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Economic Feasibility of Safety Improvements on Low-Volume Roads

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ABSTRACT

This paper presents an investigation into the economic feasibility of safety countermeasures along rural low-volume roads. While these roads may be associated with higher crash risks as they're built to meet lower standards, crash frequencies are notably lower than those on other roadways with higher traffic exposure. Therefore, it is reasonable to expect that some conventional safety countermeasures that are proven to be cost effective on well-travelled roads may turn out to be infeasible on low-volume roads. Twenty seven safety improvements were examined in this investigation for their economic feasibility along low-volume roads. A roadway sample of 681 miles of Oregon was used in this study. Detailed benefit-cost analyses were performed using countermeasure costs, ten-year crash data, and expected crash reductions using Highway Safety Manual methods. Around half of the countermeasures investigated were found cost-effective for implementation along low-volume roads. Further, most of the countermeasures that were found to have very high benefit-cost ratio are associated with low initial cost and many of them do not require much maintenance cost. At the other end of the spectrum, almost all roadway cross-section safety improvements were found economically infeasible due to higher associated costs relative to the expected crash reduction benefits on low volume roads.

Keywords: low-volume roads, safety improvements, countermeasures, economic analysis

1. INTRODUCTION

Managing safety on the highway system has become an utmost priority for most highway agencies in the US. Meanwhile, resources at the state and federal levels that are used to maintain the ongoing safety improvement programs have become increasingly limited in recent years. Therefore, a critical element in these programs is the proper identification of those locations in the network where safety improvements would ensure the maximum return on investment, i.e. highest reduction in crashes and crash severity. This principle will naturally lead to the majority of safety funds being allocated to locations on well-travelled roads, usually associated with higher crash frequencies. Consequently, using the economic feasibility principle alone has an inherent bias that would exclude the majority of locations on low-volume roads despite the higher crash risk and hazardous features that are more often encountered on these roads. Another implication of the economic feasibility principle is the fact that many proven countermeasures on other rural roads may simply prove infeasible on low-volume roads due to low traffic exposure.

In this study, the economic feasibility of a wide range of safety countermeasures on rural highways was investigated using extensive low-volume road sample and ten-year crash data from the state of Oregon. Benefit-cost analyses were performed consistent with the guidelines provided in the Highway Safety Manual (HSM), and the most viable safety treatments on low-volume roads are identified and presented.

2. BACKGROUND

The literature review that was done in the course of this study confirmed the fact that research on the economic feasibility of safety countermeasures is limited in general. Specifically, the few studies that were identified in the literature mostly involved limited investigations on specific safety treatments on all types of highways. Given the wide range of safety countermeasures used in practice, information on the economic viability of the majority of countermeasures is still lacking. This lack of information is more acute for low-volume roads where the low traffic exposure is expected to largely affect the economic feasibility of safety treatments. None of the studies identified and presented in this section exclusively investigated safety measures on low-volume roads.

Potts et al. (2011) conducted research for the Missouri Department of Transportation to evaluate the safety effectiveness of Smooth Roads Initiative (SRI). The improvements in SRI program included: wider & high visibility lane lines, wider edge lines with rumble strips, centerline rumble strips, barrier-mounted delineators and emergency reference marker signs. The evaluation of SRI was conducted using crash data for three years before and three years after the implementation of SRI improvements. The striping and delineation program resulted in an overall reduction of 16 percent in fatal and disabling-injury crashes and 11 percent in fatal and all injury crashes. The SRI program provided an overall benefit-cost ratio of 11.2.

In a study by Graham et al. (2011), the effectiveness of safety edge treatments was investigated in three states: Georgia, Indiana and New York. The study found that for two-lane highways with paved shoulder, the application of safety edge treatment had minimum benefit-cost ratio which varied between 3.8 and 43.6 for Georgia and between 3.9 and 30.6 for Indiana. For two-lane highways with unpaved shoulder, the benefit-cost ratio ranged from 3.7 to 62.8 for Georgia and from 2.8 to 12.8 for Indiana.

Srinivasan et al. (2009) investigated the safety effectiveness of improved curve delineations for two states: Washington and Connecticut. The improved curve delineation varied by site, but included individual treatments or combinations of chevrons, horizontal arrows, advanced warning signs and new fluorescent sheeting. The study reported an 18 percent reduction in injury & fatal crashes, 27.5 percent reduction in dark conditions crashes and 25.4 percent reduction in dark condition lane departure crashes. The study also reported a benefit-cost ratio of 8:1 for improving curve delineation.

A study by Neuman et al. (2003) investigated the safety effectiveness of raised pavement markers in 184 high accident locations including narrow bridges, curves and intersection approaches. The evaluation of raised pavement marker was conducted using crash data for one year before and one year after the implementation. The results indicated a total 9 percent reduction in all crashes and 15 percent reduction in injury crashes. The benefit-cost ratio of the raised pavement marker was found to be 6.5:1.

Ayala and Turochy (2009) conducted research to investigate the economic feasibility of paved shoulder installation on high-priority segments of two-lane rural highways in Alabama. For this research high priority segments were identified based on two criteria: crash rate and severity. An analysis of expected benefits and actual improvement costs was performed to derive the benefit-cost ratio. The study reported benefit-cost ratios ranging from 0.09:1 to 2.39:1 for the segments identified based on crash rate and from 1.32:1 to 8.90:1 for the segments identified based on severity.

Another recent study (Persaud et al. 2015) investigated the safety effectiveness of centerline and shoulder rumble strips at two-lane rural roads in Kentucky, Missouri and Pennsylvania. An Empirical Bayes (EB) before-after analysis was conducted to account for potential selection bias and regression to the mean. The crash modification factor (CMF) for run-off-the-road, head-on and sideswipe-opposite direction crashes was found to be 0.733 and the CMF for all type of crashes was found to be 0.80. Benefit-to-cost ratio for all types of crashes varied between 28.2 and 67.7 depending on the treatment cost and service life assumptions.

A study by Schrum et al. (2012) attempted to identify geometric features and common fixed objects including culverts, trees, slopes, ditches, and bridges that presented safety issues to drivers. The field study included 21 miles of low-volume roads in Kansas and 55 miles of low volume roads in Nebraska. Different safety treatment options (e.g. remove posts/rail, remove trees, install longitudinal barrier, install guardrail) were considered for each feature including the "do nothing" option. The "do nothing" option was often found to be the most cost-effective safety treatment for the existing configuration.

Garber and Kassebaum (2008) conducted a study in Virginia to identify the contributing factors of crashes on two-lane highways. Four years of crash data (2001-2004) from 143 five-to-ten miles segments of roads were used in this study. Fault-tree analysis and generalized linear models were used to identify crash causal factors. Run-off-road (ROR) crashes were found to be the predominant type of crashes and the significant causal factors for ROR crashes were horizontal curvature and traffic volume. To reduce the ROR crashes, this study suggested to improve the curvatures. By using different percentage of crash reductions and construction costs for improving horizontal curvature, the benefit-cost ratios were estimated which varied in the range of 1.16 to 9.60.

A study in Western Australia (Meuleners et al. 2011) examined the safety effectiveness of sealed shoulder and audible edge line (shoulder rumble strips). The study assessed the reduction in crash frequency after the implementation and the economic benefits at 13 different sites. The treatment was reported to reduce all-severity crashes by 58 percent and casualty crashes by 80 percent. The benefit-cost ratio of the treatment was found to be 40.3 for all selected sites.

One study by IRAP (Mclnerney and Smith 2009) investigated the safety effectiveness of different countermeasures at the road network in Malaysia. The study assessed the crash risk of different roads and assigned star ratings based on safety performance. For benefit-cost analysis, the researchers estimated the reduction in the number of fatalities and total serious injuries as a result of implementing a certain countermeasure and then calculated the annual benefit by using a factor and Gross Domestic Product per capita. Then the benefit-cost ratio (B/C) was calculated by comparing the economic costs and benefits. The B/C for pedestrian crossing, shoulder widening, traffic calming, regulate roadside commercial activity and roadside safety- hazard removal were found to be 19, 12, 26, 13 and 7 respectively.

3. STUDY OBJECTIVE

The objective of this research is to examine the economic feasibility of a wide range of safety countermeasures on rural low-volume roads. Traditional methods for identifying candidate locations for safety improvements has inherent bias in favor of well-travelled roadways that experience higher crash frequencies. However, low-volume roads may be associated with higher level of risks and consequently higher crash rates. The information published on the economic feasibility of countermeasures is very limited in general, and it is particularly lacking for low-volume roads. The current study exclusively examines common safety countermeasures along low-volume road segments only and is not concerned with intersections and intersection-related countermeasures.

4. STUDY SAMPLE AND CRASH DATA

A large sample of low-volume roads in the state of Oregon was selected for use in the economic feasibility analyses. For the purpose of this study, low-volume roads are defined as those roads with annual average daily traffic (AADT) less than 1000 vehicles per day (vpd). The sample consisted exclusively of paved two-lane highways in rural areas which covered different geographic regions in the state of Oregon. The total length of the study sample, which consisted of roadway segments only, is 680.85 miles. All roadway segments included in the study sample are paved, two-lane, two-way roads with posted speed limits of 55 mph. The roadway sample was collected from two different parts of Oregon: the western and eastern regions. The roads in these two regions are somewhat different due to the geographic differences in terrain between the rainy, mountainous and winding roads included in the west and the drier, flatter and straighter roads in the east. Figure 1 shows the roads included in the study sample marked in red on the state highway map.

Ten years of crash data (2004-2013) have been used in this investigation. A total of 1251 crashes occurred during the ten-year period on the road sample. Table 1 shows the crash rates per 100-million vehicle miles traveled (VMT) and crash rates per 100 mile by crash type (property damage only - PDO, injury and fatal) for the study sample.

At the National level, urban road experienced 0.72 fatal crashes per 100-million VMT and rural roads experienced 1.68 fatal crashes per 100 million VMT in 2012 (NHTSA 2014). The fatal crash rate for the study sample is much higher than the National average for rural highways (3.04 versus 1.68 fatal crashes per 100-million VMT). This is somewhat expected considering the fact that low-volume roads (many in remote rural areas) are usually designed to lower standards compared with the well-travelled rural arterials and collectors.

5. STUDY APPROACH

This study identified a wide range of safety countermeasures in the literature that could potentially be implemented on rural low-volume road segments. Almost all countermeasures identified have low to moderate implementation costs given the extremely low traffic exposure on these roads.

To determine the economic feasibility of the proposed safety measures, the costs of the treatments as well as the benefits expected from those treatments need to be established. The overall benefit-cost ratios (B/C) can then be determined to provide guidance on which treatments may be the best use of agency funds. The benefit-cost ratio was derived for various countermeasures using the procedures discussed in the following sections.

6. SAFETY COUNTERMEASURES ON LOW-VOLUME ROAD SEGEMENTS

Many countermeasures have been reported in the literature as being used by highway agencies to mitigate crash risks and improve safety on the highway system. Many of those countermeasures have been evaluated for effectiveness, and as such crash modification factors (CMFs) or crash reduction factors (CRFs) for those countermeasures are published. For the purpose of this study, emphasis has been placed on safety countermeasures that are common on highway segments along rural two-lane highways in general including low-volume roads. The countermeasures identified generally fall in four different categories:

6.1. Countermeasures Related to Highway Alignment

Some of the most serious crashes on low-volume rural roads occur at horizontal and vertical curves. The alignment of the roadway may contribute to increased crash risk under certain circumstances. Methods to mitigate risky alignments can often be costly, but some low-cost countermeasures have been documented. Alignment warning signs, markings, and delineators can improve safety by alerting drivers to changes in roadway geometry that are unexpected.

6.2. Countermeasures Related to Roadway Cross-section

Improving the roadway cross-section like adding shoulders or widening lanes and/or shoulders may improve a vehicle's ability to remain on the roadway or recover from errant maneuvers. Shoulder improvements are known to reduce the occurrence of run-off-the-road crashes especially, while wider lanes can also reduce opposite direction crashes by allowing opposing directions of traffic to be more separated. The previous discussion does not refer to the instances where extra wide lanes or shoulders are used as those features may invite more risky passing maneuvers by drivers.

6.3. Countermeasures Related to Roadside Features

Roadside hazards like steep side slopes and the presence of fixed objects near the roadway are associated with increased crash occurrence and increased severities. Countermeasures in this category involve risk mitigation outside the roadway cross-section, i.e. outside the shoulder lines on both sides of the road or outside the pavement edge in the absence of shoulders.

6.4. Other Safety Countermeasures

There are safety countermeasures that don't fit any of the previous three categories, and therefore are grouped in a separate "other" category. Examples of these countermeasures include different types of pavement marking, highway signage and use of rumble strips. Pavement markings provide directional guidance, delineation and inconspicuous warnings as drivers approach locations with higher levels of hazards such as upcoming horizontal curves and nearby intersections. Rumble strips provide both an audible warning and a physical vibration to alert drivers that they are leaving the travel lane. Transverse rumble strips are provided to alert drivers when they are expected to slow down such as on curve approaches or on approaches to nearby intersections. Some other low-cost countermeasures to mitigate animal-vehicle crashes were also considered in this study, given that 159 out of 1,251 total crashes involved animal-vehicle collisions. This is expected as some of the highways in the study sample run through some of the National forests in Oregon.

Table 2 provides the safety countermeasures identified and examined in this study for its economic feasibility.

7. ESTIMATING COUNTERMEASURE COSTS

Comprehensive and up-to-date cost information for all safety measures identified was challenging to find, and therefore, significant efforts were expended in obtaining updated cost information. There is hardly any published information on countermeasure costs that could be borrowed for use in the analysis. Accurate cost estimates that cover all situations are also difficult due to the potential for large differences in cost between treatment areas that may have varying local factors and individual circumstances. Personal contacts with state Departments of Transportation (DOTs) were essential in compiling cost data for all countermeasures included in this investigation. Several DOTs were contacted for the cost of the countermeasures, which included Oregon DOT, Texas DOT, California DOT, Florida DOT, New York DOT and New Jersey DOT. Out of the six DOTs that received the data request, only three agencies provided cost information on safety countermeasures, namely: Oregon DOT, Texas DOT, and Florida DOT. The three states represent different geographic regions in the country. Further, data on life span of different countermeasures was obtained from a recent FHWA report (Atkinson et al. 2014).

Cost data from the aforementioned sources were examined carefully to ensure consistency in the treatments reported and the assumptions used in deriving cost values. All cost estimates coming from different sources had to be converted to the same units of measurement to be of use in the analysis. When more than one cost estimate for the same treatment was obtained, the average cost was used in the analysis. Two types of cost were considered in the analysis, the initial cost of implementing the safety treatment and the operating cost which primarily involves maintenance costs (and power in a few instances). As expected, some of the treatments involve only initial cost over the lifespan (e.g. pavement marking), while others involve initial and operating costs (e.g. lane and shoulder widening). The costs were adjusted for inflation to represent 2004 dollars using US Bureau of Labor Statistics, Consumer Price Index methods. The benefit-cost analysis used the net present worth (NPW) method and the cash flow principles where all the costs and benefits during the 10-year period (2004 to 2013) were converted to 2004 values using discount rate. A sample cost estimates for alignment safety improvements is provided in Table 3. The average cost was used if a range of the cost is provided. From the life cycle and maintenance costs, the average annual maintenance cost was calculated.

8. ESTIMATING BENEFITS OF SAFETY COUNTERMEASURES

Considering the nature of safety treatments identified in this study, it is fair to state that safety benefits in the form of crash reductions are the only tangible benefits that should be considered in any economic analysis. Other potential benefits associated with a few countermeasures (e.g. wider lanes and shoulders may be associated with higher speeds and lower travel times) are deemed minimal at best.

The crash reduction benefits of safety countermeasures can be quantified in monetary value using agency defined crash cost equivalencies for different crash severities. Table 4 shows the crash costs for different crash types as defined by the Oregon DOT and the American Association of State Highway and Transportation Officials in the Highway Safety Manual (AASHTO 2010). Costs were adjusted for inflation to represent 2004 dollars using US Bureau of Labor Statistics, Consumer Price Index and Employment Cost Index methods as suggested in the HSM.

The Oregon DOT crash costs have fatal and injury type-A crashes combined, which is slightly different from the HSM values used which have separate costs for fatal and injury crashes. Injury A crashes are those crashes which result in a vehicle driver or occupant having an incapacitating injury. Similarly, injury B and injury C crashes are combined together for ODOT crash cost estimates and separated for HSM cost estimates.

Benefits associated with a particular countermeasure are estimated using the reduction in crash frequency and/or severity expected upon the implementation of the countermeasure. Therefore, crash modification factors and crash reduction factors were instrumental in assessing the benefits of countermeasures. The study utilized all published information on CMFs and CRFs including the U.S. Department of Transportation (USDOT) CMFs clearinghouse. One issue that was encountered in assessing countermeasure benefits is that a complete set of CMFs/CRFs is currently unavailable for all countermeasures and all crash severities. This is well understood given the fact that this knowledge has been growing and evolving with time, and it will take some time before a comprehensive set of CMFs/CRFs becomes available. Another issue that was encountered in the process is that the CMFs and the CRFs for a given safety countermeasure may vary in a wide range and inconsistency may exist in the CMFs/CRFs especially if those factors are obtained from different sources. Therefore, extreme caution was exercised in applying the CMFs and CRFs in this study. In most instances, when a range of values exist for the exact same countermeasure, the mid-range value was used in the analysis. The CRFs included in the analysis are meant to be estimates using the best information available.

As discussed earlier, for Oregon low-volume roads, ten years of crash data (2004-2013) for the study sample was used in assessing the benefits of safety countermeasures. Again, these roads, which are primarily located in rural areas, with AADTs lower than 1000 vpd and an average AADT for the study sample of 476 vpd. Needless to say, exposure is a very important factor in determining the economic feasibility of safety countermeasures, i.e. a measure that is proven economically feasible on well-traveled roads may not be so on low-volume roads due to a lower expected number of reduced crashes.

Some safety treatments are targeted toward curves while others are applied to all road type segments. For benefit/cost analyses, the crash reduction cost savings for possible alignment safety measures are applied to all horizontal curves in the sample. All other safety treatments are targeted toward all road segments and the cost reduction benefits for those are therefore applied to all of the road sample. For calculating the benefit of the countermeasures related to wildlife safety, only animal-vehicle crashes were considered. Table 5 shows the road sample with crash characteristics and the total 10-year equivalent crash costs using Oregon DOT and HSM cost values.

To determine the potential crash reduction benefits for each treatment, the number of crashes prevented for each crash type per unit (either curve or mile of road) is calculated using the CRFs. Then each treatment's benefit was calculated using the number of crashes prevented and the cost of each type of crash.

9. ECONOMIC FEASIBILITY OF COUNTERMEASURES

Once the costs and benefits of safety countermeasures are calculated for the study sample, the benefit-cost ratios can readily be determined. For calculating the benefit-cost ratio, the net present worth (NPW) method was used in this study. As all of the data for this study were collected for the time period from 2004 to 2013, all of the costs were converted to 2004 dollars (base year) including crash costs. The question was that, if the countermeasures were installed in 2004, how much benefit would result over the 10 year analysis period? The NPW of costs and benefits were calculated using the following equation.

$$NPW = EUAW\left[\frac{(1+i)^N-1}{i(1+i)^N}\right]$$

Where, NPW = net present worth, EUAW = equivalent uniform annual worth, i = discount rate, N = number of years

For this study, the EUAW cost was the annual maintenance cost, which was used to get the NPW of the maintenance cost. This cost was added to the installation cost (2004 dollars) to get the total cost. The EUAW benefit was the annual benefits due to crash reductions, which was used to get the NPW of the benefits. The annual interest rates from 2004 to 2013 are published by the Internal Revenue Service. The average interest (or discount) rate over the analysis period was used in this study. Table 6 shows the benefit-cost ratio of the proposed countermeasures using crash cost estimates from Oregon DOT and the HSM. Benefit cost ratios greater than 1.0 are marked (bold underlined values) to show those measures that are economically feasible for implementation on low-volume roads.

The first category of countermeasures related to highway alignment included only a few economically viable countermeasures with benefit-cost ratios that are slightly larger than 1.0. This is despite the fact that the study did not include safety improvements which involve costly changes to alignment (e.g. flattening horizontal and vertical curves). In the second category of countermeasures, i.e. those related to cross-section elements, only widening unpaved shoulders and stabilizing shoulders were found economically feasible with benefit-cost ratios varying in the range of 1.32 to 2.02. Unlike the previous two categories, most countermeasures in the third category, i.e. those related to changes in roadside features, were found economically feasible with a couple of measures showing relatively high return on investment (using safety edge and object markers). Most of the countermeasures in the "other" category were found economically feasible with shoulder and centerline rumble strips showing the highest return on investment (benefit-cost ratios greater than 20) followed by installing and widening centerline markings (benefit-cost ratios greater than 7). Overall, the benefit-cost ratios shown in Table 6 suggest that the majority of economically feasible countermeasures are low-cost safety improvements which is somewhat expected given the low traffic exposure on these roads. At the other end of the spectrum, the table shows that higher cost measures (e.g. lane and shoulder widening) were associated with minimal return on investment.

10. SUMMARY AND FINDINGS

Information on economic feasibility of safety countermeasures is critical for the success of safety improvement programs. Such information helps the agency in identifying safety improvements which are likely to maximize the return on investment under different scenarios. Consequently, this will ensure an optimum use of the agency limited resources. Unfortunately, published information on the economic feasibility of safety treatments is very limited, especially so in the case of low-volume roads where traffic exposure is extremely low.

This paper presents an investigation into the economic feasibility of safety countermeasures on low-volume roads. The study identified a wide range of safety improvements on low-volume roads which were grouped in four different categories: highway alignment, cross section elements, roadside features and other countermeasures. Benefit-cost analyses were performed using ten years of crash data from an extensive low-volume road sample in the state of Oregon.

Figure 2 shows safety countermeasures ranked based on the benefit-cost ratio starting with the most economically feasible measures. The benefit-cost ratios shown here are conservative given the fact that this study only considered reported crashes. This figure clearly shows that the use of shoulder rumble strips, centerline rumble strips, object markers, centerline markings, safety edge, and widening centerline markings are associated with the highest return on investment (benefit/cost ratios greater than 7). All of the countermeasures that are found to be most cost-effective are low-cost countermeasures. For example – installation of rumble strips cost only $2,100 per mile and no maintenance cost is required. Similarly installation of object markers, centerline marking and safety edge require lower initial costs and lower or no maintenance costs. Some of the costlier measures such as stabilizing shoulders, widening unpaved shoulders and flattening side slopes were also found economically feasible but they were associated with much lower return on investment. At the other end of the spectrum, higher cost measures (e.g. lane and shoulder widening) were found economically infeasible for implementation along low-volume roads. This is despite the fact that some of those countermeasure that were found infeasible may still have notably high crash reduction factors. Overall, the majority of economically feasible countermeasures are low-cost safety improvements which is somewhat expected given the low traffic exposure on these roads.

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Table 1 Crash Rates by Crash Type for the Study Sample

Crash Type	Total VMT	No. of Crashes	Crash Rate (per 100 Million VMT)	Total Length (mile)	Crash Rate (per 100 mile)
PDO	1.182 Billion	550	46.51	680.85	80.78
Injury	1.182 Billion	665	56.23	680.85	97.67
Fatal	1.182 Billion	36	3.04	680.85	5.29

Table 2 Safety Countermeasures Identified for Low-Volume Roads

Low-Volume Roads Safety Countermeasures	
Measures related to highway alignment	***Measures related to roadside features***
- Horizontal alignment sign	- Flatten side slopes
- Horizontal alignment sign with static advisory speed	- Improve roadside hazard rating
	- Install object markers
- Chevrons	- Install safety edge
- Dynamic speed feedback display on curves	- Relocate fixed objects near roadway
- Flashing beacon for curve warning	- Remove fixed objects near roadway
- High friction surface treatment for curves	- Install Guardrail
- Post mounted delineators for curves	***Other safety countermeasures***
- Raised pavement markers for curves	
	- Install shoulder rumble strips
	- Install centerline marking
Measures related to highway cross-section	- Install centerline rumble strips
	- Install edge-line marking
- Widen lanes	- Install edge-line and centerline markings
- Widen paved shoulder	- Widen centerline marking
- Widen unpaved shoulder	- Widen edge-line marking
- Add paved shoulder	- Install seasonal wildlife warning sign
- High friction surface treatment	- Vegetation removal
- Stabilize shoulder	- Install fence
	- Install fence, gap & crosswalk

Table 3 Sample Cost Estimates for Alignment Safety Improvements

Safety Countermeasures	Initial Cost	Maintenance Cost and Life Cycle	Annual Maintenance Cost
Horizontal Alignment Sign	\$300 to \$2,800 per installation	\$1,100 / 5 years	\$220
Horizontal Alignment Sign with Static Advisory Speed	\$300 to \$2,800 per installation	\$1,100 / 5 years	\$220
Flashing Beacon for Curve Warning	\$2,100 per installation	\$900 / 2 years	\$450
Chevrons	\$500 to \$6,800 per installation	\$2,900 / 5 years	\$580
Post Mounted Delineators for Curves	\$4,500 per installation	Life ≥ 10 years	-
Raised Pavement Markers for Curves	\$600* per installation	\$600 / 2 years	\$300
Dynamic Speed Feedback Display on Approach to Curves	\$1,900 to \$11,500 per installation	\$800 / 2 years	\$400
High Friction Surface Treatment for Curves	\$10,900** to \$14,700	Life ≥ 10 years	-

* *Calculated for a 500 foot horizontal curve and 40 foot marker spacing*

** *Calculated for a 500 foot horizontal curve with two 12-foot lanes, 1 inch mill, and 1 inch overlay*

Table 4 Crash Costs by Severity

<table>
<tr><th>Crash Type</th><th>Oregon DOT Cost*</th><th>HSM Cost
(AASHTO 2010)</th></tr>
<tr><td>Fatal</td><td rowspan="2">$1,414,452</td><td>$4,574,553</td></tr>
<tr><td>Injury A</td><td>$241,852</td></tr>
<tr><td>Injury B</td><td rowspan="2">$68,704</td><td>$88,334</td></tr>
<tr><td>Injury C</td><td>$49,726</td></tr>
<tr><td>PDO</td><td>$16,156</td><td>$8,016</td></tr>
</table>

*   *Rural, non-Interstate, state highway values*

Table 5 Estimated Crash Costs on Road Sample

Sample	Quantity	10 Year Crash Total						ODOT Cost	HSM Cost
		Fatal	Inj A	Inj B	Inj C	PDO	Total		
Curves	2841 curves	8	36	120	66	145	375	$77.4M	$60.3M
All	680.85 miles	36	117	349	199	550	1,251	$262.9M	$238.1M

Table 6 Benefit-Cost Ratio of Countermeasures

Countermeasures	B/C ratio (ODOT)	B/C ratio (AASHTO)
Alignment Safety Measures		
Horizontal Alignment Sign	**1.63**	**1.08**
Horizontal Alignment Sign with Static Advisory Speed	**1.63**	**1.08**
Flashing Beacon for Curve Warning	**1.17**	0.91
Chevrons	0.94	0.74
Post Mounted Delineators for Curves	**1.26**	0.98
Raised Pavement Markers for Curves	**1.02**	0.91
Dynamic Speed Feedback Display on Approach to Curves	0.20	0.17
High Friction Surface Treatment for Curves	0.31	0.24
Roadway Cross Section Safety Measures		
Widen 1 ft. Lanes	0.08	0.13
Widen 1ft. Paved Shoulder	0.03	0.06
Widen Un-paved shoulder – unspecified amount	**1.46**	**1.32**
Add Paved Shoulder	0.90	0.82
Stabilize Shoulder	**2.02**	**1.83**
High Friction Surface Treatment	0.20	0.19
Roadside Features Safety Measures		
Flatten Side Slopes	**1.53**	**1.39**
Install Safety Edge	**7.74**	**7.01**
Improve Roadside Hazard Rating	0.77	0.69
Install Object Markers for Objects Near the Roadway	**10.64**	**8.82**
Relocate Objects Near the Roadway	**1.49**	**1.27**
Remove Objects Near the Roadway	**1.84**	**1.56**
Install Guardrail	**1.44**	**1.34**
Other Safety Measures		
Install Shoulder Rumble Strips	**25.32**	**22.92**
Install Centerline Rumble Strips	**21.49**	**19.46**
Install Edge-line Markings	**2.79**	**2.40**
Install Centerline Markings	**8.18**	**7.41**
Install Edge-line and Centerline Markings	**2.06**	**1.87**
Widen Edge-line Markings	**2.38**	**2.15**
Widen Centerline Markings	**7.53**	**6.82**
Install Seasonal Wildlife Warning Sign	**3.56**	**1.80**
Vegetation Removal	**1.05**	0.53
Install Fence	0.13	0.07
Install Fence, Gap & crosswalk	0.05	0.03

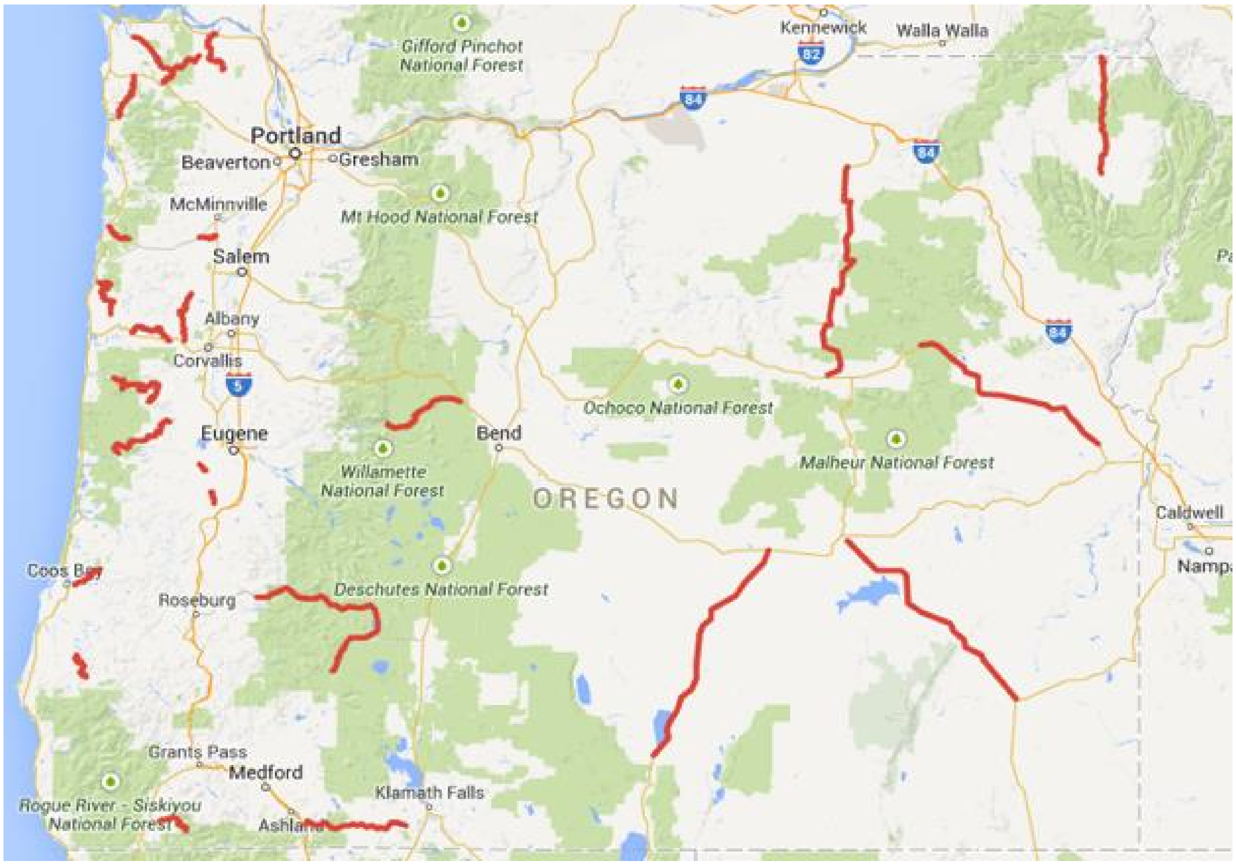

Figure 1 Low-volume road study sample (Source: Google Maps)

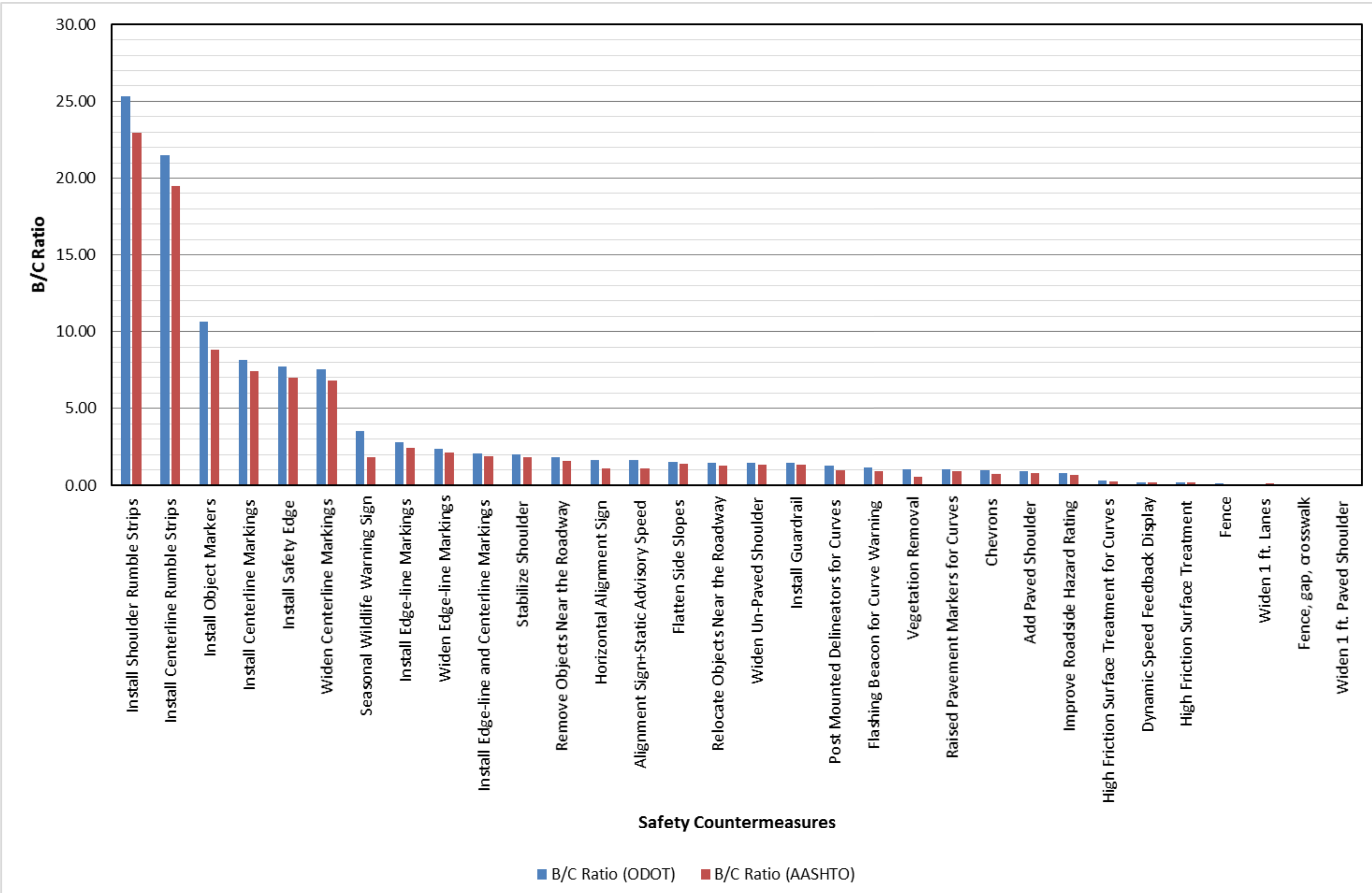

Figure 2 Benefit-cost ratios of safety countermeasures ranked in descending order