on Date	Precip. Week Before	Ground	Vehicle Damage
Feb. 8, 1997	Chrysler	266	None	7.6 mm (0.3 in.)	Firm	Not specified
June 29, 1997	1991 Subaru	274	0.3 mm (0.01 in.)	6.6 mm (0.3 in.)	Firm	Tore hood & crushed windshield
Feb. 14, 1999	1994 Mitsubishi	278	None	30.7 mm (1.2 in.)	Possibly soft	Not specified
July 19, 2000	1996 Saturn	262	None	None	Firm	Not specified
Aug. 27, 2000	1989 Pontiac Firebird	268	None	Trace	Firm	Front end of the vehicle

Cable Barrier Penetration Events

Of the 231 impacts to the cable median barrier between December 1996 and April 2002, only two vehicles were reported to penetrate the cables and, rather fortunately, neither of these resulted in a serious injury. On September 23, 1997, a semi-trailer went through the median barrier, dragging the cables across the opposing traffic lanes and hitting a GMC Yukon. The driver of the Yukon suffered minor injuries. The semi-trailer driver suffered from a seizure before crossing through the median. This crash is during the transition period and is not shown in the reported crash analysis. A second vehicle, a Ford F-250 pickup, crossed through the cable barrier system into the opposing lanes of traffic on May 8, 2001 coming to rest in the outside shoulder of the road. The driver lost consciousness before crossing the median. This crash occurred outside the after period and is not shown in the previous analysis. To date, there has not been a cross-median crash in a location where the barrier needs repair. Even so, consideration should be given to the risk where the barrier is non-functional after a crash until it is repaired.

Economic Analysis

As way to evaluate the tradeoffs between the reduced severity of crashes and an increase in minor and property damage crashes because of the barrier installation, the two graphs were combined to show the total economic cost of the barrier. The cost of each crash, by severity, was calculated using the most recent FHWA guidance on the cost of collisions inflated to 2001 dollars with GDP implicit price deflator, which is shown in Table 3 (*11*). All crashes shown in both Figures 5 and 6 were included in the calculation. The installation cost of the barrier was annualized over 20 years with a 4% discount rate and the annual maintenance costs were included in the economic cost in the after period. The results are shown in Figure 7.

Table 3 - FHWA Recommended Costs of Motor Vehicle Crashes Adjusted to 2001

Crash Severity	Comprehensive Economic Cost (2001 Dollars)
Fatal	2,917,600
Injury A	202,000
Injury B	40,400
Injury C	21,300
PDO	2,200

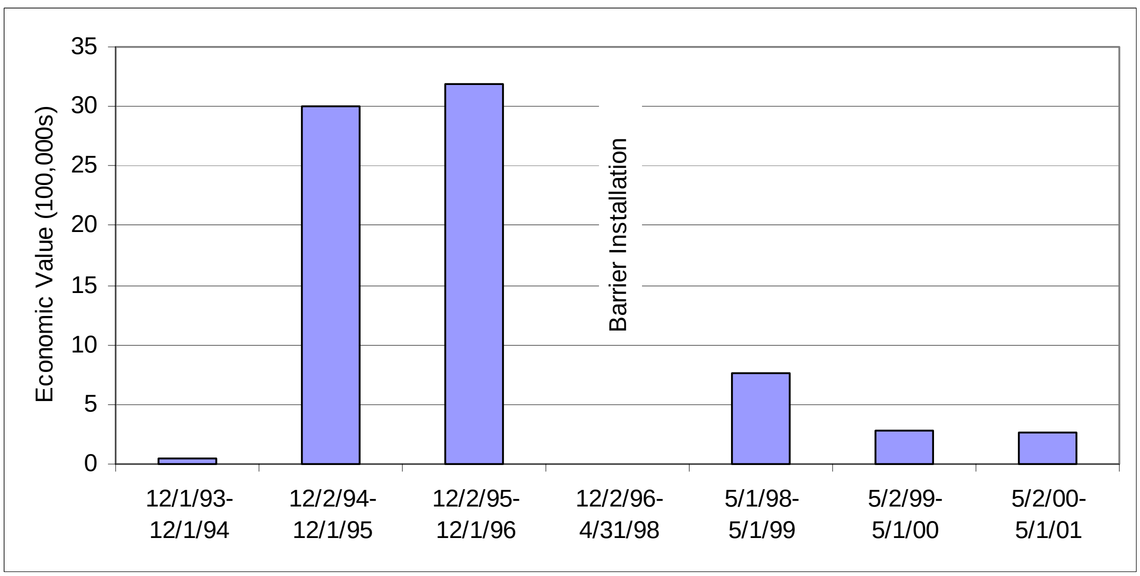


Figure 7 - Total Economic Cost of Crashes and Barrier

Discussion

The data in Figure 5 indicate that the cable median barrier has been effective at reducing cross-median collisions. In the reported database, there has not been one collision in which a vehicle has crossed the median. The review of maintenance records of damage to the cable barrier also supports this observation. From the maintenance records, we estimate approximately 45% of the road departures that could have resulted in a cross median event were stopped by the cable barrier. However, the maintenance and Oregon State Police logs indicate that the barrier was not totally effective in reducing potential crossovers as there were 5 vehicle under-rides of the cable system and 2 complete penetrations. The penetrations involved larger vehicles, which the barrier was not designed to restrain. The penetrations are not included in the graphed data in Figures 5 and 6, since both occurred during the transition period. In addition, shoulder rumble strips were installed at nearly the same time as the barrier, which also may have had an effect on the reduction in cross-median crashes. Other studies have shown rumble strips effective in the range of 15 to 70 percent reducing run-off-the road crashes (*12*). Nonetheless, the reduction in cross median crashes is notable given the limitations discussed in the first part of this section.

This increase in reported crashes was expected; any barrier device is designed to reduce the severity of collisions and does have the effect of increasing minor damage collisions. Vehicles that had departed the roadway previously and did not incur any significant damage could reenter the roadway, if they had not crossed over. Now, with a cable barrier in-place, these vehicles impact the cable system. Other studies have found similar results (*8*). It should be noted that effective September 1, 1997 the minimum reporting threshold for property damage crashes doubled from $500 to $1000. This increase in the reporting threshold might mean that even more crashes would have been reported if the threshold was the same in the before and after periods. A review of statewide crash data, however, indicates that while there was an increase in PDO crashes for the years following the change in the reporting threshold, the trend was similar to injury and fatal crashes whose reporting threshold was not changed. The severe injury A crash involving the barrier is worth noting, since it involved a drinking driver at high speeds who lost control of his vehicle. If the vehicle has crossed into opposing travel, the crash could have been fatal.

By comparing the total economic cost of the barrier related crashes, it is clear that the barrier has reduced the severity of crashes even if it has increased the frequency of reported crashes. The two crashes that penetrated the barrier could change this analysis substantially, especially if they resulted in fatal collision, but since the barrier is not designed to restrain the larger vehicles, this crash would have occurred with or with out the barrier. In addition, the comprehensive cost for fatal collisions dominate the analysis, a more balanced weighting of the crash costs would produce different results.

CONCLUSIONS

The cable median barrier system was effective in preventing crossover crashes at the subject location. First, a review of the state's crash database for target crashes indicated a reduction in cross median crashes. In addition, a review of maintenance records indicated that 105 potential crossovers were restrained from entering the opposing traffic lanes. Again, readers are reminded that the section was chosen for treatment because of the occurrence of median crossover crashes and is likely to exhibit some regression-to-the-mean which is not adjusted or accounted for in the analysis. In addition, the installation of shoulder rumble strips between the before and after periods and the change in reporting threshold for crashes likely have some effect on the results, but their effects were not be separated out.

Although the cable barrier installation costs are less than other systems, maintenance and repair costs for cable barrier are typically higher. ODOT’s experience with the cable barrier is consistent with the studies other states have done; however, the repair costs are considerably higher in Oregon. Appropriate budget increases should take place for the agency charged with system maintenance. The cable median barrier may be considered in all locations that, at a minimum, meet the performance capabilities of the system as it is cost effective and exhibits good performance. Other cable barrier systems, such as the proprietary Brifen system, are being tested by Oklahoma and Iowa and may be an option in the future.

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