Factors Contributing to Median Encroachments and Cross-Median Crashes

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 790

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By B. Ray Derr
Staff Officer
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This report identifies design and operational factors that contribute to the frequency and severity of median encroachments and cross-median crashes. It also identifies countermeasures for addressing those contributory factors. The report will be useful to designers and safety professionals in reducing these highly visible crashes.

Cross-median crashes frequently result in high-severity injuries and fatalities. Previous studies of contributory factors associated with cross-median crashes have typically focused on median width and average daily traffic (ADT). A few studies have looked at the influence of geometry and cross-sectional elements. Although these studies have been helpful, they did not explore many other design and operational factors that may contribute to cross-median crash frequency or severity (e.g., interchange ramps, interchange spacing, mixture of vehicle types, peak-period volumes, peak-period duration, land use, access control, driver workload, posted speed, or presence of speed transition zones).

All median-related incidents begin with a median encroachment. Reducing median encroachments will reduce both cross-median crashes and fixed-object crashes in the median. Consequently, analyzing median encroachments should provide additional insight into the causes of cross-median crashes.

There is also a knowledge gap regarding countermeasures appropriate for the various factors contributing to median encroachments and cross-median crashes. Although installing a barrier will greatly reduce cross-median crashes, it will also increase fixed-object crashes and the crash risk of maintenance personnel. Other countermeasures besides barriers exist, and knowing which ones effectively address the contributory factors on a highway will allow an engineer to develop a more effective design.

In NCHRP Project 17-44, MRIGlobal reviewed the literature on median encroachments and cross-median crashes. Based on a survey of states, Canadian provinces, and turnpike/toll road authorities, the team compiled a list of design and operational factors likely to contribute to median encroachments and cross-median crashes. The research team then collected data to determine the relative contribution of each of the factors to median encroachments and cross-median crashes.

Appendix D of the report provides recommended guidelines for reducing the frequency and severity of median-related crashes. This material is designed to be easily incorporated into a transportation agency's design manual.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

Factors Contributing to Median Encroachments and Cross-Median Crashes

Research was conducted to investigate the factors that contribute to median-related crashes and to identify design treatments and countermeasures that can be applied to improve median safety on divided highways. The research used a combination of interdisciplinary field studies of locations with high frequencies of median-related crashes and systemwide crash data analysis including sites with the full range of median-related crash frequencies. The interdisciplinary field studies included both engineering and human factors specialists who assessed the factors that contributed to median-related crashes at 47 divided highway sites with high median-related crash frequencies in four states. Wherever practical, the results of the interdisciplinary field studies were confirmed through crash data analyses.

Based on interdisciplinary field studies of sites in four states with high median-related crash frequencies, the following factors were found to contribute to the occurrence of median-related crashes on divided highways:

- On-ramps,
- Off-ramps,
- Closely spaced on- and off-ramps,
- Sharp horizontal curves,
- Steep grades,
- Bridges,
- At-grade intersections, and
- Wet and snow-covered pavement conditions.

These factors were found to contribute to median-related crashes both individually and in combination.

A separate analysis of crash data for rural freeways in Washington confirmed that the following factors are overrepresented in median-related crashes:

- On-ramps,
- Off-ramps,
- Sharp horizontal curves (particularly curves with radii less than 3,000 feet),
- Steep grades (particularly grades of 4 percent or more, including both upgrades and downgrades), and
- Wet and snow-covered pavement conditions.

Other potential contributing factors, and combinations of contributing factors, could not be verified as contributing to median-related crashes either because of limited sample sizes of sites and crashes or because of lack of systemwide data. Although no separate

confirmation could be developed for some factors, the interdisciplinary field studies, by themselves, provide evidence that all of the factors listed above contribute to median-related crashes.

The findings summarized above indicate that improvements to the contributing factors listed have the potential to reduce the frequency of median-related crashes and can supplement traditional median safety programs that focus on reducing the consequences of leaving the roadway and encroaching on the median.

The research confirmed the importance of the traditional approach to improving median safety, which involves design improvements to reduce the consequences of median encroachments. The following design improvements are recommended to implement this approach to improving median safety:

- Remove, relocate, or use breakaway design for fixed objects in medians;
- Provide barrier to shield objects in medians;
- Provide wide medians;
- Provide continuous median barrier;
- Flatten median slopes;
- Provide U-shaped (rather than V-shaped) median cross sections; and
- Provide barrier to shield steep slopes in median.

The research also found that median safety can be improved by design treatments and countermeasures to reduce the likelihood of median encroachments (i.e., using design treatments and countermeasures to make it less likely that motorists will run off the roadway into the median).

Design treatments recommended to reduce the likelihood of median encroachments include the following:

- Provide wider median shoulders,
- Minimize the use of sharp horizontal curves with radii less than 3,000 feet,
- Minimize use of steep grades of 4 percent or more,
- Increase separation between on- and off-ramps,
- Minimize left-hand exits,
- Improve design of merge and diverge areas by lengthening speed-change lanes,
- Simplify design of weaving areas, and
- Increase decision sight-distance to on-ramps.

High-cost treatments, such a realigning curves or grades, may be impractical for existing roadways and may be applicable primarily in design of new construction projects.

The following countermeasures are recommended to reduce the likelihood of median encroachments:

- Provide edgeline or shoulder rumple strips;
- Improve/restore superelevation at horizontal curves;
- Provide high-friction pavement surfaces;
- Improve road surface or cross-slope for better drainage;
- Improve visibility and provide better advance warning for on-ramps;
- Improve visibility and provide better advance warning for curves and grades;
- Improve delineation;
- Provide transverse pavement markings;
- Provide weather-activated speed signs;

- Provide static signs warning of weather conditions (e.g., bridge freezes before road surface);
- Apply sand or other materials to improve road surface friction during winter storms;
- Apply chemical de-icing or anti-icing as a location-specific treatment;
- Install snow fences; and
- Raise the state of preparedness for winter maintenance.

The contractor's final report included four appendixes:

- Appendix A, Survey Questionnaire;
- Appendix B, Predictive Models for Median-Related Crashes from NCHRP Project 22-21;
- Appendix C, Site-by-Site Summary of Interdisciplinary Field Review Sites; and
- Appendix D, Guidelines for Reducing the Frequency and Severity of Median-Related Crashes on Divided Highways.

Appendixes A through C of the contractor's final report are not published herein but are available from the NCHRP.

Appendix D presents recommended guidelines for reducing the consequences and likelihood of median-related crashes on divided highways. The guidelines address the application of each design treatment or countermeasure together with known information on the effectiveness of each design treatment or countermeasure.

SECTION 1

Introduction

1.1 Background

Median-related crashes on divided highways, which include cross-median crashes and other crashes in which one or more vehicles enter or encroach on the highway median, frequently result in high-severity injuries and fatalities. Most previous studies of contributory factors associated with cross-median crashes have typically focused on median width and average daily traffic (ADT). A few studies have looked at the influence of geometry and cross-sectional elements. Although these studies have been helpful, they have not explored many other design and operational factors that may contribute to cross-median crash frequency or severity, such as presence of interchange ramps, spacing between interchange ramps, horizontal and vertical alignment, and pavement surface conditions.

Median encroachments involve an unintentional entry into the median by a motorist. A median encroachment is part of the sequence of events for every median-related crash, including every cross-median crash. It has generally been assumed that most median encroachments result from driver inattention or fatigue, which leads to the driver drifting into the median and losing control. There is undoubtedly a substantial proportion of median encroachments of this type, which explains the effectiveness of rumble strips on median shoulders. However, the available evidence suggests that many median encroachments may be initiated in a different way by vehicle–vehicle interactions on one roadway of a divided highway. In this situation, a motorist may lose control and run into the median (and, indeed, may cross the median and enter the opposing lanes) as a result of a multiple-vehicle collision or as a result of a maneuver to avoid a multiple-vehicle collision. There has been very little research conducted on median encroachments that result from multiple-vehicle collisions or other vehicle–vehicle interactions.

Similarly, most research on addressing median-related crashes has focused on countermeasures to reduce the frequency and severity of collisions that may occur after a vehicle has left the roadway and entered the median. Attention is needed on countermeasures that reduce the likelihood that vehicles will leave the roadway and enter the median in the first place. This research addresses the roadway factors that appear to initiate median encroachments by using the concept of driver workload. Roadway segments on divided highways have been classified as involving a range of driver workload levels from very high to very low. The research has sought evidence on how median encroachment and crash frequencies relate to the driver workload and how median-related crashes can be reduced by roadway improvements as well as median improvements.

Relationships between factors related to cross-median crashes have been developed by MRIGlobal in NCHRP Project 22-21, “Median Cross-Section Design for Rural Divided Highways” (*1*). Variables that were found to affect median-related crash frequencies, in addition to ADT and median width, include roadside slopes, median shoulder width, presence of horizontal curves, and presence of shoulder rumble strips.

1.2 Research Objectives and Scope

The objectives of this research are to (1) identify design and operational factors and combinations of factors that contribute to the frequency of median encroachments and cross-median crashes and (2) identify potential countermeasures suitable for addressing these contributing factors.

The scope of the research will address both the design of medians on divided highways and the design and operation of adjacent roadways to minimize the occurrence of median encroachments that lead to cross-median crashes and to minimize the severity of crashes that occur. Both rural and urban divided highways will be considered in the research and the procedures developed will address both controlled-access and non-controlled-access roadways (i.e., both freeways and divided nonfreeway facilities, also known as expressways).

The primary focus of the research is on obtaining a better understanding of how median-related crashes are initiated and on providing guidelines that can be used by highway agencies to identify and select appropriate countermeasures to median-related crashes for specific road segments.

1.3 Research Approach

The research approach has involved identification of more than 40 divided highway sections with high median-related crash frequencies. These divided highway sections were located in four states: California, Missouri, Ohio, and Washington. An interdisciplinary team, including both a highway traffic engineer and a human factors specialist, reviewed the median-related crash reports and performed field visits to classify the driver workload level for each site and identify factors that contribute to median-related crashes at each site. Broader crash data analysis was then conducted for the entire freeway network of one state to determine whether the factors identified in the interdisciplinary field studies were, in fact, associated with higher likelihood of median-related crashes. The research findings were then used in the development of guidelines for implementing countermeasures to reduce the frequency of median-related crashes.

1.4 Organization of This Report

This report presents the results of the research on reducing the frequency and consequences of median encroachments and cross-median crashes. The remainder of this report is organized as follows. Section 2 describes the review of literature on median encroachments, median-related crashes, crash countermeasures for improving median safety, road safety audits, and median design practice. Section 3 summarizes the survey of agency practice on median design and perceived median encroachment factors. Section 4 presents the results of interdisciplinary field reviews, including the contributing factors identified. Section 5 presents the results of crash data analyses to investigate the contributing factors. Section 6 summarizes guidance on countermeasure implementation to address the contributing factors and reduce the frequency and severity of median-related crashes. Section 7 presents the conclusions and recommendations of the research.

Appendixes A through C of the contractor's final report are not published herein but are available on the TRB website and can be found by searching for NCHRP Research Results Digest 390.

Appendix D presents guidance on countermeasures to reduce median-related crashes on divided highways. Appendix D has been formatted so that it can be used as a stand-alone document, if highway agencies wish to use the guidelines in that form.

SECTION 2

Review of Median Safety Studies

Past research on median safety has investigated the factors that caused vehicle encroachments, median crash frequency or severity, and countermeasures to prevent median encroachments. This section of the report summarizes the history of median safety research by reviewing past encroachment and crash studies, potential countermeasures, human factors research related to median encroachments, and scanning tours aimed at identifying median encroachment contributing factors.

2.1 Median Encroachments

A median encroachment is any vehicle maneuver in which all or a portion of a vehicle unintentionally crosses the edge line on the left side of the traveled way for one roadway of a divided highway and enters the median area. Median encroachments range from momentary excursions into the median area and returns to the roadway, to maneuvers in which a vehicle leaves the roadway and then comes to rest or overturns within the median area, to maneuvers in which a vehicle collides with an object in the median area. Some median encroachment maneuvers extend so far that the vehicle enters or crosses the roadway in the opposing direction of travel.

The total frequency of median encroachments is very difficult to measure. One of the founding documents of roadside safety, the Hutchison and Kennedy study (*2*), estimated roadside encroachment frequency by periodic monitoring of fresh vehicle tracks in the snow on rural freeway medians in Illinois during winter months and assessed which tracks appeared to be attributable to uncontrolled entries into the median. There have been other studies over the years that have attempted to quantify roadside encroachment rates (*3, 4*), but most such studies have been limited in scope because of the very low frequency of encroachments and the resulting very high cost of observing a sufficient number of encroachments to reliably estimate their frequency. A limitation of these encroachment studies has been the difficulty in deciding whether observed encroachments were accidental or deliberate.

Early median safety studies sought to determine and quantify factors that caused vehicle encroachments into the median area on divided highways. In the early 1960s, Hutchinson and Kennedy (*2*) studied vehicle encroachments along I-74 and the Kingery Expressway (I-57) in Illinois. Each facility was a four-lane divided highway. I-74 had a depressed median width of 40 feet, while the Kingery Expressway had a depressed median width of only 18 feet. After 6 years of data collection, four relationships were observed, each containing ADT as one-half of the relation. One of the relationships examined was ADT versus encroachment rate, which is based on encroachments per vehicle-mile traveled. It was shown that for ADT volumes of 4,000 vehicles per day and less, the encroachment rate was stable and slightly above 400 encroachments per 100 million vehicle-miles traveled (MVMT). As the ADT increased from 4,000 to 5,000 vehicles per day, there was a sharp decline in the encroachment rate to approximately 150 encroachments per 100 MVMT. As the ADT volume continued to increase, the encroachment rate then stayed relatively constant at 150 encroachments per 100 million vehicle-miles traveled. Figure 2-1 shows the relationship between ADT and encroachment rates.

The driving environment was considered a primary reason for the fluctuation in encroachment rates in relation to traffic volumes. At low traffic volumes, drivers are less attentive. There is more freedom of movement within the travel lanes and the only restrictions are the physical features of the roadway (*2*). Therefore, it is likely that vehicles tend to sway off the traveled way and eventually into the median area. As traffic volumes increase, driver alertness also increases and the percentage of "lateral veering" vehicles is greatly reduced because of the decreased vehicle spacing within the traffic stream. In addition, with the presence of other vehicles, a "follow-the-leader" phenomenon results in which vehicles farther back in

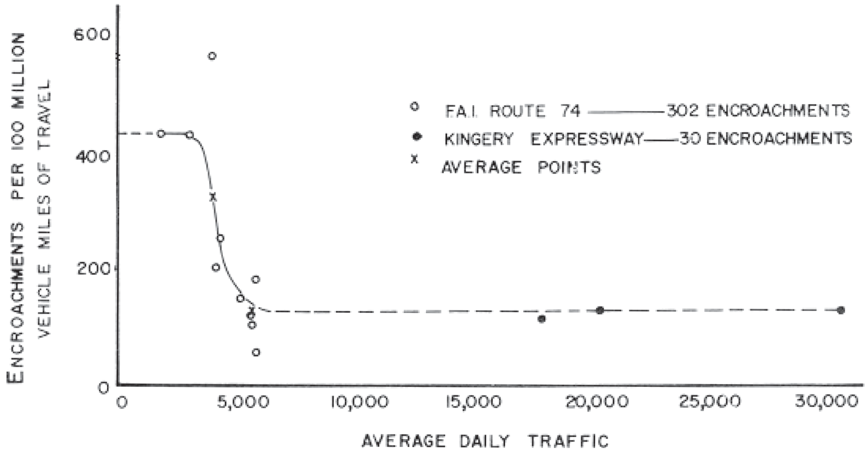


Figure 2-1. Encroachment rate for Interstate 74 and Kingery Expressway (2).

the traffic stream tend to position in the same vehicle path as those farther downstream.

A 1980 study by Cooper (*3*) attempted to build on the research by Hutchinson and Kennedy in determining the factors involved in roadside encroachments and their effect on the severity of the encroachment using Canadian provincial data. Data were collected over a 5-month period in 5 provinces on 59 roadway sections with lengths between 37 and 62 miles. The author stated that transitory evidence (e.g., vehicle tracks off the roadway) was used in collecting the field data that supplemented police crash records so that unreported encroachments might be considered in the modeling. The factors that were considered included posted speeds, traffic volumes, horizontal alignment, vertical alignment, departure direction, ditch slope, shoulder type, and shoulder width. Since the information was not available in the raw data, the author did have to make an assumption of the roadway type based on the posted speed limit. Roads with speed limits less than or equal to 90 km/h (56 mph) were assumed to be two-lane roads; divided highways and freeways were represented by roads with speed limits greater than 90 km/h (56 mph). During the analysis, there was no strong correlation that could ever be drawn between any geometric feature (or series of geometric features) and roadside encroachments. Some other interesting conclusions drawn by the author include the following:

- Since only 25 to 30 percent of the roadside encroachment rate variance could be explained by the factors included in the study, the author postulated that external factors to this study (i.e., weather, light conditions, and road surface characteristics) could play a part in explaining a large percentage of roadside encroachments.
- The highest encroachment rates occurred with mid-ranged shoulder widths.
- Vertical alignment played a larger role in contributing to roadside encroachments than did horizontal alignment.
- Higher speed roadways experienced higher encroachment rates.
- Although the analysis yielded an encroachment rate vs. vehicle volume graph similar to Hutchinson and Kennedy (Figure 2-1), the author was skeptical of the relationship's accuracy and hypothesized that the effect was caused by a flawed data reduction technique.

An analysis conducted by Davis and Morris (*5*) reexamined the data from the Hutchinson and Kennedy study using statistical tools that were not available to the original authors to determine if the conclusions drawn by the authors were accurate with regard to encroachment rates vs. ADT relationships. Of particular interest was the unanticipated decrease in encroachments that was originally modeled between ADT values of 4,000 and 5,000 vehicles per day. Davis and Morris hypothesized that other factors could have played a part in the encroachment rates, including winter weather and roadway maturation, which would account for the anomaly in the data. The authors used the 10 observation periods originally analyzed, as shown in Table 2-1, and plotted the data including the standard errors as shown in Figure 2-2. This illustration is similar to the relationship demonstrated in Figure 2-1, except that the standard errors were included to illustrate the confidence bounds for the true encroachment rate. The standard error bars indicate whether the true rates are the same between observation periods. Of concern were the high encroachment rates observed in Periods 1 through 3 at lower ADT values that did not appear to be in sync with the remainder of the study. Because these data were collected along a newer freeway (I-74), there is concern that drivers may have been encroaching on the median as they adjusted to a new driving environment. An incremental increase of

Table 2-1. Hutchinson and Kennedy encroachment data for 10 observation periods (*5*).

Period	Dates	ADT	Duration (days)	Observed Encroachments	Encroachments/ MVMT	Standard Error
1	10/60–12/60	1900	79	16	4.33	1.08
2	12/60–3/61	3000	97	31	4.33	0.78
3	3/61–7/61	4000	105	58	5.61	0.74
4	7/61–12/61	4150	143	30	2.06	0.38
5	12/61–3/62	4350	119	32	2.51	0.44
6	3/62–6/62	5250	87	17	1.51	0.37
7	6/62–10/62	5750	109	16	1.04	0.26
8	10/62–4/63	5950	185	50	1.85	0.26
9	4/63–6/63	5950	72	5	0.47	0.21
10	6/63–4/64	5700	284	47	1.18	0.17

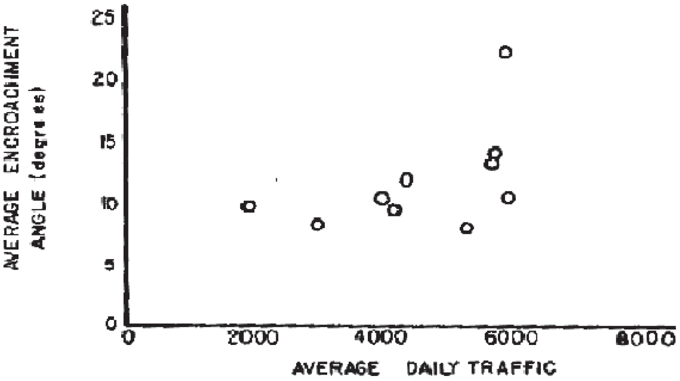


Figure 2-3. Relationship between ADT and average encroachment angle (2).

0.46 encroachments per MVMT was derived for winter weather conditions and attributed to the effect that pavement conditions have on driver behavior. The authors concluded that while there is a strong relationship between encroachments and ADT, Periods 1 through 3 are not recommended for consideration and that encroachments can be expected to increase during winter months. The results of this research would substantially lower the expected encroachments on lower volume roads and place more emphasis on encroachments occurring on roadways with ADT values above 5,000.

Another relationship studied by Hutchinson and Kennedy related ADT to the average encroachment angle. As ADT increased from 2,000 to 6,000 vehicles per day, the degree of angle encroachment also increased from 9 to 14 degrees. Figure 2-3 shows the relationship between ADT and average encroachment angle. The theory behind these observations is that there is an increase in vehicle conflict as traffic volumes increase. As a result, a driver may suddenly leave the traveled way and enter the median area because another vehicle unexpectedly merges into the occupied lane.

Hutchinson and Kennedy also examined the relationship between ADT and the percent of vehicles that entered into (i.e., encroached on) the median. As shown in Figure 2-4, as ADT increased from 4,000 to 6,000 vehicles per day, the percentage of vehicles crossing into the median increased.

The final relationship studied by Hutchinson and Kennedy was that between ADT and lateral distance traveled by encroaching vehicles on I-74. The ADT volumes range from 2,000 to 6,000 vehicles per day. These vehicles traveled an average of 19 to 27 feet into the median area over this range of ADTs. This relationship is shown in Figure 2-5.

In 1978, data from several Canadian provinces were collected to investigate single-vehicle run-off-the-road crashes on divided and undivided rural highways. A multiple regression analysis of 1,937 encroachments explained only 30 percent of the variance between crashes and traffic volumes (*6*). Factors such as alcohol, weather, and driver variables were considered to have a significant effect on the models developed. This study showed no significant correlation between ADT volumes and encroachment rates; however, when the data were forced into 2,000 vehicles per day groupings and averaged over a set of ranges, the results were nearly identical to the Hutchinson and Kennedy (*2*) study discussed previously. This study also showed that,

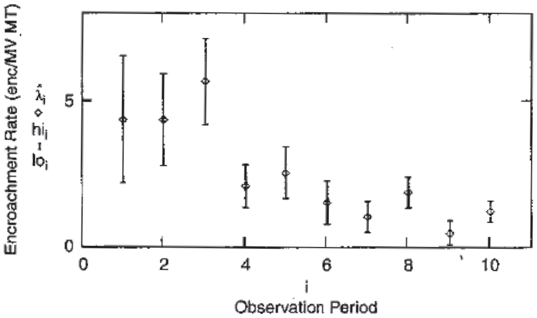


Figure 2-2. Encroachment rates including standard errors for the Hutchinson and Kennedy study periods (5).

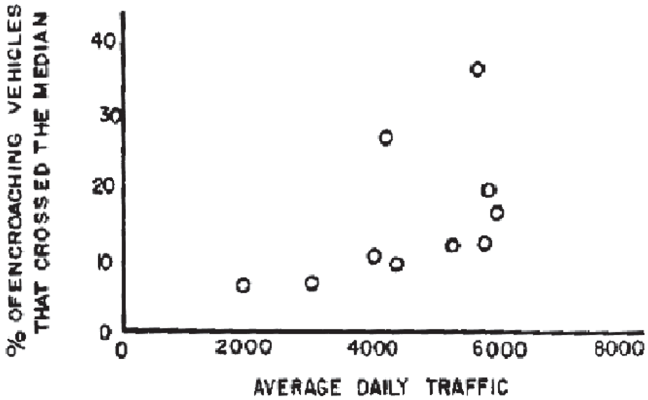


Figure 2-4. Relationship between ADT and percent of vehicles encroaching on median (2).

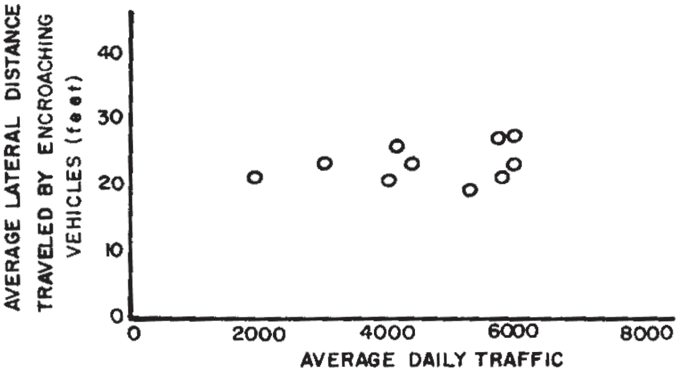


Figure 2-5. Relationship between ADT and encroachment distance (2).

on average, the ratio of observed to reported crashes was 3.75:1 for two-lane undivided highways and 5:1 for multilane divided highways.

A study by Miaou (*7*) published in 2001, sought to model encroachment rates on rural two-lane highways based on factors deemed to be responsible for such encroachments. The model utilized crash data from Washington State for a 3-year period and was built upon previous research by the author (*8, 9*). The developed model is shown in Equation 1.

$$E = (365 * AADT/1000000) * \exp\left(\beta_{st} - 0.04 * AADT \middle/ 1000 + Lnf + Hazf + 0.12 * HC + 0.05 * VG\right) \qquad (1)$$

where

E = expected number of roadside encroachments per mile per year
AADT = average annual daily traffic (in number of vehicles) from 1,000 to 12,000
β_{st} = state constant (with a default value of −0.42)
Lnf = 0, 0.20, and 0.44, respectively, for road segments with 12-foot, 11-foot, and 10-foot-wide lanes
Hazf = 0.4 to 0.5 (with a default value of 0.45)
HC = horizontal curvature (in degrees per 100-foot arc) from 0 to 30 degrees
VG = vertical grade (in percent) from 0 to 10 percent

The major drawback of this approach is that the modeling was based exclusively on reported crashes. Since encroachments involving a collision are more likely to be reported than encroachments that do not involve a collision, it can therefore be assumed that minor roadside encroachments are not well represented in the model. It is important to note that the author found traffic volume, lane width, horizontal curvature, and vertical grade to be significant factors to include in the model.

An investigation into the factors causing median encroachments and cross-median crashes was conducted by Sicking et al. (*10*). This involved a review of more than 43,000 Kansas freeway crash reports from 2002 to 2006, which identified 8,233 crashes that involved a vehicle entering the median. Of these, 525 events involved vehicles traversing the median and crossing into the opposing lanes of traffic, and 115 involved vehicles crossing the median and colliding with a vehicle traveling in the opposite direction. By looking at the reported snow and ice conditions over the 5-year study period, it was determined that winter driving conditions were present less than 12.5 percent of the time, yet nearly 25 percent of the total cross-median events occurred in winter conditions indicating an overrepresentation of crashes in these conditions. However, only 7 percent of cross-median crashes in winter conditions involved a fatality compared to 22 percent in non-winter conditions. These data seem to suggest that although winter weather conditions are prone to cause more median encroachments and cross-median events, they are less likely to be fatal; which could be due, in part, to the lower speeds that vehicles travel during inclement weather.

The relationship between cross-median events and traffic volumes appears to have a constant relationship for the Kansas data (*10*). An average of 2.2 cross-median events per 100 million vehicle-miles of travel was observed for ADT ranges between approximately 4,000 and 17,000 vehicles per day. This constant relationship of events involving median encroachments to vehicle exposure is similar to the recommendations made in the research conducted by Davis and Morris (*5*).

2.2 Median-Related Crashes

Median-related crashes are traffic crashes in which one or more of the involved vehicles leaves the left side of one roadway of a divided highway and enters the median. A median-related crash in which one or more of the involved vehicles leaves the left side of one roadway of a divided highway, enters the median, crosses the entire median width, enters the opposing roadway of the divided highway, and collides with a vehicle in that opposing roadway is referred to as a cross-median collision (CMC). If a vehicle involved in a crash enters the opposing roadway of a divided highway, but does not collide with an opposing vehicle, this is referred to as a non-collision cross-median crash (NCMC). In an NCMC, the vehicle that enters the opposing roadway may come to rest or roll over in the opposing roadway; may cross the entire opposing roadway, come to rest, roll over, or strike an object on the far side of the opposing roadway; or may enter the opposing roadway and then return to the median area.

Crosby (*11*) evaluated the cross-median crash experience on the New Jersey Turnpike over a 7-year period (1952 through 1958, inclusive). The crash data were from the original

118-mile New Jersey Turnpike before the installation of median guardrails. In 1958, 18 miles of median guardrail were installed on sections with variable median widths of 6 to 26 feet. The data used for the research were limited to the through travel lanes excluding those within service areas, interchanges, and their interconnecting roadways and ramps. During the analysis period, 48 of 158 (30.4 percent) fatal crashes were considered cross-median crashes. During the analysis period, there were a total of 455 cross-median crashes. They constituted approximately 8.3 percent of all crashes on the New Jersey Turnpike during the analysis period (455 of 5,473 total collisions). The cross-median crash rate was higher when the medians were narrower. When grouping roadways together based on traffic volumes, the crash rates were calculated as follows:

- 10.8 cross-median crashes per 100 million vehicle-miles traveled on medians 26-foot wide with ADT between 13,400 and 14,800 vehicles per day;
- 7.3 cross-median crashes per 100 million vehicle-miles traveled on medians 26-foot wide with ADT between 18,800 and 27,400 vehicles per day;
- 0.4 cross-median crashes per 100 million vehicle-miles traveled on medians 24-foot wide with ADT between 23,100 and 36,900 vehicles per day;
- 6.2 cross-median crashes per 100 million vehicle-miles traveled on medians 20-foot wide with ADT between 36,000 and 37,600 vehicles per day; and
- 5.5 cross-median crashes per 100 million vehicle-miles traveled on medians 20-foot wide with ADT between 23,600 and 24,400 vehicles per day.

Garner and Deen (*12*) compared various median types on divided, four-lane Interstate highways with similar geometric features in Kentucky. The two variables that were the primary focus in the study were median width and median cross section. For the routes studied, variables such as pavement width and shoulder width remained constant. The types of medians that were analyzed in the study were raised, depressed, deeply depressed, and irregular medians.

The results of the Garner and Deen study verified previous conclusions from other researchers that wider medians had fewer CMC crashes. Their data indicated that the percentage of vehicles crossing the median decreases as the median width increases. Their data also indicated that the relationship between crash rate and median width was not clear. However, deeply depressed medians had a higher crash rate than raised medians. Garner and Deen suggested that the beneficial effects of wide medians can be offset by steep median side-slopes. As such, they recommended slopes of 1V:6H or flatter when the median is 60 feet wide. Additionally, median widths of 30 to 40 feet were recommended on high-speed divided highways. However, Garner and Deen also stated that other median elements such as cross slopes and the presence of obstructions can have a greater effect on median crash experience than the median width.

Garner and Deen (*12*) indicated that median cross slopes have a substantial impact on median crash experience. They indicated that deeply depressed medians with cross slopes of 1V:4H and 1V:3H for a 36-foot wide median have been shown to have a significantly higher crash rate than the raised and depressed medians with flatter cross slopes for widths of 20, 30, and 60 feet. Medians with steep slopes may not provide reasonable recovery areas (*12*). In addition, steep slopes also increase the likelihood of vehicle rollover. It was shown that the roadways studied with cross slopes of 1V:4H and 1V:3H had crash rates of 10.3 and 16.5 crashes per 100 million vehicle-miles traveled, respectively, whereas the average crash rates for roadways with flatter median slopes were found to be 3.4 crashes per 100 million vehicle-miles.

The raised median design analyzed in the Garner and Deen study also was shown to have some downfalls. This design seemed to have a higher number of crossover crashes. It was concluded that when drivers hit the median, they tend to overreact, which causes them to lose control of the vehicle. There are other disadvantages associated with raised medians. Raised medians do not provide an adequate storage area for snow removal. Also, water tends to migrate onto the roadway, which allows icy spots to form during cold weather. Garner and Deen also concluded that irregular medians, which have a varying median width and nature, have higher median crash rates, total crash rates, and severity rates.

Foody and Culp (*13*) studied the safety aspects between mound and depressed medians, each having an 84-foot design width. They observed the crash frequency and severity of single-vehicle crashes on four-lane divided Interstates in Ohio from 1969 to 1971 for each median type. They observed 125 miles of highway with the mound median design and 103 miles of highway with the depressed median design. The depressed median had side slopes of 1V:8H. The mound median had 1V:8H foreslopes and 1V:3H backslopes. The study detailed single-vehicle median crashes, crash severity, vehicle path encroachments, and median rollover crashes. The following summarizes the study results obtained by Foody and Culp:

- The crash rate is slightly higher for the raised median than for the depressed median section.
- There is no difference in injury-related crashes between the two median types.
- There is no difference between the two types of medians in the number of median encroachments.
- There is no significance in the difference of rollover frequency between the two median designs.

A study by Kniuman et al. (*14*) investigated median safety using Highway Safety Information System (HSIS) data from Utah and Illinois. In Utah, the total crash rate was found to decline from 650 crashes per 100 million vehicle-miles for medians with zero width, to 111 crashes per 100 million vehicle-miles for median widths in the range of 85 to 110 feet. In Illinois, the data suggest a similar trend, with a crash rate of 692 crashes per 100 million vehicle-miles for the medians with zero width and 53 crashes per 100 million vehicle-miles where the median was 85 to 110 feet wide. It also was reported that the average rate of head-on collisions for median widths greater than 55 feet was 1 and 3 crashes per 100 million vehicle-miles for the Utah and Illinois data, respectively. For the Utah data, single-vehicle crashes do not decline as the median width increases from a range between 1 and 24 feet to a range between 85 and 110 feet. For the Illinois data, single-vehicle crashes were found to decline by almost half as the median width increased from a range of 1 to 24 feet to a range of 85 to 110 feet. It was shown that little reduction in crash rate was obtained for median widths in the range of 0 to 25 feet. The most apparent decline in total crash rate was found to occur roughly between 20 and 30 feet. For medians between 60 and 80 feet, the decline in crash rates seems to level off. All of the previously discussed results can be found in Table 2-2, which is an excerpt from the study results.

Relationships were developed between the type of collision and the relative effects of the median width. The type of crash most affected by the increase in median width was head-on collisions. For the Utah data, the relative effects were fairly linear. It showed an approximate 17 percent decrease in the relative effects of increasing the median width in 10-foot increments. As for the Illinois data, there is a sharp decline in relative effects between median widths in the range from 10 to 40 feet. The largest decline was between the interval of 10 and 20 feet, in which there was a 45-percent decrease in the relative effects of increasing the median width. From 20 to 40 feet, the average decline in relative effects was 42 percent. For median widths greater than 40 feet, the relative effect of increasing the median width for head-on collisions stayed fairly constant around 0.10, or a 10 percent reduction in the total crash rate.

The validity of the results observed from the Illinois and Utah HSIS study are controlled by the variables that were used. There are clearly other variables that were either not measured by the database or not used in the final model simply because of the need to limit the model to as few variables as possible (*14*). Other variables that could have been included in the model are median slope, type of traffic, environmental factors, and other geometric factors. The general results of this study indicate that crash rates decrease as the median width is increased. It is apparent from the data that there is little decrease in crash rates for medians less than 20 to 30 feet. Therefore, increases in safety effects are not seen until the median reaches at least 20 to 30 feet in width. Even greater safety benefits can be seen for median widths up to 65 to 80 feet, at which point the safety effects begin to level off.

Mason et al. (*15*) used crash and roadway inventory data to characterize CMC crashes on Pennsylvania Interstates and expressways. In 5 years, 267 of these crashes occurred; 15 percent resulted in fatalities and 72 percent resulted in reported injuries. When compared to all crash types on Interstates and expressways, the severity level of CMC collisions is

Table 2-2. Relationship between median width and crash rate in Utah and Illinois (*14*).

Median width (ft)			Average crash rate (crashes per 100 MVMT)			
Category	Mean	N	Single-vehicle	Head-on	Rollover	Total
			Utah			
0	0.0	176	127	10	14	650
1 to 10	9.4	257	97	10	5	618
11 to 29	14.9	213	89	8	7	462
30 to 54	46.3	52	109	1	29	159
55 to 84	71.7	179	106	1	22	137
85 to 110	101.0	105	93	0	29	111
All	32.0	982	103	6	14	424
			Illinois			
0	0.0	567	86	21	5	692
1 to 24	12.8	199	69	12	8	647
25 to 34	29.8	176	92	3	15	292
35 to 44	39.7	479	51	2	6	129
45 to 54	49.2	200	61	2	7	127
55 to 64	63.8	450	27	1	3	45
65 to 84	71.9	239	40	1	5	59
85 to 110	88.9	171	36	1	6	53
All	39.4	2,481	58	7	6	283

significantly more severe. Additionally, nearly 63 percent of CMC crashes occurred during daylight conditions, 58 percent occurred during wet or snowy and icy conditions, and 12 percent involved drugs or alcohol usage. Limited field data collection found that median shoulder width, roadway grade, median cross slopes, the presence and degree of horizontal curvature, presence of roadside obstacles, and vehicle type did not statistically influence CMC crashes. However, there was preliminary evidence to conclude that the presence of interchange entrance ramps does increase the likelihood of CMC crashes.

Using the CMC crash data from Pennsylvania, Donnell et al. (*16*) estimated models of crash frequency for Interstate highways. The model took the form shown in Equation 2.

$$N_{CMC} = 0.2 \times e^{-18.203} \times L \times AADT^{1.770} \times e^{-0.0165MW} \qquad (2)$$

where

N_{CMC} = number of CMC crashes per year for one direction of travel

L = segment length (mi)

$AADT$ = average annual daily traffic (veh/day)

MW = median width (ft)

All of the parameters were statistically significant ($p < 0.0001$). However, the model explained only a small proportion of the variation in CMC crash frequency. Interpretation of the AADT parameter (1.77) suggests that CMC crashes are a two-stage process. First, the likelihood that a vehicle loses control and enters the median when traveling in one direction of travel is roughly proportional to the traffic volume (AADT) in that direction. The out-of-control vehicle must then traverse the median, enter the opposing traveled way, and collide with a vehicle traveling in the opposite direction. The likelihood of this occurring should be roughly proportional to the one-way traffic volume (AADT) in the opposing travel lanes. Since the traffic volumes on opposing roadways are typically quite similar on Interstate highways, it seems logical that the likelihood of a CMC crash be roughly proportional to the square of the one-way AADT. A one-unit increase in the median width decreases the CMC crash frequency by approximately 1.7 percent.

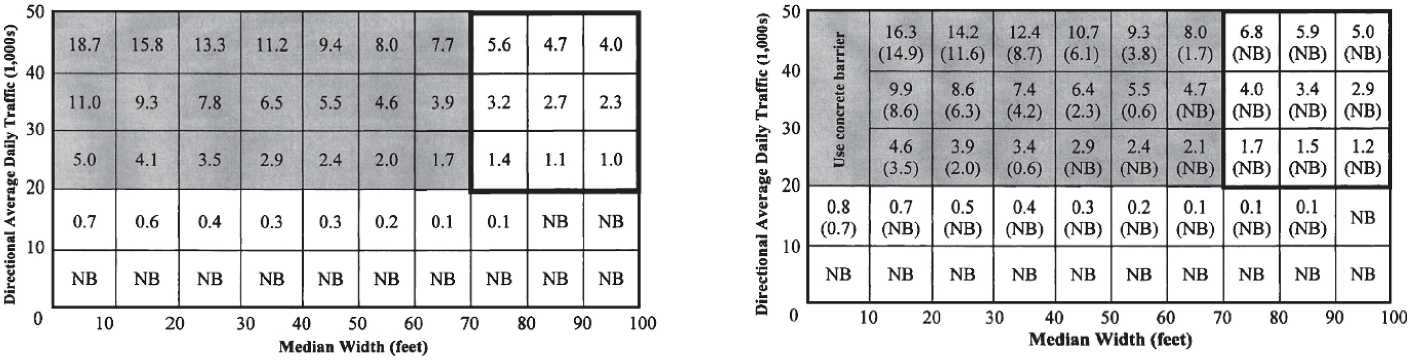
Donnell and Mason (*17*) used negative binomial regression to predict the frequency of median barrier crashes on Pennsylvania Interstate highways. There were a total of 4,416 median barrier collisions that occurred during the 5-year study period (1994 through 1998) on 738 miles of divided highway that were protected with a longitudinal barrier. The ADT, presence of an interchange entrance ramp, posted speed limit, horizontal curve indicator, and median barrier offset from the left edge of the traveled way were all statistically significant predictors of median barrier crash frequency. Curved roadway sections were expected to increase the median barrier crash frequency, holding all other variables constant. A unit increase in the median barrier offset was expected to decrease the median barrier crash frequency by 3.5 percent, holding all other variables constant. A lower posted speed limit was expected to decrease the median barrier crash frequency while the absence of interchange entrance ramp was also expected to decrease the expected median barrier crash frequency, holding all other variables constant.

Donnell and Mason (*18*) predicted the severity of both CMC and median barrier crashes using crash event and roadway inventory data from Pennsylvania Interstate highways. Three severity levels (fatal, injury, and property damage only) were considered. In the CMC crash severity model, an ordered response was used while the multinomial logit was used to estimate median barrier crash severity. In the CMC crash severity model, the use of drugs or alcohol and the direction of the horizontal curve influenced severity. The predicted probabilities of a fatal CMC crash were between 9.8 and 24.3 percent when considering the various categories of independent variables. The predicted probabilities of an injury CMC crash were between 68.1 and 70.5 percent when considering the various categories of the independent variables. The assumption of parallel regression lines was violated when predicting the severity of median barrier crashes. As such, a nominal response was considered. The independent variables that influenced crash severity included pavement surface condition, drug or alcohol use, the presence of an interchange ramp, and ADT. The predicted severity probabilities were as follows:

- Fatal: 0.5 to 0.8 percent,
- Injury: 53.5 to 60.2 percent, and
- Property damage only: 39.0 to 46.0 percent.

Donnell and Mason (*19*) used both CMC and median barrier crash frequency and severity models to evaluate existing median barrier warrant criteria in Pennsylvania. Interstate highways with and without median barrier were compared using roadway inventory and crash data. The economic evaluation consisted of benefits derived from changes in crash costs and the costs were derived from barrier installation, maintenance, and user costs. The benefit-cost analysis results are shown in Figure 2-6.

In Figure 2-6(a), the concrete barrier was assumed to be installed only in the center of a median. The gray-shaded area represents benefit-cost (B/C) ratios that exceed 1.0 and where the data used in the analysis represent most CMC and median barrier crashes. The outlined region also contains B/C ratios that exceed 1.0. The frequency of crashes was very low in the outlined region and, therefore, a site-specific evaluation



18.7	15.8	13.3	11.2	9.4	8.0	7.7	5.6	4.7	4.0
11.0	9.3	7.8	6.5	5.5	4.6	3.9	3.2	2.7	2.3
5.0	4.1	3.5	2.9	2.4	2.0	1.7	1.4	1.1	1.0
0.7	0.6	0.4	0.3	0.3	0.2	0.1	0.1	NB	NB
NB	NB	NB	NB	NB	NB	NB	NB	NB	NB

(a) Concrete Median Barrier

Use concrete barrier	16.3 (14.9)	14.2 (11.6)	12.4 (8.7)	10.7 (6.1)	9.3 (3.8)	8.0 (1.7)	6.8 (NB)	5.9 (NB)	5.0 (NB)
	9.9 (8.6)	8.6 (6.3)	7.4 (4.2)	6.4 (2.3)	5.5 (0.6)	4.7 (NB)	4.0 (NB)	3.4 (NB)	2.9 (NB)
	4.6 (3.5)	3.9 (2.0)	3.4 (0.6)	2.9 (NB)	2.4 (NB)	2.1 (NB)	1.7 (NB)	1.5 (NB)	1.2 (NB)
0.8 (0.7)	0.7 (NB)	0.5 (NB)	0.4 (NB)	0.3 (NB)	0.2 (NB)	0.1 (NB)	0.1 (NB)	0.1 (NB)	NB
NB	NB	NB	NB	NB	NB	NB	NB	NB	NB

(b) W-Beam Guiderail Median Barrier

Figure 2-6. Benefit-cost ratios for median barrier installation (*19*).

using the methodology described was recommended. In Figure 2-6(b), two numerical values are shown in each cell. The value on top represents the B/C ratio for center placement location, while the value on the bottom represents a 4-foot offset from the edge of the traveled way. Because the strong-post W-beam guiderail used along medians in Pennsylvania has design deflection ranging from 2 to 4 feet, it is not used when the median is less than 10-foot wide. The "NB" in Figure 2-6(b) represents a condition where no benefits were found by considering a longitudinal barrier. Either the crash severity or frequency did not change enough when comparing the with/without median barrier scenario to show a net benefit in crash cost.

Ulfarsson and Shankar (*20*) estimated a predictive model of median crossover crash frequencies with a multiyear panel of cross-sectional roadway data. The study compared three different count regression models, including negative multinomial (NM), negative binomial (NB), and random-effects negative binomial (RENB). The results showed that the negative multinomial model outperformed the other two due to the existence of section-specific correlation in the panel. Variables considered in the model included indicator variables for the following conditions:

- ADT less than 5,000 vehicles per day;
- ADT between 5,000 and 10,000 vehicles per day per lane;
- Median width between 9 and 12 m (30 to 40 feet);
- Number of horizontal curves per km;
- Length of section (km) if median width is less than 12 m (40 feet);
- Length of section (km) if median width is between 12 and 18 m (40 feet to 60 feet);
- Length of section (km) if median width is greater than 18 m (60 feet);
- Difference between maximum and minimum shoulder width is greater than 1.2 m (4 feet) and the number of horizontal curves is greater than two per section;
- Roadway friction factor if number of horizontal curves is greater than 0.67 per km (1.08 per mile); and
- Section location (Interstate Route 90, Interstate Route 205, U.S. Route 2, or State Route 16).

These indicator variables had the value of 0 when the condition specified was not present or not applicable and had the value of 1 (or a specified length, width, or number of curves) if the condition specified was present or applicable.

A comparison of the model output for NM, NB, and RENB is shown in Table 2-3. The results of the negative multinomial regression model indicate that crash frequencies are lower along road sections with lower traffic volumes. The predicted median crossover crash frequency decreases as the number of horizontal curves per km increases. However, the indicator for the difference between the maximum and minimum shoulder width (greater than 4 feet) and number of horizontal curves is greater than two per section, and this suggests that the crash frequency increases as the curve frequency and shoulder width difference increases. The section length variables were all positive in the negative multinomial model.

Miaou et al. (*4*) presented predictive models of crash frequency and severity as well as B/C analysis results for a cross-sectional with/without median barrier study in Texas. Two years of data (1998 and 1999) were collected from Interstates, freeways, and expressways with four or more lanes and a posted speed limit of 55 mph or greater. Only divided highway sections with ADT less than 150,001 vehicles per day were considered in the analysis as were sections with medians between 15 and 150 feet wide. There were 346 reported cross-median crashes in 52 Texas counties during the 2-year analysis period. An additional 3,064 median-related crashes were reported on sections with no longitudinal median barrier. There were 3,672 median-related crashes included in the analysis time period along sections with longitudinal median barrier. Of these 3,672 reported crashes, 2,714 crashes (74 percent) were defined as hit-median-barrier crashes.

Table 2-3. NM model coefficient estimation results for median crossover crash frequency (*20*).

Variable	NB	RENB	NM
Constant	–1.551 (0.181)†	–0.118 (0.391)	–1.500 (0.251)†
ADT less than 5,000 vehicles per lane daily, indicator	–1.398 (0.186)†	–1.373 (0.190)†	–1.381 (0.312)†
ADT between 5,000 and 10,000 vehicles per lane daily, indicator	–0.233 (0.158)	–0.266 (0.157)‡	–0.298 (0.290)
Median width between 30 and 40 ft, indicator	0.463 (0.206)†	0.368 (0.215)‡	0.432 (0.309)
Number of horizontal curves per kilometer	–0.309 (0.128)†	–0.325 (0.141)†	–0.502 (0.262)‡
Length of section (km) if median width is less than 40 ft, 0 otherwise	0.281 (0.047)†	0.278 (0.062)†	0.175 (0.052)†
Length of section (km) if median width is between 40 and 60 ft, 0 otherwise	0.526 (0.065)†	0.502 (0.070)†	0.292 (0.068)†
Length of section (km) if median width is greater than 60 ft, 0 otherwise	–0.358 (0.060)†	–0.343 (0.065)†	0.105 (0.026)†
Difference between maximum and minimum shoulder width is > 4 ft and the number of horizontal curves is greater than 2 per section, indicator	0.542 (0.321)‡	0.489 (0.285)‡	0.486 (0.580)
Roadway friction factor if number of horizontal curves is greater than 1.08 per mi, 0 otherwise	0.011 (0.004)†	0.010 (0.005)†	0.009 (0.006)
Washington State Route 2, indicator	–2.093 (1.098)‡	–1.973 (1.371)	0.271 (0.587)
Washington State Route 16, indicator	–1.338 (0.581)†	–1.290 (0.792)	–1.188 (0.746)
Washington State Route 90, indicator	–0.722 (0.199)†	–0.732 (0.195)†	–0.560 (0.341)
Washington State Route 205, indicator	–1.814 (1.055)‡	–1.756 (1.150)	–8.815 (0.533)†
Parameter α	0.447 (0.172)†		0.258 (1.074)
Parameter *a*		128.780 (312.380)	
Parameter *b*		34.514 (90.241)	
ln $L(\beta=0, \alpha=1)$, naïve model	**	**	–827.556
ln *L* at NB values	—	—	–883.746
ln *L* at convergence	–711.931	–715.801	–613.078

NOTE: Standard errors are given in parentheses. An "indicator" variable is 1 or a specified quantity if the condition holds and 0 otherwise. The NB and RENB model results presented elsewhere (*6*) are presented here for comparison with the NM model results.

† = Significance at the 95% level by the two-tailed t-test: ‡ = significance at the 90% level by the two-tailed test. *a,b* = parameters of the beta distribution used in the RENB model: ** = information not available.

Four median crash types were considered in the frequency and severity models: cross-median crashes on sections with no barrier, other median-related crashes on sections with no barrier, all median-related crashes on sections with a barrier, and hit-median-barrier-only crashes on sections with a barrier. A Poisson-gamma model, using a full Bayes approach, was used to specify and estimate the crash frequency prediction model. The advantage of using such a modeling technique is that it accounts for the uncertainty associated with the model parameter estimates. The roadway inventory and traffic volume variables included in the models were as follows:

- Median width (ft);
- Logarithm of ADT;
- Number of lanes;
- Posted speed limit (dummy variable for 60 mph, dummy variable for 65 mph, dummy variable for 70 mph); and
- A dummy variable for the year 1999.

Results of the crash frequency modeling effort are shown in Table 2-4. As shown, the median width is negatively correlated with crash frequency in all models. This indicates that as the median width increases, the crash frequency decreases.

Ordered multinomial logit models were used to develop crash severity models for all four crash types described previously. The variables considered in these models included the following:

- Five levels of crash severity (K: fatal injury; A: incapacitating injury; B: nonincapacitating injury; C: possible injury; O: property damage only);
- Dummy variable for year 1999;
- Median width (feet);
- Logarithm of ADT;
- Number of lanes; and
- Posted speed limit (dummy variable for 60 mph, dummy variable for 65 mph, dummy variable for 70 mph).

None of the explanatory variables used in the crash severity models were found to be statistically significant; therefore, the observed crash severity distributions were used in the economic analysis. The severity distributions for each of the four crash types are shown in Table 2-5.

The crash frequency models and severity data were used to estimate B/C ratios for both concrete and high-tension cable median barrier in Texas. Figure 2-7 shows a potential guideline for concrete median barrier based on B/C ratios. As shown, the B/C ratios increase from lower-left to upper-right. Zone No. 4 includes divided, limited-access roadways with low traffic volumes and the entire range of median widths considered in the study. The B/C ratios in Zone No. 4 were

Table 2-4. Posterior mean and standard error of estimated parameters of Texas median safety crash frequency models (*4*).

	Crash frequency model			
	No barrier		With barrier	
Covariate (coefficient)	Cross-median crashes	Other median-related crashes	All median-related crashes	Hit-median-barrier crashes
Offset = exposure (in MVMT) = v_1 (=365*AADT*Segment Length/1,000,000)	—*	—	—	—
Intercept term				
Overall intercept (β_0)	–3.779 (±0.48)	–2.239 (±0.07)	–1.771 (±0.07)	–1.740 (±0.99)
Dummy variable for 1999: 1 if 1999 and 0 if 1998 (β_1)	1.163 (±0.14)	–0.068 (±0.05)	–0.031 (±0.001)	–0.018 (±0.06)
Median width (in ft) (β_2)	–0.011 (±0.003)	–0.002 (±0.001)	–0.006 (±0.001)	–0.013 (±0.002)
Log (AADT) (β_3) (AADT in 1,000s)	—	—	—	—
Number of lanes (=β_4)	–0.293 (±0.09)	—	—	—
Posted speed limit (mph)				
Dummy variable for 60 mph (=1 if 60 mph; =0 if otherwise) (β_5)	–0.139 (±0.54)	–0.342 (±0.17)	–0.575 (±0.08)	–0.063 (±0.10)
Dummy variable for 65 mph (=1 if 65 mph; =0 if otherwise) (β_6)	0.500 (±0.16)	–0.126 (±0.06)	–0.075 (±0.07)	–0.188 (±0.09)
Dummy variable for 70 mph (=1 if 70 mph; =0 if otherwise) (β_7)	0.284 (±0.18)	–0.079 (±0.07)	–0.007 (±0.07)	0.004 (±0.09)
Inverse dispersion parameter				
Inverse dispersion parameter for this model (Ψ)	0.727 (±0.17)	1.388 (±0.12)	1.956 (±0.16)	1.464 (±0.13)
Inverse dispersion parameter for worst possible model of crash frequency (Ψ_0^{freq})	0.158 (±0.02)	0.429 (±0.02)	(0.466 (±0.02)	0.367 (±0.02)
Goodness-of-fit measures				
Deviance information criterion/sample size (DIC/n)	0.39	1.71	2.54	2.14
$R_{\frac{1}{\Psi freq}} = 1 - (1/\Psi)(1/\Psi_{0}^{freq})$	0.78	0.69	0.76	0.75

NOTE: All models were structured using the full Bayes framework with noninformative priors (or hyperpriors). Parameters (β and Ψ) were estimated by using Markov chain Monte Carlo techniques, and the values shown in the table are their posterior means. Values in parentheses are the estimated 1 standard error of parameters to their left based on the posterior density of the parameter.
*—indicates not statistically significant at the10% significance level.

Table 2-5. Texas median crash severity distribution (*4*).

Barrier and Crash Type	N	Severity Type K	%	A	%	B	%	C	%	PDO	%
No Median Barrier											
Cross-Median	346	73	21.1	73	21.1	82	23.7	58	16.8	60	17.3
Other Median-Related	3,046	71	2.3	272	8.9	639	20.9	734	23.9	1,348	44.0
With Median Barrier											
All Median-Related	3,672	36	1.0	190	5.2	681	18.5	1,098	29.9	1,667	45.4
Hit-Median-Barrier	2,714	13	0.5	128	4.7	490	18.0	835	30.8	1,248	46.0

N = total number of crashes
K = fatal
A = Incapacitating injury
B = Nonincapacitating injury
C = Possible injury
PDO = Property damage only

less than 2.0; thus, the combination of traffic volume and median width was considered a lower priority for longitudinal barrier consideration than the other zones. Zone No. 1 includes average annual daily traffic volumes between 70,000 and 125,000 vehicles per day and median widths between 0 and 60 feet. In Zone No. 1, various median width-traffic volume combinations produced B/C ratios greater than 10. As such, divided highways in Zone No. 1 without longitudinal median barrier were considered the highest priority for median barrier installation. Further, it was recommended that road sections with a mean B/C ratio greater than 10 be given the highest priority when installing concrete median barriers.

To develop a potential guideline for the installation of high-tension-cable barriers, a favorability ratio was developed. A favorability ratio was defined as the ratio of the high-tension-cable barrier's mean B/C ratio over the concrete barrier's mean B/C ratio. Table 2-6 shows the calculated favorability ratios for various median widths and traffic volumes. A favorability ratio of 1.0 indicated that concrete and high-tension-cable barriers had the same mean B/C ratio and higher ratios suggested increased favorability of using the high-tension-cable barrier over the concrete barrier in terms of the mean B/C ratios. Miaou et al. (*4*) recommended considering high-tension-cable barriers only when the favorability ratio exceeded 2.

Noyce and McKendry (*21*) investigated the magnitude of, and factors affecting, median crossover crashes in Wisconsin using data from freeways and expressways. In 3 years (2001 through 2003), there were 631 median crossover crashes on four Interstates and 17 other freeways and expressways in Wisconsin. Of these, 81 percent (511 of 631) were single-vehicle crashes. In such instances, single-vehicle crashes involve motorists running off the road to the left and enter-

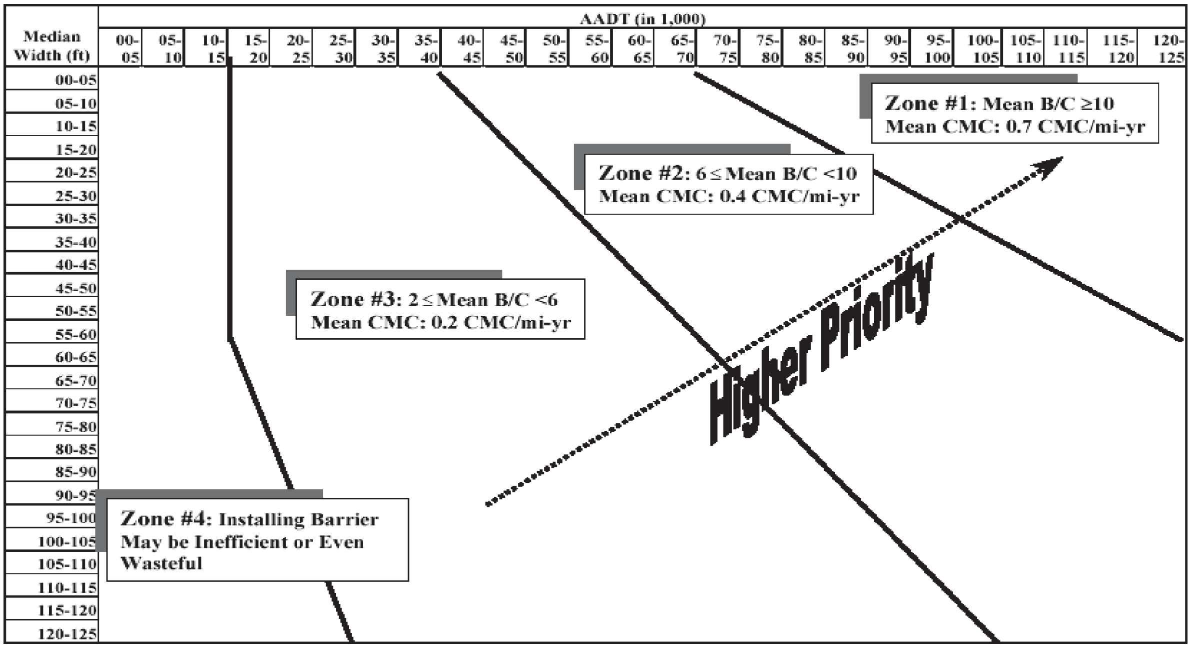


Figure 2-7. Benefit-cost ratios based on Texas study (4).

Table 2-6. Favorability ratios from Texas study (*4*).

Median Width (ft)	AADT (in 1,000s)																								
	5**	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
25*	2.3	2.1	2.0	1.9	1.8	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0	1.0
30	2.3	2.2	2.1	2.0	1.9	1.9	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.1
35	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.2
40	2.6	2.4	2.3	2.2	2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.7	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.3
45	2.7	2.5	2.4	2.4	2.3	2.2	2.1	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.4	1.4
50	2.8	2.6	2.5	2.5	2.4	2.3	2.2	2.2	2.1	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.5	1.5
55	2.9	2.7	2.7	2.6	2.5	2.4	2.4	2.3	2.2	2.2	2.1	2.1	2.0	2.0	1.9	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.7	1.6	1.6
60	3.0	2.9	2.8	2.7	2.6	2.5	2.5	2.4	2.4	2.3	2.2	2.2	2.2	2.1	2.1	2.0	2.0	1.9	1.9	1.9	1.8	1.8	1.8	1.8	1.7
65	3.1	3.0	2.9	2.8	2.7	2.7	2.6	2.5	2.5	2.4	2.4	2.3	2.3	2.2	2.2	2.1	2.1	2.1	2.0	2.0	2.0	1.9	1.9	1.9	1.8
70	3.2	3.1	3.0	2.9	2.8	2.8	2.7	2.7	2.6	2.5	2.5	2.4	2.4	2.3	2.3	2.3	2.2	2.2	2.2	2.1	2.1	2.1	2.0	2.0	2.0
75	3.3	3.2	3.1	3.0	3.0	2.9	2.8	2.8	2.7	2.7	2.6	2.6	2.5	2.5	2.4	2.4	2.3	2.3	2.3	2.2	2.2	2.2	2.1	2.1	2.1
80	3.4	3.3	3.2	3.1	3.1	3.0	3.0	2.9	2.8	2.8	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.4	2.4	2.4	2.3	2.3	2.3	2.2	2.2
85	3.5	3.4	3.3	3.3	3.2	3.1	3.1	3.0	3.0	2.9	2.9	2.8	2.8	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.5	2.4	2.4	2.4	2.3
90	3.6	3.5	3.4	3.4	3.3	3.3	3.2	3.1	3.1	3.0	3.0	2.9	2.9	2.8	2.8	2.8	2.7	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.5
95	3.7	3.6	3.6	3.5	3.4	3.4	3.3	3.3	3.2	3.2	3.1	3.1	3.0	3.0	2.9	2.9	2.9	2.8	2.8	2.7	2.7	2.7	2.6	2.6	2.6
100	3.8	3.7	3.7	3.6	3.5	3.5	3.4	3.4	3.3	3.3	3.2	3.2	3.1	3.1	3.1	3.0	3.0	2.9	2.9	2.9	2.8	2.8	2.8	2.7	2.7
105	3.9	3.8	3.8	3.7	3.7	3.6	3.6	3.5	3.5	3.4	3.4	3.3	3.3	3.2	3.2	3.2	3.1	3.1	3.0	3.0	3.0	2.9	2.9	2.9	2.8
110	4.0	4.0	3.9	3.8	3.8	3.7	3.7	3.6	3.6	3.5	3.5	3.4	3.4	3.4	3.3	3.3	3.2	3.2	3.2	3.1	3.1	3.1	3.0	3.0	3.0
115	4.1	4.1	4.0	3.9	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.5	3.5	3.4	3.4	3.4	3.3	3.3	3.3	3.2	3.2	3.2	3.1	3.1
120	4.2	4.2	4.1	4.1	4.0	4.0	3.9	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.5	3.5	3.5	3.4	3.4	3.4	3.3	3.3	3.3	3.2
125	4.3	4.3	4.2	4.2	4.1	4.1	4.0	4.0	3.9	3.9	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.5	3.5	3.5	3.4	3.4	3.4

Based on a 4-lane highway with a posted speed limit of 65 mph (104 km/hr) scenario.

*Due to the deflection characteristic of cable barriers upon impact, installing on medians with a width less than 25 ft is usually not recommended.

**Low estimates of the B/C ratios for high-tension cable barriers are less than 1 when AADT is less than 5,000.

ing the median; however, a collision with a vehicle traveling in the opposing travel lanes did not result. The crossover crash severity distribution was as follows:

- Fatal: 6.5 percent (41 of 631),
- Injury: 53.2 percent (336 of 631), and
- Property damage only: 40.3 percent (254 of 631).

The most common initial cause of median crossover crashes was lost control due to weather (44.0 percent), lost control on dry pavement (41.7 percent), and vehicle collision (11.1 percent).

Fitzpatrick et al. (*22*) used crash data from Texas along approximately 1,200 miles of roadway to develop crash modification factors for freeway and rural multilane highway median-related crashes. Models that quantify the effect of median-related factors on the cross-median crashes were created for medians with rigid barriers, urban medians without barriers, and rural medians without barriers.

In NCHRP Project 22-21, Graham et al. (*1*) studied crash statistics of rural highways with and without median barriers to determine guidelines for designing typical cross sections for medians (i.e., width, slope, and barrier). Simulation of vehicle incursions into medians of various designs also was conducted. The fatal-and-injury crash analysis results for rural four-lane freeways generally indicate that CMC crashes decrease with wider medians, while rollover crashes generally increase with wider medians. These two effects are of almost equal magnitude but in opposite directions. The vehicle dynamics simulation results indicate that, at a median width in the range from 50 to 60 feet, there is a boundary at which the probability of a CMC crash becomes less than the probability of a rollover crash. This suggests that when the lower severity of rollover crashes is taken into account, that there are diminishing returns in continuing to make the median wider.

Crash prediction models for rural four-lane freeways show that flatter slopes are associated with more CMC crashes and fewer rollover crashes. The models indicate that flatter slopes on freeways are associated with fewer fixed-object crashes. The vehicle dynamics simulations show an interaction between median slope and median width that was not evident in the crash analysis. For median slopes in the range from 1V:4H to 1V:7H, the boundary between medians where CMC crashes are most prevalent and those for which rollover crashes are most prevalent falls in the median width range from 50 to 55 feet. For median slopes of 1V:8H or flatter, that boundary falls at 60 feet. Thus, the vehicle dynamics simulations indicate that the concerns about high-severity CMC crashes are greatest for median widths less than 60 feet and for median slopes steeper than 1V:8H. Furthermore, these results suggest that the likelihood of CMC crashes does not continue increasing as the median slope becomes flatter than 1V:8H.

In considering median barrier use, crash prediction models and a before/after evaluation estimated crash modification factors for flexible, semi-rigid, and rigid barriers. A benefit-cost analysis showed that all of these barrier types can be cost-effective in reducing severe CMC crashes. However, they increase the frequency of less severe fixed-object crashes. The cost-benefit analysis results indicate that flexible barriers may be cost-effective even at lower traffic volumes than shown in current AASHTO median barrier warrants.

2.3 Crash Countermeasures for Improving Median Safety

One of the most frequently used countermeasures to prevent median encroachments is shoulder rumble strips, which may be considered for implementation on a range of roadway types, including urban and rural freeways, multilane divided highways, multilane undivided highways, and two-lane roads. Recent research by Torbic et al. (*23*) has provided some of the most reliable and comprehensive estimates to date of the safety effectiveness of shoulder rumble strips. The safety effectiveness estimates for shoulder rumble strips and the standard errors (SE) for the estimates are as follows:

- **Urban/Rural Freeways**
  Rolled shoulder rumble strips [based on results from Griffith (*24*)]
  - 18 percent reduction in single-vehicle run-off-the-road (SVROR) crashes (SE = 7)
  - 13 percent reduction in SVROR fatal-and-injury (FI) crashes (SE = 12)
- **Rural Freeways**
  Shoulder rumble strips [based on combined results from Torbic et al. (*23*) and Griffith (*24*)]
  - 11 percent reduction in SVROR crashes (SE = 6)
  - 16 percent reduction in SVROR FI crashes (SE = 8)
- **Rural Two-Lane Roads**
  Shoulder rumble strips [based on results from Torbic et al. (*23*) and Patel et al. (*25*)]
  - 15 percent reduction in SVROR crashes (SE = 7)
  - 29 percent reduction in SVROR FI crashes (SE = 9)

Estimates on the safety effectiveness of shoulder rumble strips along rural multilane divided highways are also available but are not considered as reliable as the estimates for freeways and rural two-lane roads. The safety estimates for rural multilane divided highway are as follows:

- **Rural Multilane Divided Highways**
  Shoulder rumble strips [based on results from Carrasco et al. (*26*)]
  - 22 percent reduction in SVROR crashes
  - 51 percent reduction in SVROR FI crashes

The lack of reliable estimates on the safety effectiveness of shoulder rumble strips along other roadway types does not indicate that shoulder rumble strips are ineffective on these roadway types. Rather, their safety effects are not known at this time.

Torbic et al. (*23*) also conducted a review of safety evaluations of shoulder rumble strips that have been conducted in many states, and in some cases the evaluations included data from multiple states. Table 2-7 summarizes the results of these safety evaluations, along with results from several unpublished materials. Table 2-7 shows the state/location of the evaluation, the type of facility where the rumble strips were installed, the types of collisions included in the analysis, the estimated safety effectiveness of the rumble strip application, and the type of analysis that was performed (i.e., if it could be determined from the reference material). Several key findings are as follows:

- Most of the studies evaluated the safety effectiveness of shoulder rumble strips installed along freeway facilities. Only a limited number of studies investigated the safety effectiveness of shoulder rumble strips along lower class roadways (i.e., nonfreeways).
- Most of the evaluations were limited to those collision types most directly affected by the installation of shoulder rumble strips (i.e., SVROR type crashes). However, several studies did investigate the safety impact of shoulder rumble strips on total crashes.
- SVROR crashes were reduced by 10 to 80 percent due to shoulder rumble strips. The simple average percent reduction in SVROR crashes from these studies is 36 percent.
- Total crashes were reduced by 13 to 33 percent due to shoulder rumble strips. The simple average percent reduction in total crashes from these studies is 21 percent.

Concerning the safety effectiveness of shoulder rumble strips, *NCHRP Report 617: Accident Modification Factors for Traffic Engineering and ITS Improvements* (*40*), summarizes the current status of crash reduction factors for a variety of treatments. In preparing *NCHRP Report 617*, a panel of safety experts assigned a level of predictive certainty to each crash modification factor based upon a critical review of the published research. In assigning a single value or values of the safety effectiveness of shoulder rumble strips, the panel only referenced the 1999 study by Griffith (*24*) and assigned a medium-high level of predictive certainty to these estimates. *NCHRP Report 617* specifically states that the estimated safety effects are only applicable to freeways and no other types of roads (i.e., two-lane or multilane roads).

Although the employment of rumble strips has been shown to have a positive effect on roadside encroachment, there is research to suggest that they might have a secondary effect that could still eventually lead to roadside encroachment. Spainhour and Mishra (*41*) conducted an investigation of run-off

Table 2-7. Summary of safety benefits attributed to the installation of shoulder rumble strips (*23*).

State/location	Type of facility	Type of collisions targeted	Percent decrease (–) or percent increase (+) in target collision frequency from application of shoulder rumble strips (standard deviation)	Type of analysis
Arizona (*27*)	Interstate	SVROR	–80%	Cross–sectional comparison
California (*28*)	Interstate	SVROR	–49%	Before–after with comparison sites
		Total	–19%	
Connecticut (*29*)	Limited–access roadways	SVROR	–32%	Before–after with comparison sites
Florida (*27*)		Fixed object	–41%	Naïve before–after
		Ran–into–water	–31%	
Illinois and California (*24*)	Freeways	SVROR (total)	–18% (±6.8%)	Before–after with marked comparison sites and a comparison group
		SVROR (injury)	–13% (±11.7%)	
	Rural freeways	SVROR (total)	–21.1% (±10.2%)	
		SVROR (injury)	–7.3% (±15.5 %)	
Kansas (*30*)	Freeways	SVROR	–34%	Unknown
Maine (*31*)	Rural freeways	Total	Inconclusive	Before–after with comparison sites
Massachusetts (*30*)		SVROR	–42%	Unknown
Michigan (*32*)		SVROR	–39%	Cross–sectional comparison
Minnesota (*26*)	Rural multilane divided highways	Total	–16%	Naïve before–after
		Injury	–17%	
		SVROR (total)	–10%	
		SVROR (injury)	–22%	
		Total	–21%	Before–after with comparison sites
		Injury	–26%	
		SVROR (total)	–22%	
		SVROR (injury)	–51%	
Minnesota (*25*)	Rural two–lane roads	SVROR (total)	–13% (8%)	Before–after EB analysis with a reference group
		SVROR (injury)	–18% (12%)	
Montana (*33*)	Interstate and primary highways	SVROR	–14%	Before–after with comparison sites
New Jersey (*30*)		SVROR	–34%	Unknown
New York (*34*)	Interstate Parkway	SVROR	–65% to 70%	Naïve before–after
Pennsylvania (*35*)	Interstate	SVROR	–60%	Naïve before–after
Tennessee (*36*)	Interstate	SVROR	–31%	Unknown
Utah (*37*)	Interstate	SVROR	–27%	Before–after with comparison sites
		Total	–33%	
Virginia (*38*)	Rural freeways	SVROR	–52%	Before–after with comparison sites
Washington (*39*)		Total	–18%	Naïve before–after
Multistate (*27*)	Rural freeways	SVROR	–20%	Before–after with comparison sites

road crashes in Florida as a result of driver overcorrection. In one-third of the crashes where overcorrection has occurred the vehicle actually ended up encroaching on the opposite roadside of its initial encroachment. The most often cited known factors for causing drivers to initially leave the travel lanes, in order of occurrence in crash reports, were alcohol, excessive speeds, driver inattention, and fatigue. In attempting to establish a regression model for predicting crashes due to overcorrection, the authors found that the presence of rumble strips has a strong association with this crash type. To this end, it was concluded that while rumble strips are effective at preventing cars from leaving the roadway in the initial direction, they can also cause panic to the driver resulting in an overcorrection and possible loss of vehicle control.

2.4 Road Safety Audits

Agencies will occasionally conduct road safety audits (RSAs) to formally examine the safety performance of the highways within their jurisdictions. RSAs from two agencies were identified that were focused on locations with excessive median-related crashes.

The Massachusetts Highway Department (MassHighway) has conducted three RSAs on Interstate roadways. The first report reviewed (*42*) a site on I-195 in Westport, Massachusetts. The purpose of the review was to identify current safety issues on the section under study and to recommend countermeasures for these safety issues.

The section chosen was 1.4 miles long and included Interchanges 9, 10, and 11 on I-195 in southeastern Massachusetts. An 11-person team made the reviews and included traffic engineers, highway designers, safety management professionals, state police, and RSA consultants.

The analysis procedure was based on FHWA's *Road Safety Audit Guidelines* (*43*) and included the following steps:

- Obtaining and reviewing crash and other traffic characteristics data and available roadway plans,
- Conducting site reviews including photographing and videotaping current roadway conditions,
- Identifying potentially hazardous issues, and
- Identifying and evaluating countermeasures to correct or lessen the noted issues.

Issues were categorized by a frequency and severity rating scale. The two ratings scales are shown in Tables 2-8 and 2-9. The relative risk of each identified issue, which combines the frequency and severity rating, is shown in Table 2-10.

Site reviews were guided by a prompt list developed for median crossover RSAs by the consultant. Seven contributing

Table 2-8. Frequency rating used in road safety audits (*43*).

Estimated		Expected crash frequency (per audit item)	Frequency rating
Exposure	Probability		
high	high	5 or more crashes per year	Frequent
medium	high		
high	medium	1 to 4 crashes per year	Occasional
medium	medium		
low	high		
high	low	Less than 1 crash per year, but more than 1 crash every 5 years	Infrequent
low	medium		
medium	low	Less than 1 crash every 5 years	Rare
low	low		

Table 2-9. Severity rating used in road safety audits (*43*).

Typical crashes expected (per audit item)	Expected crash severity	Severity rating
High-speed crashes; head-on and rollover crashes	Probable fatality or incapacitating injury	Extreme
Moderate speed crashes; fixed object or off-road crashes	Moderate to severe injury	High
Crashes involving medium to low speeds; lane changing or sideswipe crashes	Minor to moderate injury	Moderate
Crashes involving low to medium speeds; typical of rear-end or sideswipe crashes	Property damage only or minor injury	Low

Table 2-10. Crash risk assessment used in road safety audits (*43*).

Frequency rating	Severity ratings			
	Low	Moderate	High	Extreme
Frequent	C	D	E	F
Occasional	B	C	D	E
Infrequent	A	B	C	D
Rare	A	A	B	C

Crash risk ratings:
A: minimum risk level
B: low risk level
C: moderate risk level
D: significant risk level
E: high risk level
F: extreme risk level

Table 2-11. Contributing factors and countermeasures for sites from road safety audits performed in Wisconsin (*44*).

Site	Contributing factors	Countermeasures
2	Driving too fast for weather conditions	1. Flatten vertical curves 2. Flatten bridge deck 3. Install safety edge 4. Install rumble strips 5. Install pull-off areas
5	Driver inattention Vehicle malfunction Congestion	1. Investigate drainage issues 2. Increase law enforcement 3. Install exit signs 4. Flatten median side slopes
17	Driving too fast for weather conditions Vehicle malfunction	1. Install de-icing technology on bridge decks 2. Provide enforcement pull offs 3. Install safety edge
20	Driver inattention Loss of control Vehicle malfunction	1. Install safety edge 2. Remove fixed objects 3. Review ramp design
24	Driver inattention Avoiding an animal	1. Install safety edge 2. Repave

factors to the median-related crashes were rated by the RSA team. The specific factors were related to travel speeds, advanced warning of merging traffic, and guidance through the interchange in the middle of the study section. Although lack of a median barrier along most of the site was noted and discussed, the RSA team did not recommend adding barrier in the study section.

Countermeasures were recommended for each of the noted issues and included installation of overhead sign warning of the major merge movement, addition of chevron sign in an on-ramp curve, improvement of sight distance to merging areas, and increased enforcement patrols.

MassHighway has completed at least two other RSAs using the rating scheme shown in Tables 2-8, 2-9, and 2-10.

The University of Wisconsin Traffic Operations and Safety Laboratory (TOPS) has researched the history of cross-median crashes in Wisconsin. The TOPS lab reviewed crash data for the period of 2001–2005 (*21*). During this period, they reviewed 227 cross-median crashes that resulted in 63 fatalities. The TOPS lab developed a top 25 list of roadway segments within Wisconsin that have high rates of cross-median crashes. A consultant was hired by Wisconsin DOT to develop an RSA process and to audit the top five sites from the TOPS list (*44*).

The RSA process developed, including the following steps:

- Site selection—Five representative sites were selected from the TOPS list.
- Data assembly and analysis—Traffic information and site information were analyzed with 5 years of crash reports for each of the five sites.
- Site review—The five-member RSAR team met with local officials who were familiar with the site, and conducted a comprehensive audit of each site.
- Report preparation—Results of the audit, including recommended countermeasures, were documented.

The contributing factors and recommended countermeasures for each of the five sites are shown in Table 2-11. Interchange spacing was investigated at the five sites and revealed that three of the five sites had minimal spacing between interchanges. Further study of weaving and merging distances was recommended.

Some of the summary points from these audits included the following:

- At four of the five sites, over 70 percent of the crashes occurred in one direction.
- Many of the cross-median crashes occur after or just before bridges.
- Many drivers involved in cross-median crashes were in the right lane or shoulder prior to the crash.
- There were clusters of crashes at bridges, on/off ramps, and weave sections.

2.5 Median Design Practice

A WISDOT Transportation Synthesis Report, *Putting the Brakes on Crossover Crashes: Median Barrier Research and Practice in the U.S.* (*45*), outlines a survey sent to all AASHTO Research Advisory Committee members. The survey covered three topics related to median barrier policy in the state agencies. The first was to determine which states use the AASHTO *Roadside Design Guide* (*46*) to decide where to consider installation of median barriers. The second was to determine which states have their own policies or guidelines for deciding where to install median barriers or the appropriate barrier type to use. The third was to determine which states have acceptance/rejection criteria for temporary concrete barriers used in work zones.

Survey responses were received from 22 state DOTs and 3 Canadian agencies. The key findings were that most agencies (76 percent) primarily use the AASHTO *Roadside Design Guide* for guidance on where to install median barriers. Although the *Roadside Design Guide* recommends median closure for median widths of 50 feet or less, Oregon DOT is adopting a 60-foot median width as a closure warrant, and wider medians may be closed with evidence of cross-median crashes. The Arizona DOT adopted a median width policy in 1999 similar to the current guidance in Chapter 6 of the *Roadside Design Guide*, but with some modifications. More than half of the agencies (60 percent) have developed their own policy or guidelines for deciding where to install median barriers and which barrier type to use. The Indiana DOT's *Design Manual* incorporates guidelines for deciding where to install median barriers and which types to use, and the DOT also is developing design guidelines for high-tension-cable barriers. Guidelines developed by Alberta Infrastructure and Transportation indicate the most forgiving system that will serve the purpose should be used; that is, flexible systems are preferred over rigid systems. Most agencies (80 percent) have criteria for accepting or rejecting temporary concrete barriers used in work zones. New Hampshire DOT uses material certifications for acceptance of all concrete barriers and performs a visual inspection to ensure that the proper connection is used and that no chips to the concrete are problematic. New York State DOT recently issued a new engineering instruction intended to address fabrication issues.

SECTION 3

Survey Results

This section presents the combined results from three recent surveys of highway agencies related to median design practices: a 2003 survey conducted as part of NCHRP Project 17-14 (*47*); a 2006 survey conducted as part of NCHRP Project 22-21 (*22*); and a 2009 survey conducted as part of the current research.

3.1 Survey Method

A survey of state highway agencies concerning their median design practices was conducted in 2003 as part of NCHRP Project 17-14. This previous survey was updated in 2006 as part of the research conducted for NCHRP Project 22-21. That survey was not identical to the earlier survey, but did contain several of the same questions relating to typical median cross sections and use of median barriers. In 2009, the survey was once again updated for the current research, containing some of the same questions found in previous surveys, but including new questions as well.

Both the 2003 and 2006 surveys were sent to the design engineers of the 50 state highway agencies. The 2009 survey was sent to design and traffic engineers at the 50 state highway agencies, as well as to engineers at 9 of the Canadian provincial highway agencies, and 19 toll and turnpike agencies in the United States. The survey was distributed by email as a link to the survey website. To avoid duplication of effort, survey respondents were first asked whether their median design policies had changed since 2006. If the agency had responded to the 2006 survey and their response to this first question in the 2009 survey indicated that the agency's median design policies had not changed since 2006, many of the subsequent questions that had already been answered in the previous survey were not repeated.

The summary of survey results presented below is based on the combined results of the 2003, 2006, and 2009 surveys for all cases in which common questions were asked.

3.2 Response Rate

The 2003 survey received responses from 37 of the 50 states, or 74 percent. The 2006 survey received responses from 34 of the 50 states, or 68 percent. Of the 78 agencies that were sent the 2009 survey, responses were received from 22 state highway agencies, 3 Canadian provincial agencies, and 6 turnpike or toll road authorities, for a response rate of 44 percent for the state highway agencies and 40 percent for all survey recipients. The combination of all three surveys includes responses from 47 states (or 94 percent). Table 3-1 lists the agencies that responded to each of the surveys.

Table 3-2 summarizes the state agency responses concerning changes in median design policies from the 22 states that responded to the 2009 survey. No Canadian provincial agencies or toll authorities responded to this question. Half of the respondents reported that their median policy had not changed since 2006, and only three agencies reported a change in their policy between 2006 and 2009. Table 3-3 lists all of the state agencies that responded to any of the surveys and indicates whether there were median design policy changes from 2003 to 2006 or from 2006 to 2009.

3.3 Survey Summary

3.3.1 Median Design Criteria

Respondents were asked whether their agency uses design criteria for highway medians that differ from AASHTO's *Policy on Geometric Design of Highways and Streets*, commonly known as the *Green Book (48, 49, 50)*. There were 15 responses to this question. One state highway agency, one Canadian provincial agency, and one toll authority responded that they had median design criteria that differed from that provided in the AASHTO *Green Book*. All responses to this question are summarized in Table 3-4.

Table 3-1. State highway agencies that responded to each of the surveys.

Agencies responding to the 2003 survey	Agencies responding to the 2006 survey	Agencies responding to the 2009 survey
Alabama	Alabama	Alaska
Alaska	Arkansas	Arizona
Arizona	California	Florida^
Arkansas	Connecticut	Georgia*
California	Delaware	Indiana^
Colorado	Florida	Iowa^
Connecticut	Idaho	Kentucky
Delaware	Indiana	Maryland^
Florida	Iowa	Massachusetts
Hawaii	Kentucky	Michigan
Indiana	Maine	Mississippi^
Iowa	Maryland	Montana^
Kansas	Minnesota	New Mexico
Maine	Mississippi	North Carolina^
Maryland	Missouri	Ohio^
Massachusetts	Montana	Oregon
Michigan	Nebraska	Rhode Island*
Minnesota	Nevada	South Carolina^
Mississippi	New Jersey	South Dakota^
Missouri	New Mexico	Texas
Montana	New York	Utah*
Nebraska	North Carolina	Vermont*
Nevada	Ohio	**Canadian Provincial Agencies**
New Hampshire	Oregon	British Columbia
New Jersey	Pennsylvania	Saskatchewan
New York	South Carolina	New Brunswick
North Carolina	South Dakota	**Toll and Turnpike Authorities**
North Dakota	Tennessee	Florida's Turnpike Enterprise
Ohio	Texas	Illinois State Toll Highway Authority
Pennsylvania	Virginia	Kansas Turnpike Authority
South Carolina	Washington	New York State Thruway Authority
South Dakota	West Virginia	North Texas Tollway Authority
Virginia	Wisconsin	Oklahoma Turnpike Authority
Washington	Wyoming	
West Virginia		
Wisconsin		
Wyoming		

^ Indicates states that responded to all three surveys.
* Indicates states that responded only to the 2009 survey.

Table 3-2. Changes in median design policies between 2006 and 2009 indicated by state agencies that responded to the 2009 survey.

Response	Number (percentage) of highway agencies
No change in policy since 2006	11 (50.0)
Policies have changed since 2006	3 (13.6)
No response	8 (36.4)
Total	22 (100.0)

Table 3-3. Response from specific state agencies about changes in median cross-section design policies from 2003 to 2006 and from 2006 to 2009.

Agency	2006 Response	2009 Response
Alabama	No change from 2003	Did not complete 2009 survey
Alaska	Did not complete 2006 survey	Did not respond to this question
Arizona	Did not complete 2006 survey	Did not respond to this question
Arkansas	Did not respond to this question	Did not complete 2009 survey
California	No change from 2003	Did not complete 2009 survey
Colorado	Did not complete 2006 survey	Did not complete 2009 survey
Connecticut	No change from 2003	Did not complete 2009 survey
Delaware	New policies or practices since 2003	Did not complete 2009 survey
Florida	Did not respond to this question	No change from 2006
Georgia	Did not complete 2003 or 2006 survey	Did not respond to this question
Hawaii	Did not complete 2006 survey	Did not complete 2009 survey
Idaho	Did not respond to the 2003 survey	Did not complete 2009 survey
Indiana	New policies or practices since 2003	No change from 2006
Iowa	New policies or practices since 2003	No change from 2006
Kansas	Did not complete 2006 survey	Did not complete 2009 survey
Kentucky	Did not respond to the 2003 survey	No change from 2006
Maine	No change from 2003	Did not complete 2009 survey
Maryland	Did not respond to the 2003 survey	No change from 2006
Massachusetts	Did not complete 2006 survey	Did not respond to this question
Michigan	No change from 2003	Did not respond to this question
Minnesota	New policies or practices since 2003	Did not complete 2009 survey
Mississippi	No change from 2003	New policies or practices since 2006
Missouri	New policies or practices since 2003	Did not complete 2009 survey
Montana	No change from 2003	No change from 2006
Nebraska	New policies or practices since 2003	Did not complete 2009 survey
Nevada	No change from 2003	Did not complete 2009 survey
New Jersey	New policies or practices since 2003	Did not complete 2009 survey
New Hampshire	Did not complete 2006 survey	Did not complete 2009 survey
New Mexico	No change from 2003	New policies or practices since 2006
New York	New policies or practices since 2003	Did not complete 2009 survey
North Carolina	No change from 2003	No change from 2006
North Dakota	Did not complete 2006 survey	Did not complete 2009 survey
Ohio	No change from 2003	No change from 2006
Oregon	Did not respond to the 2003 survey	New policies or practices since 2006
Pennsylvania	No change from 2003	Did not complete 2009 survey
Rhode Island	Did not complete 2003 or 2006 survey	Did not respond to this question
South Carolina	No change from 2003	No change from 2006
South Dakota	New policies or practices since 2003	No change from 2006
Tennessee	No change from 2003	Did not complete 2009 survey
Texas	Did not respond to the 2003 survey	No change from 2006
Utah	Did not complete 2003 or 2006 survey	Did not respond to this question
Vermont	Did not complete 2003 or 2006 survey	Did not respond to this question
Virginia	Did not respond to the 2003 survey	Did not complete 2009 survey
Washington	Did not respond to the 2003 survey	Did not complete 2009 survey
West Virginia	New policies or practices since 2003	Did not complete 2009 survey
Wisconsin	New policies or practices since 2003	Did not complete 2009 survey
Wyoming	New policies or practices since 2003	Did not complete 2009 survey

3.3.2 Median Barrier Design Criteria

Respondents were asked whether their agency uses design criteria for highway median barriers that differ from the AASHTO *Roadside Design Guide (46)*. There were 18 responses to this question. One state highway agency and two Canadian provincial agencies responded that they had median barrier design criteria that differed from that provided in the AASHTO *Roadside Design Guide*. All responses to this question are summarized in Table 3-5.

3.3.3 Median Barrier Warrant Criteria

Highway agencies were asked in both the 2003 and 2006 surveys if they used the median barrier warrants in the 2002 AASHTO *Roadside Design Guide*. Table 3-6 indicates that 20 of the 30 states (66.7 percent) that responded to the question in at least one of the two surveys indicate that they use the AASHTO median barrier warrants. In the 2009 survey, the question was asked in an open-ended format. Agencies were asked simply to identify any median barrier warrants that their agency uses. Twelve agencies, including seven state highway agencies, responded to the 2009 question. Three state agencies and one toll agency indicated, in response to the open-ended question, that they use AASHTO median barrier warrants. All responses to this question in the 2009 survey are combined with the responses from the 10 states that indicated they did not use the AASHTO median barrier warrants in the 2003 and 2006 surveys. The responses are shown in Table 3-7 and include the most recent response

Table 3-4. Survey responses concerning use of AASHTO *Green Book* for median design criteria.

		Response	
Agency	Agency type	Design criteria different from AASHTO *Green Book*	Agency design criteria
Alaska	State Highway Agency	No	
Arizona	State Highway Agency	No	
Georgia	State Highway Agency	Yes	From the GDOT Design Policy Manual available through the following link: http://www.dot.ga.gov/doingbusiness/PoliciesManuals/roads/Pages/DesignPolicies.aspx 6.8. Medians–Several factors will be considered when determining the applicable median treatments, such as classification of roadway, number of lanes, base year traffic, design year traffic, posted speed limit, design speed limit, and accident/crash data. Below are the roadway classifications and the median guidelines for those classifications. 6.8.1. Interstate Medians–All Interstates shall require a depressed median, as specified in the AASHTO *Green Book* (2004), or positive barrier separation in areas of right-of-way restrictions. Positive barrier separation is required for all median widths ≤ 52-ft or where mutually exclusive clear zone for each direction of traffic cannot be obtained. Positive barrier separation will not be required for median widths > 64-ft. Median barrier is optional for median widths between 52-ft and 64-ft. Positive barrier separation should be considered for all existing medians where there is a history of cross-median type accidents. 6.8.2. Arterial (Non-GRIP) Medians with Posted Speeds or Design Speeds < 45 mph Median ADT (Base Year) ADT (Design Year) 5-lane section (paved median) < 18,000 < 24,000 5-lane section (paved median) (1) < 18,000 > 24,000 20-ft raised median (2) > 18,000 > 24,000 **NOTES:** (1) The project shall be designed to incorporate a future 20-ft raised median or preferably a 24-ft raised median depending on impacts. Right-of-way shall be purchased for footprint determined by raised 20-ft or 24-ft median typical section. The need and implementation of a raised median section shall be determined by monitoring of accidents and traffic volumes on a 5-year cycle by the Safety Engineer in the GDOT Office of Traffic Operations. (2) GDOT prefers the use of a 24-ft raised median if there are minimal impacts associated with a wider median. Raised medians shall be constructed on multilane facilities at intersections that exhibit one of the following characteristics: high turning volumes relating to 18,000 ADT (base year) and 24,000 ADT (design year) accident rate greater than the state average for its classification excessive queue lengths (as determined by District Traffic Engineer) in conjunction with excessive number of driveways.

Table 3-4. (Continued).

Agency	Agency type	Response Design criteria different from AASHTO *Green Book*	Agency design criteria
			All arterials with design speeds greater than 45 mph will require: a 24-ft raised median with a sloped curb (Type 7 curb-face), which will require a 2-ft additional paved shoulder offset from the edge of travel to the edge of the gutter (4-ft inside shoulder width from the edge of travel to the face of the curb). A 44-ft depressed median or a positive barrier system depending upon functional classification, the type of development along the corridor, type of access management and right-of-way impacts. All multilane facilities with three or more lanes in each direction shall include positive separation of opposing traffic using a median. The type of median required shall depend on guidelines stated above. All rural multilane roadways interchanging with an Interstate highway shall have a raised median for a minimum distance of 1,000 ft from the ramp termini or the first major intersection. A median break may be provided in accordance with GDOT's access guidelines.
Massachusetts	State Highway Agency	No	
Mississippi	State Highway Agency	No	
Oregon	State Highway Agency	No	
Rhode Island	State Highway Agency	No	
Vermont	State Highway Agency	No	
Illinois	State Toll Highway Authority	No	
Kansas	Turnpike Authority	No	
New York	Thruway Authority	No	
North Texas	Tollway Authority	No	
Oklahoma	Turnpike Authority	Yes	In the past, medians were 15 ft but since 1991 we use AASHTO.
British Columbia	Canadian Provincial Agency	Yes	http://www.th.gov.bc.ca/publications/eng_publications/geomet/TAC/TAC_2007_Supplement/Ch400-2007.pdf. Please refer to Fig 440.B - 440.D.
Saskatchewan	Canadian Provincial Agency	No	

Table 3-5. Survey responses concerning use of AASHTO Roadside Design Guide for median barrier design criteria.

		Response	
Agency	Agency type	Design criteria different from AASHTO *Green Book*	Agency design criteria
Alaska	State Highway Agency	No	
Arizona	State Highway Agency	Yes	Our guidelines are located at: http://www.azdot.gov/highways/Roadway_Engineering/Roadway_Design/Guidelines/Manuals/PDF/RoadwayDesignGuidelines.pdf Median barriers are covered in Sections 304.4, 305, 305.9, and 305.11. Median barriers shall be installed on: a) Rural high-speed controlled-access highways with a median width 30 ft and less. From > 30 ft to < 50 ft, utilize Figure 6.1 of the AASHTO *Roadside Design Guide*; b) urban freeway sections with median widths 50 ft and less; c) all freeway sections with median widths 75 ft and less when there are three or more through lanes in each direction and natural barriers are not present.
Georgia	State Highway Agency	No	
Massachusetts	State Highway Agency	No	
Michigan	State Highway Agency	No	
Mississippi	State Highway Agency	No	
New Mexico	State Highway Agency	No	
Oregon	State Highway Agency	No	
Rhode Island	State Highway Agency	No	
Vermont	State Highway Agency	No	
British Columbia	Canadian Provincial Agency	Yes	680 mm for roadside barrier; 810 mm for median barrier
New Brunswick	Canadian Provincial Agency	Yes	TAC Geometric Design Guide for Canadian Roads
Saskatchewan	Canadian Provincial Agency	No	
Illinois	State Toll Highway Authority	No	
Kansas	Turnpike Authority	No	
New York	Thruway Authority	No	
North Texas	Tollway Authority	No	
Oklahoma	Turnpike Authority	No	

Table 3-6. Response from specific agencies on whether they use the 2002 AASHTO median barrier warrants from 2003 and 2006 surveys.

Agency	Does your agency use the 2002 AASHTO median barrier warrants?
Alabama (2003)	Yes
California (2003)	No
Delaware (2006)	Yes
Florida (2006)	No
Idaho (2006)	Yes
Indiana (2006)	Yes
Iowa (2006)	Yes
Kentucky (2006)	Yes
Maine (2003)	No
Maryland (2006)	No
Minnesota (2006)	Yes
Mississippi (2003)	Yes
Missouri (2006)	Yes
Montana (2003)	Yes
Nebraska (2006)	Yes
Nevada (2003)	Yes
New Jersey (2006)	No
New York (2006)	No
North Carolina (2003)	No
Ohio (2003)	Yes
Oregon (2006)	No
Pennsylvania (2006)	Yes
South Carolina (2006)	Yes
South Dakota (2006)	Yes
Texas (2006)	Yes
Virginia (2006)	Yes
Washington (2006)	No
West Virginia (2006)	Yes
Wisconsin (2006)	No
Wyoming (2006)	Yes

received from each agency that provided an answer to the question in any of the surveys. The AASHTO median barrier warrants were revised in 2006; however, only one agency that responded in 2006 also responded in 2009, so it is difficult to know if the changes in the median barrier warrants led to changes in the various agencies' warrants.

Table 3-7 summarizes the median barrier warrant criteria of the 10 states that indicated that they do not use the 2002 AASHTO criteria in the 2003 and 2006 surveys, as well as the 12 agencies that responded to the question in the 2009 survey. Where more than one criterion is used by an agency, multiple columns appear in Table 3-7. Factors other than median width that were considered in these criteria included ADT, posted speed limit, cross-median crash rates, location within 1 mile of entrance/exit ramp gore areas, and roadway type (freeway vs. nonfreeway).

For criteria based on median width alone, minimum median widths where barriers are not required ranged from 18 to 64 feet. One state (Maryland) specified that they do not install barrier if the median is more than 75 feet wide.

The remaining survey questions, discussed in the following sections, were unique to the 2009 survey and, therefore, cannot be compared to previous responses.

3.3.4 Factors Contributing to Median Encroachments and Cross-Median Crashes

In the 2009 survey only, respondents were presented a list of factors related to the design of the traveled way and the roadside that may contribute to median encroachments or cross-median crashes. They were asked for their professional opinions regarding which of the factors they believe contribute most to these types of crashes in their states. Responses were marked by indicating how much each factor contributed to these crash types and using a five-point scale. Although the positions on the scale from *least contribution* to *greatest contribution* were not given numerical values on the survey page, they were later assigned ratings 1 through 5 so that an "average rating" could be developed and the factors could be compared. Those factors that were ranked by more agencies as being greater contributors received a higher rating average than did those that were ranked as lower contributors by a majority of respondents. The list of factors, the frequency of responses for each factor, and the average rating for each factor are presented in Table 3-8.

Respondents also were given an opportunity to rank a factor labeled *other* and invited to share what they considered to be contributing factors to median encroachments and cross-median crashes in their states. Other contributing factors named by respondents are listed below; the number in parenthesis indicates the number of agencies identifying that factor:

- Median width (7),
- Excessive speed (5),
- Inattentive/distracted driving (8),
- Driver error (3),
- Weather/road conditions (5),
- Glare/lighting—dawn, dusk, headlights (1),
- Fatigue (3),
- Impaired drivers (3),
- ADT (2), and
- Presence of median barrier (1).

After respondents identified the factors that contribute to median encroachments and cross-median crashes, they were asked if their agencies had taken any measures to address those factors and to share what those measures were. Twenty-four agencies responded to this question and those responses are presented in Table 3-9.

Table 3-7. Median barrier warrant criteria.

Agency	Response			
	Median barrier warrant criteria			
Arizona (2009)	Our guidelines are located at: http://www.azdot.gov/highways/Roadway_Engineering/Roadway_Design/Guidelines/Manuals/PDF/RoadwayDesignGuidelines.pdf Section 304.4 covers median barrier warrants. For items not covered here, we use AASHTO RDG.			
California (2003)	Conduct study if median width is 0 to 20 ft and ADT exceeds 20,000 vehicles per day.	Conduct study if median width is less than 75 ft and ADT exceeds 60,000 vehicles per day.	Study any median with 0.5 cross-median crashes per mile per year or 0.12 fatal crashes per mile per year.	
Florida (2006)	On Interstate, install barrier if median width less than 64 ft; 50 ft on other freeways.	On Interstates and expressways, median barrier is required within 1 mile of exit/entrance gore with one or more cross-median crashes within 5 years.		
Georgia (2009)	For Interstate highways or other grade-separated facilities: less than or equal to 52 ft requires barrier; barrier is optional for median widths greater than 52 ft and less than 64 ft; barrier not required for median widths greater than 64 ft.	Cable barrier is sometimes installed if crash experience indicates the need for median protection.	Depends on AADT and speed for other types of routes.	Refer to Design Policy Manual Section 6.8.2.
Maine (2003)	Install barrier if the median width is < 20 ft and ADT > 20,000.	Install barrier if median width is < 30 ft and ADT > 30,000 vehicles per day.	Barrier optional if width is < 20 ft and ADT is 5,000 to 20,000 vehicles per day.	Barrier optional if median width is 30 ft to 50 ft and ADT > 40,000 vehicles per day.
Maryland (2006)	Install median barrier if width <= 30 ft.	Install median barrier if width > 30 ft but < 50 ft and ADT > 40,000 vehicles per day.	Install median barrier if width > 50 ft but < 75 ft and ADT > 80,000 vehicles per day.	Do not install barrier if median width > 75 ft.
Massachusetts (2009)	Use AASHTO RDG median warrant criteria.			
Michigan (2009)	Michigan DOT uses the median Barrier Warrant specified in the AASHTO *Roadside Design Guide*.	In addition, Michigan DOT utilizes cost-benefit analyses to justify median barrier installations.		
New Mexico (2009)	We do not have any in place but are in the process of developing a policy for median barrier placement.			
New York (2006)	Install barrier if median width < 36 ft and ADT > 20,000 vehicles per day.	Barrier encouraged if median width < 72 ft.	Barrier is optional if median width is < 45 ft and ADT > 10,000 vehicles per day.	

Table 3-7. (Continued).

Agency	Response		
	Median barrier warrant criteria		
North Carolina (2003)	Install barrier if median width < 70 ft.		
Oregon (2009)	Install barrier if median width less than or equal to 60 ft. Over 60 ft base warrant on cross-median collision statistics.		
Vermont (2009)	AASHTO *Roadside Design Guide*		
Virginia (2006)	18 ft		
Washington (2006)	Provide median barrier on multilane highways with full access control with median widths of 50 ft or less and posted speeds of 45 mph or more.	Consider median barrier on highways with wider medians or lower posted speeds when there is a history of cross-median accidents.	Median barrier is not normally placed on collectors or other state highways that do not have limited-access control.
Wisconsin (2006)	On new freeway construction: range (median width, ADT) from (< = 20 ft, > = 20,000 vehicles per day) to (< 60-ft, > = 50,000 vehicles per day)	No retro-fit warrant	
Illinois State Toll Authority (2009)	Use AASHTO barrier warrants.		
New York State Thruway Authority (2009)	In a programmed manner, the Thruway installs median barrier in medians up to 72 ft in width, pursuant to most current New York State DOT criteria.		
North Texas Tollway Authority (2009)	NTTA specifies concrete barrier on all high-speed divided facilities. Barrier is placed on one direction of roadway only.		
Oklahoma Turnpike Authority (2009)	AASHTO and accident data		
British Columbia (2009)	http://www.th.gov.bc.ca/publications/eng_publications/geomet/TAC/TAC_2007_Supplement/Ch600-2007.pdf Please refer to Section 630.		

Respondents were then asked what factors related to driver behavior and weather conditions played a role in median encroachments and cross-median crashes. Response frequency and rating average for each factor are shown in Table 3-10. This question was presented and analyzed in the same manner as the previous question presented in Table 3-8.

Respondents also were given an opportunity to rank a factor labeled *other* and invited to share what they consider to be contributing factors to median encroachments and cross-median crashes in their states. Other contributing factors named by respondents are listed below; the number in parenthesis indicates the number of agencies identifying that factor:

- Driving too fast for conditions/speeding (4),
- Alcohol/substance abuse (3),
- Horizontal curvature (1),
- Poor or inadequate delineation (signs and striping) (1),
- Roadside obstacles (1), and
- Unexpected roadway geometry (1).

Table 3-8. Traveled way and roadside factors contributing to median encroachments and cross-median crashes.

	Number of agencies responding						
Answer options	Greatest contribution (5)	(4)	(3)	(2)	Least contribution (1)	Rating average	Response count
Absence of rumble strips	3	10	5	0	5	3.26	23
Horizontal curves	3	9	6	3	3	3.25	24
Peak-period volumes	4	5	7	4	3	3.13	23
Other unexpected roadway geometry	2	6	8	3	3	3.05	22
Poor roadway delineation	1	8	5	3	4	2.95	21
Left shoulder width	1	6	2	7	5	2.57	21
Posted speed	1	5	5	5	7	2.48	23
Mixture of vehicle types	1	3	4	12	3	2.43	23
Presence of interchange ramps	1	3	5	7	6	2.36	22
Peak-period duration	0	2	9	3	7	2.29	21
Lane drops	1	2	4	6	8	2.14	21
Access control	0	1	6	6	8	2.00	21
Interchange spacing	0	1	5	7	8	1.95	21
Presence of speed-transition zones	0	1	3	8	9	1.81	21
Land use	0	3	2	3	14	1.73	22
Presence of rumble strips	0	0	1	2	19	1.18	22
Other (please specify)	12	3	0	0	0	4.80	15
						answered question	**26**
						skipped question	**5**

3.3.5 Availability of Safety Evaluations and Maintenance Records

Respondents were asked whether their agencies had conducted any published or unpublished safety evaluations of the factors listed above, or whether their agencies had any data to support the professional opinions given above regarding factors that contribute to median encroachment and cross-median crashes. Of the 27 agencies that responded to the question, 10 answered *yes.* Of those 10 respondents, 4 state highway agencies, 1 toll agency, and 2 Canadian provincial agencies provided further explanation. Their responses are shown in Table 3-11.

Respondents were asked whether their agencies had maintenance records in a form that could be used to identify locations in highway medians with high frequencies of encroachments. Of the 26 agencies that responded, 9 indicated that those types of records were available, and 13 agencies provided further explanation. The responses to this question can be found in Table 3-12.

Many highway agencies use rumble strips on the median shoulder to reduce the frequency of median encroachments and use median barriers, where warranted, to reduce the severity of crashes resulting from such encroachments. Survey respondents were asked whether their agencies used countermeasures other than rumble strips and median barriers intended specifically to reduce the frequency and severity of crashes resulting from median encroachments. Out of the 25 responding agencies, six replied that they did use countermeasures other than rumble strips and median barriers to reduce the frequency and severity of median encroachments. The responses are shown in Table 3-13.

After responding to the question asking about the use of countermeasures other than rumble strips and median barriers to reduce the rate or severity of median encroachments and cross-median crashes, agencies were asked if they had conducted any formal evaluations of the countermeasures they identified. The responses of the six agencies that identified alternative countermeasures above are shown in Table 3-14. The agencies were asked to provide information about, or a copy of, their evaluations, and the comments received in response to this request also are shown in the table. Only one agency indicated that formal evaluations had been conducted of these countermeasures.

Finally, survey respondents were asked to provide any additional information that they believe might be relevant

Table 3-9. Measures taken to address factors that contribute to median encroachments and cross-median crashes by highway agency.

Agency	Description of Measures
Arizona	Relocated median cable barrier from center of median to edge of shoulder.
Florida	1. Require shoulder rumble strips on center of all freeways and more recently require audible-vibratory edge lines on non-limited-access rural roads. 2. Require median barrier on limited-access roadways with less than 64-ft median width. 3. Require median barrier within 1 mile of interchanges where there is any history of cross-median crashes.
Georgia	Inclusion of rumble strips on all shoulders 4 ft or wider. Addition of cable barrier in areas with higher crash experience.
Indiana	We are deploying approximately 360 mi of median cable barrier to segments of Interstate highway that have a significant history of cross-median crashes. We are also reviewing our rumble strip policy.
Iowa	Added shoulder rumble strips and have begun to add median cable
Kentucky	Speed blitzes, installed cable median barrier
Maryland	Since 2005, we have established a special funding category to address traffic barriers throughout the state. The funding is to install new and/or upgrade existing barrier to meet today's standards and criteria. We have been focusing our efforts to install median barrier on divided highways with narrow medians, high speeds, and high volumes of traffic.
Massachusetts	During resurfacing projects, we try to reclaim shoulder width. We try to delineate the horizontal curves.
Michigan	Michigan DOT has taken steps to reduce median crossover crashes by installing centerline rumble strips, enhancing roadway delineation, and installing median barrier where deemed appropriate.
Mississippi	We have started placing cable barrier in locations as needed.
Montana	We install rumble strips on both the outside and median shoulder on all Interstate projects. We also are developing criteria to determine where the installation of median rail would be beneficial.
New Mexico	In determining locations for test sections for median barrier we identified locations with a history of median crossover crashes. Many of these locations occur on either horizontal curves or on stretches of Interstate highways where we have had a history of lane departures, many attributed to driver fatigue. The state's Highway Safety Improvement Program has placed a priority on projects addressing lane departures.
Ohio	We are installing cable guardrail in our high crossover sections.
Oregon	Mandatory closure for any median 18 m (60 ft) in width or less (fogline to fogline) policy statement (see attached Q No. 6).
South Carolina	SCDOT has developed a project to install rumble strips along all suitable four-lane divided highways. We also are conducting corridor studies on four-lane divided roads to systematically install offset left turn lanes
Texas	Developed a rumble strip policy. Revised the median barrier policy. Funding towards installation of median barriers/cable barrier.
Vermont	Increased delineation, shoulder rumble strips from engineering perspective. General increase in safety awareness through Strategic Highway Safety Plan, none directly related to median crashes.
Illinois State Toll Highway Authority	The Tollway has always had full roadway delineation using crystal amber reflectors on the left and white on the right. Skip-dash striping is 6" in width with a 25 ft stripe/25 ft space pattern. On all pavement, raised pavement markers are installed in conjunction with skip dash striping. The Tollway employs continuous shoulder edge rumble strips on both right and left shoulders, both directions on all mainline and directional, high-speed ramps. In urban/suburban segments of our system with ADT greater than 70,000 vehicles per day, the Tollway has installed continuous concrete barrier median protection. In rural segments, cable median barrier has been installed over the past 3 to 4 years. The Tollway currently has 100 percent median protection.
Kansas Turnpike Authority	Use of rumble strips and roadway delineation
New York State Thruway Authority	Rumble strips
North Texas Tollway Authority	NTTA added concrete barrier to the entire length of the President George Bush Turnpike in 2004. NTTA implements a snow and ice mitigation plan to address roadway conditions.
Oklahoma Turnpike Authority	Using AASHTO
British Columbia	Installed median barriers. Installed rumble strips on median shoulders. Improved delineation.
Saskatchewan	The Ministry has established geometric standards for medians. The Ministry has also established access control standards and policies. All are in an effort to provide a safer road corridor.

Table 3-10. Driver behavior and weather factors contributing to median encroachments and cross-median crashes.

	Number of agencies responding						
Answer options	Most important (5)	(4)	(3)	(2)	Least important (1)	Rating average	Response count
Drive fatigue/drowsiness	8	9	5	3	1	3.77	26
Wet pavement, snow- and ice-covered pavement, or other adverse weather condition	6	6	8	4	2	3.38	26
Previous collision or driver maneuver to avoid a collision	1	3	4	12	4	2.38	24
Other factors [to be specified]	3	3	1	1	2	3.40	10
						answered question	**26**
						skipped question	**5**

to their agency's efforts to reduce the frequency and severity of median encroachments and cross-median crashes. Comments were received from eight agencies as follows:

- **Arizona:** Implemented speed-enforcement cameras on many of our urban freeways.
- **Georgia:** Addressing lane departure crashes using a systemwide approach continues to be an integral part of our Highway Safety Improvement Plan. High crash corridors are identified and reviewed annually to determine appropriate countermeasures.
- **Indiana:** Continuing crash reviews will be conducted on divided highways to determine the need for median barrier and rumble strip deployments.
- **Massachusetts:** We have identified the top median crossover crash locations and then conducted RSAs at these locations. We have developed site-specific countermeasures for these locations including prioritizing (in process) median barrier installation. We have not taken a systemic approach to evaluating median barrier locations.
- **Oregon:** In today's uncertain fiscal climate it is becoming very difficult to push a policy upgrade that could have fiscal impact without proving where funding comes from. Even then, there is turf protection everywhere and I fear that safety upgrades will take the back seat to preservation.
- **South Dakota:** SD Department of Public Safety has been providing a good campaign regarding that drivers need to "Buckle Up." Majority of the fatalities in median encroachments involve rollovers and occupants are ejected due to not using seat belts. Our medians are relatively wide with 1V:6H median inslopes with relatively flat median ditch bottoms.

Table 3-11. Agency responses regarding the availability of safety evaluations related to factors contributing to median encroachment and cross-median crashes.

Agency	Information provided about the availability of safety evaluations
Georgia	Field investigations of areas where wet weather crashes appear to be overrepresented. Format of reports is not conducive to inclusion in this text box, but a contact for obtaining these reports is provided.
Iowa	Increase in cross-median crashes in adverse winter weather can be documented.
New Mexico	Our data is in the form of safety and/or engineering analysis related to applications submitted by our districts for HSIP funding. A copy can be provided; we will need to scan into an email-able file.
Ohio	OH-1 reports (crash reports) from the Ohio Highway Patrol.
Illinois State Toll Highway Authority	Since the Illinois Tollway does not enjoy tort immunity or any other form of protective liability legislation, all such studies and reports are considered draft in nature and hence are privileged and not publicly available.
British Columbia	Attached are the contributing factors for the three regions that cover the province of British Columbia.
Saskatchewan	The Ministry investigates all fatal collisions to determine if the roadway and/or the roadside contributed to the collision. These investigations are not published.

Table 3-12. Availability of maintenance records that would help identify locations of median encroachments and cross-median crashes.

Agency	Are maintenance records available?	Information provided about the availability of maintenance records
Arizona	Yes	There is a spreadsheet that could be used to identify some locations with high encroachments. Data includes route, MP, direction, date. The missing data is the begin date of install and the duration that a location has been in place.
Florida	No	
Georgia	Yes	Highway Maintenance Management System (HMMS) contains location information. Encroachments can be located if they resulted in damages that require repair to signs, guardrail, cable barrier, etc.
Indiana	No	
Iowa	Yes	Already done for 2001 to 2008 crashes.
Kentucky	Yes	Crash through the KY State Police
Maryland	No	Even though statistics are “reported,” the data used to develop statistics is questionable. To my knowledge, the only way to determine if a crash is truly a cross-median fatality or non-fatality is to read through the accident reports that are completed by the State Police and to read the description of what happened. This is a very tedious process and to my knowledge, is not being done.
Massachusetts	No	
Michigan	No	
Mississippi	No	
Montana	No	
New Mexico	No	
Ohio	Yes	All state highways are inspected yearly with GPS to record maintenance problems.
Oregon	No	"No" because some police report location to the nearest mile only.
South Carolina	Yes	SCDOT has installed cable guardrail along the Interstate system where criteria such as median width is met. Our maintenance office keeps records of every median hit along these corridors.
South Dakota	No	
Texas	No	
Vermont	No	Only crash reports
Illinois State Toll Highway Authority	Yes	Since we have full median protection, computerized maintenance records can be used to determine number of hits on cable barrier system and costs to restore. Crash data can be cross-referenced with this repair to further analyze the nature and cause of the encroachment. On concrete median barrier protected areas of the system, crash data can be obtained indicating vehicle vs. barrier median wall.
Kansas Turnpike Authority	No	
New York State Thruway Authority	No	
North Texas Tollway Authority	No	
Oklahoma Turnpike Authority	Yes	Spreadsheet and histories
British Columbia	No	
New Brunswick	Yes	Accident reports
Saskatchewan	No	Our provincial insurance agency, Saskatchewan Government Insurance, maintains a Traffic Accident Information System that contains all reported roadway collisions.

Table 3-13. Countermeasures used to reduce the frequency and severity of median encroachments.

Agency	Are countermeasure records available?	Information provided about the availability of countermeasure records
Arizona	Yes	We have enhanced the delineation of the posts to provide increased awareness for nighttime driving.
Florida	Yes	Audible-vibratory pavement markings
Georgia	Yes	Replacement of select median drainage structures, vegetation removal. In some cases, median barriers were removed from wide medians where absence of barrier would result in less serious crashes.
Indiana	No	
Iowa	Yes	For the most part, Iowa four-lane divided rural roadways were built with wider than "normal" (at the time) medians to mitigate cross-median multi-vehicle crashes.
Kentucky	No	
Maryland	No	
Massachusetts	No	
Michigan	No	
Mississippi	Yes	Cable barrier
Montana	No	
New Mexico	No	
Ohio	No	
Oregon	Yes	Raised median berm, but it is too low and the slopes are too flat to be effective. It is slated to be replaced with barrier.
South Carolina	No	
South Dakota	No	
Texas	No	
Vermont	No	
Kansas Turnpike Authority	No	
New York State Thruway Authority	No	
North Texas Tollway Authority	No	
Oklahoma Turnpike Authority	No	
British Columbia	No	
New Brunswick	No	
Saskatchewan	No	

- **Illinois State Toll Highway Authority:** The Tollway has installed a network of 39 over-the-road dynamic message signs prior to all system (Interstate to Interstate) interchanges. These signs are used 24/7 to provide motorists information regarding road conditions, travel times, and incidents—with a small percentage of information for safety messages. Regular relevant messaging to the motorists can enhance their attention to driving and potentially changing conditions that we feel can enhance driving safety and reduce encroachments or run-off-road accidents.
- **Kansas Turnpike Authority:** We have installed concrete median barrier the entire length of our roadway.

Table 3-14. Formal evaluations of countermeasures identified in previous question.

Agency	Were evaluations conducted?	Information provided about evaluations
Arizona	No	
Florida	No response	
Georgia	Yes	Benefits of vegetation removal projects were monitored.
Iowa	No	
Mississippi	No	
Oregon	No	FHWA local office has expressed desire to have the berm removed.

SECTION 4

Interdisciplinary Field Reviews

This section of the report describes the field data collection methodology and presents the results of the interdisciplinary field reviews conducted as part of the current research. The section includes an overview of the interdisciplinary field review approach, a description of the site selection activities, a description of the interdisciplinary investigations, and a summary of the results obtained.

4.1 Overview of Interdisciplinary Field Review Approach

Interdisciplinary field reviews were conducted for more than 40 divided highway sites with high frequencies of median-related crashes to identify the most common contributing factors to those crashes. The sites with high frequencies of median-related crashes were identified using the network screening algorithms developed to identify sites with high crash frequencies in the *Safety Analyst* software tools for safety management of specific highway sites (*51*). The selected sites all had relatively high frequencies of median-related crashes, but were not necessarily, in all cases, the sites with the highest median-related crash frequencies. Copies of police crash reports, including the officer's narrative description of the crash, were obtained for all median-related crashes that occurred at each site during a period of 3 to 5 years. An interdisciplinary team consisting of a highway traffic engineer specializing in crash analysis and highway geometric design, and a human factors engineer specializing in driver behavior studies, reviewed all of the crash reports and visited each site in the field to review the geometric design and traffic control features of the site, the characteristics of the specific crash locations, and observable traffic patterns. Based on these reviews, the interdisciplinary team classified the workload level for drivers traversing the site, and identified specific roadway factors that explain the driver workload level and contributed to the occurrence of the crashes. In subsequent tasks, described in Section 5 of this report, the research team investigated whether the contributing factors observed at the selected field sites are overrepresented in median-related crashes at these sites (i.e., whether the identified factors are, in fact, associated with increased likelihood of median-related crashes). Section 6 of the report identifies countermeasures that address the contributing factors and, therefore, might be used to reduce median-related crashes.

4.2 Site Selection for Interdisciplinary Field Reviews

Sites for the interdisciplinary field studies were sought in four states: California, Missouri, Ohio, and Washington. Network screening analyses were conducted for divided highways on the entire state highway systems of these states to identify sites with high median-related crash frequencies. Separate analyses were conducted for rural freeways, other rural divided highways (nonfreeways), and urban freeways. The network screening analyses for divided highways in each state were conducted with network screening procedures based on both the peak-searching and sliding-window algorithms developed by Harwood et al. (*51*) in FHWA research for use in the *Safety Analyst* software tools for safety management of specific highway sites. The network screening analyses were not conducted with the *Safety Analyst* software, but rather by using the published network screening algorithms programmed in the SAS software package. Roadway, traffic volume, and crash data for these analyses were obtained for California, Ohio, and Washington from the FHWA HSIS, and for Missouri from the MoDOT Transportation Management System (TMS).

The network screening analyses identified sites with high frequencies of median-related crashes that were sorted in descending order of median-related crash frequency per mile per year. Each site consisted of a directional divided highway segment (i.e., the roadway in one direction of travel on a divided highway), generally at least 1.6 km (1.0 mi) in length. The interdisciplinary field study sites were selected from among these high crash frequency sites. The research team sought a minimum of 10 study sites in each state. A total of 47 sites were selected for evaluation, as follows:

• California	10 sites,
• Missouri	12 sites,
• Ohio	13 sites, and
• Washington	12 sites.

These sites do not necessarily represent the sites with the very highest median-related crash frequencies in each state. This is due to the fact that geographic locations of the sites were considered in site selection so that it would be feasible for the interdisciplinary team to visit all sites in a given state during a 1-week period. Sites were selected so that each site experienced at least 10 median-related crashes over a 5-year period. The majority of the sites were located on rural freeways. Finally, selections were made to ensure that the overall set of sites included some rural divided highways (nonfreeways), some urban freeways, and a range of median types, median widths, and terrain types.

4.3 Interdisciplinary Field Review Procedure

The object of the interdisciplinary field reviews was to identify factors associated with median encroachments, especially those associated with the initiation of cross-median crashes at sites with higher-than-expected crash frequencies identified through a screening of all potential sites. This review addressed both engineering and human factors considerations and was conducted by an interdisciplinary team that included engineers from MRIGlobal and human factors specialists from Human Factors North.

The interdisciplinary review considered geometric design, traffic control, and traffic operational, weather, and driver condition factors and involved a review of hard-copy police crash reports, video logs of crash sites, and aerial photographs prior to field visits to crash sites. These office reviews were performed first and led to a decision as to which sites were most suitable for field visits.

The interdisciplinary team visited all sites in a particular state on a single trip and spent a sufficient amount of time at each site to collect geometric data, observe traffic behavior at various locations, videotape a drive-through of the site from the driver's perspective, and—when appropriate—collect speed data. The specific nature of the reviews conducted at each site was based on the crash history of the site; however, the general plan for the field investigations follows. The interdisciplinary field investigations included consideration of four elements.

- Driver tasks and information requirements,
- Traffic operations,
- Roadway and roadside design, and
- Environmental considerations.

A critical aspect of the field investigation was the systematic examination of the driver's task in negotiating the location under investigation. Driver tasks involve all the potential tasks that a driver might make through a site. On a freeway, this could include sign reading, merging, lane changing, passing, slowing, and exiting. Because a majority of collisions involved human error, the team took opportunity to drive through the site multiple times to understand the level of workload required of a driver. The investigators were adequately prepared with an understanding of collision history and patterns for the site, as well as potential performance issues. It was during these runs that the human factors expertise was the focal point of the investigation. The goal of the drive-through was to

- Experience the site from the perspective of the highway user, keeping in mind unfamiliar users.
- Identify highway elements and roadside features that may be contributing to driver error—in particular, to note usual highway designs that may violate driver expectations (e.g., left exits on freeways, traffic queuing at an exit ramp, drivers entering the freeway at low speeds because of short acceleration lanes, drivers changing lanes at the last second because of inadequate bullnose-to-bullnose separation or inadequate placement of guide signs, etc.); features, such as an usually sharp curve, that are different from what the driver might expect given experience of the road upstream; and cues that may mislead the driver about the actual road alignment (e.g., tangential exit ramp within mainline curves).
- Check adequacy of sight distances to hazards such as lane drops, lane splits, bridges, tunnels, and work zones.
- Check sufficient warning is given for hazards, especially at night, and especially for hazards featured in past collisions.
- Check that signs are conspicuous, especially in cluttered backgrounds; easily understood; legible at the point at which the driver needs the information to make lane changes or other maneuvers; and spaced to allow easy reading.
- Check that markings are clearly visible and likely to be understood by unfamiliar drivers.
- Determine whether driver attention is distracted at critical points when it should be focused elsewhere (e.g., a billboard to the right, when the driver is approaching an interchange with the potential of slowing traffic ahead).

- Consider work zone issues (signing, marking, lane closures, and lane re-alignments) that may have contributed to past collisions and may contribute to future ones.

The team used a head-mounted audio and video recorder, as show in Figure 4-1, to record the site from the perspective of the driver. A video recording of the location was made to create a permanent record of each study site for review in the office. The video recording included a time and date stamp and a view of the roadway as seen from the driver perspective (recorded with a camera attached to the frame of glasses worn by the driver). At the beginning of filming each section of roadway, the observer noted the following:

- Site and location identifications,
- Direction of the approach, and
- Numbers of collisions associated with the approach.

During filming of each section of roadway, the investigating team also noted the following:

- Sight distance to hazards and
- Legibility distance of signs and markings.

The verbal commentary that accompanied the video recording was important because not all signs, signals, and markings are as visible on the video as they are to the human eye. Among other observations, the team noted when various hazards can be seen by the naked eye, and when signs are first legible.

Figure 4-1. Head-mounted audio and video recorder.

These interdisciplinary site reviews at locations with a high frequency of median-related or cross-median crashes lead the researchers to identify factors related to high driver-workload conditions, such as the presence of interchange ramps, horizontal curves, lane drops, or combinations of these factors. These reviews were conducted in an unbiased manner, and the study team was careful that their findings were not shaped by preconceptions as to which factors might prove to be important. This approach gave an opportunity for unanticipated factors to come to light.

Based on the contributing factors identified (or the absence of factors), the field visits, and review of the videos, the interdisciplinary review team classified the driver workload at each site into one of seven categories based on task difficulty in relation to road design, as follows:

- Very low driver workload—straight and level, no entrances or exits, no lane drops;
- Low driver workload—generally straight or gentle curves, gentle grade, may include exit to/entrance from rest area;
- Low-to-moderate driver workload—generally straight or gentle curves, some grade, may include bridges or an exit to/entrance from a rest area, widely separated interchanges;
- Moderate driver workload—gentle curves, moderate grade, compound curves, interchanges more than 2 miles apart, lane additions or lane drops, bridges;
- Moderate-to-high driver workload—gentle curves, moderate grade, compound curves, interchanges 1.5 to 2 miles apart, entrances with short acceleration lanes, lane addition or lane drops, bridges;
- High driver workload—gentle curves, moderate grade, compound curves, interchanges less than 1.5 miles apart, lane additions or lane drops, difficult merging conditions (e.g., merging or curves or grades, or with short acceleration lanes), bridges; and
- Very high driver workload—sharp curves, steep grades, interchanges less than 1 miles apart, compound curves, lane additions or lane drops, bridges, inappropriate superelevation, entrance or exit ramps with sharp curves.

In selecting the appropriate category, attention was paid not only to which geometric design elements were present, but their number, combination, and severity. Road condition also contributes to driver workload, with wet, snowy, and icy roads demanding more attention due to a lower coefficient of friction. Similarly, dense traffic will contribute to increased workload. With all these factors in mind, a global estimate was made of workload severity.

Finally, it should also be noted that driver workload is a product of not only task difficulty, but also of driver effort and arousal. An easy task may be more difficult for an older, impaired, unfamiliar driver in comparison to a difficult task for a middle-aged, sober, and familiar driver. We assume that generally there are equal numbers of such drivers exposed to easy and difficult driving tasks, although this is not always true. Younger drivers do more of their driving at night as compared to middle-aged drivers, and older drivers do less of their driving in high-volume, poor traffic conditions as compared to middle-aged drivers. Generally, however, it is reasonable to assume that there are similar proportions of low-effort, low-arousal drivers on various sections of roadway.

In addition to driving through the site multiple times, the team observed traffic operations from a convenient vantage point and took geometric field measurements for important elements, including grade, shoulder width, ramp spacing, and curve radii for locations and elements that could not be measured in the office using aerial photographs or project plans. When a feature of potential interest—such as an interchange ramp or a horizontal curve—was found to be present at a site, the team took time to study that feature in detail to determine whether and how it might be contributing to the initiation of median encroachments that may potentially lead to cross-median crashes. Depending on the nature of the location and its crash history, this review focused on geometric design elements, design dimensions, spacing between adjacent design elements, traffic operational conditions (including time-of-day variations), signing, marking, speed zoning, speed transitions, lighting, pavement conditions, sun angle, and surrounding development.

An important aspect of the interdisciplinary review was looking for evidence of median encroachments that did not result in reportable crashes. Such evidence may have included damaged roadside hardware, tire marks, or tire tracks. These "encroachment indicators" can furnish a qualitative idea of the encroachment level at a site without a quantitative measurement of encroachment frequency.

4.4 Site Characteristics for Interdisciplinary Field Review Sites

Table 4-1 presents a summary of the characteristics of the 47 interdisciplinary field sites, including state, route, county, direction of travel, length, roadway type, median type, median width, and directional annual average daily traffic volume (AADT). The overall distribution of site characteristics is as follows:

- Total length: 97.4 miles;
- Average site length: 2.1 miles (range: 0.7 to 10.7 miles);
- Directional AADT: Range: 7,500 to 229,000 vehicles per day; and
- Median width: Range: 16 to 160 feet.

Roadway Type

- Rural freeways: 69.9 miles (72 percent);
- Rural divided nonfreeways: 11.1 miles (11 percent); and
- Urban freeways: 16.4 miles (17 percent).

Terrain Type

- Mountainous: 6.2 miles (6 percent) and
- Level/rolling: 91.2 miles (94 percent).

Median Type

- Traversable: 11.6 miles (12 percent);
- Nontraversable: 10.2 miles (10 percent);
- Barrier: 75.6 miles (78 percent);
  - Guardrail: 4.3 miles (4 percent);
  - Concrete Barrier: 28.0 miles (29 percent); and
  - Cable Barrier: 43.3 miles (45 percent).

4.5 Interdisciplinary Field Review Results

Table 4-2 identifies the classification of driver workload made for each site by the interdisciplinary review team and the contributing factors on which that classification was based. Tables 4-3 and 4-4 present individual contributing factors and combined contributing factors, respectively. No contributing factors to increasing workload were noted for roads that were essentially level and straight and without interchanges.

Table 4-5 presents a frequency distribution of contributing factors that includes both individual and combined contributing factors. Table 4-6 presents a frequency distribution for the individual contributing factors.

4.6 Interdisciplinary Crash Review Results

Table 4-7 summarizes the median-related crash frequencies for the interdisciplinary field review sites, based on crash data for a 5-year period. Median-related crashes are defined in this study as crashes in which one or more of the involved vehicles left the roadway and entered the highway median. Crashes have been classified into categories based on crash initiation type (single-vehicle loss of control vs. vehicle interaction) and pavement surface condition (dry conditions vs. wet conditions).

4.6.1 Crash Initiation Type

Crash initiation type was categorized based on review of police crash reports, including review of the investigating officer's narrative description of the crash. Single-vehicle loss-of-control crashes are those in which a vehicle left the roadway for reasons that appear unrelated to the action of any

Table 4-1. Characteristics of field study sites.

Site number	County	Route	Direction of travel	Length (mi)	Roadway type	Median type[a]	Median width (ft)[a]	Directional AADT (veh/day)
California Sites								
CA01	Merced	I-5	NB	2.0	Rural Freeway	Traversable	75	39000
CA02	Merced	I-5	NB	2.0	Rural Freeway	Guardrail	80	39000
CA04	Sacramento	I-5	NB	2.0	Rural Freeway	Traversable	70	58000
CA05	Shasta	I-5	NB	1.0	Rural Freeway	Concrete Barrier	40	61000
CA07	Shasta	I-5	NB	2.0	Urban Freeway	Traversable	30	61000
CA10	San Joaquin	SR 99	NB	1.0	Rural Freeway	Concrete Barrier	20	75000
CA11	San Joaquin	SR 99	NB	1.0	Urban Freeway	Concrete Barrier	20	72000
CA13	San Joaquin	SR 99	NB	1.0	Urban Freeway	Concrete Barrier	10	67000
CA14	San Joaquin	SR 99	NB	1.0	Rural Freeway	Concrete Barrier	10	67000
CA15	San Joaquin	SR 99	NB	1.0	Rural Freeway	Concrete Barrier	10	64000
Missouri Sites								
MO01	Franklin	I-44	EB	2.0	Rural Freeway	Cable Barrier	30	15000
MO02	Franklin	I-44	EB	3.0	Rural Freeway	Cable Barrier	30	17000
MO03	Johnson	US 50	EB	2.0	Rural Divided Nonfreeway	Traversable	100	7500
MO04	Johnson	US 50	EB	3.6	Rural Divided Nonfreeway	Traversable	50	7000
MO05	Lafayette	I-70	EB	10.7	Rural Freeway	Cable Barrier	30	20000
MO06	Boone/Callaway	I-70	EB	2.0	Rural Freeway	Cable Barrier	30	17000
MO07	Callaway	I-70	EB	2.0	Rural Freeway	Cable Barrier	30	15000
MO08	Callaway	I-70	EB	2.0	Rural Freeway	Cable Barrier	30	11000
MO09	Montgomery	I-70	EB	2.0	Rural Freeway	Cable Barrier	30	11000
MO10	Montgomery	I-70	EB	2.0	Rural Freeway	Cable Barrier	30	15000
MO11	St Charles	I-70	EB	2.1	Urban Freeway	Concrete Barrier	16	80000
MO12	Clay	I-35	SB	3.0	Urban Freeway	Concrete Barrier	25	36400
Ohio Sites								
OH01	Ashland	I-71	NB	1.0	Rural Freeway	Cable Barrier	40	42000
OH02	Butler	I-75	NB	1.0	Urban Freeway	Concrete Barrier	38	97000
OH03	Butler	I-75	NB	1.0	Urban Freeway	Concrete Barrier	34	97000
OH04	Clark	I-70	NB	1.0	Rural Freeway	Cable Barrier	75	57000
OH05	Clark	I-70	NB	1.0	Rural Freeway	Cable Barrier	75	57000
OH06	Montgomery	I-675	NB	2.1	Urban Freeway	Cable Barrier	80	40000
OH07	Montgomery	I-75	NB	1.0	Urban Freeway	Cable Barrier	150	96000
OH08	Montgomery	I-75	NB	1.0	Urban Freeway	Cable Barrier	160	104000
OH09	Montgomery	I-75	NB	1.0	Urban Freeway	Cable Barrier	50	104000
OH10	Montgomery	I-75	NB	1.0	Urban Freeway	Cable Barrier	50	104000
OH11	Richland	I-71	NB	1.0	Rural Freeway	Cable Barrier	40	40000
OH12	Richland	I-71	NB	1.0	Rural Freeway	Cable Barrier	30	39000
OH13	Richland	I-71	NB	1.0	Rural Freeway	Cable Barrier	30	40000
Washington Sites								
WA02	Cowlitz	I-5	NB	7.2	Rural Freeway	Concrete Barrier	30	45000
WA03	King	I-5	SB	1.1	Urban Freeway	Concrete Barrier	20	229000
WA04	King	I-5	NB	0.7	Urban Freeway	Concrete Barrier	20	208000
WA05	King	I-5	SB	1.4	Urban Freeway	Concrete Barrier	16	211000
WA06	Snohomish	I-5	NB	2.2	Urban Freeway	Concrete Barrier	20	129000
WA07	Skagit	I-5	NB	2.3	Urban Freeway	Guardrail	42	62000
WA08	Grays Harbor	US 12	EB	5.5	Rural Divided Nonfreeway	Cable Barrier	30	19000
WA10	King	I-90	WB	2.8	Rural Freeway	Nontraversable	Variable	56000
WA11	King	I-90	WB	3.5	Rural Freeway	Nontraversable	Variable	56000
WA12	King	I-90	WB	3.9	Rural Freeway	Nontraversable	Variable	30000
WA13	King/Kittitas	I-90	EB	1.0	Rural Freeway	Concrete Barrier	22	30000
WA14	Kittitas	I-90	EB	1.3	Rural Freeway	Concrete Barrier	24	30000

[a] The median type and width represents the character of the median for all or most of the length of the site.

other vehicle. Single-vehicle loss-of-control crashes included crashes initiated by driver inattention, driver distraction, or driver fatigue, as well as other crashes not related to vehicle interactions (e.g., tire blowouts, loss of control on curves, striking or avoiding an animal, etc.). A total of 73 percent of all median-related crashes were classified as single-vehicle loss-of-control crashes. Vehicle-interaction crashes are those in which it appears that the vehicle would not have left the road and entered the median, but for the interaction of that vehicle with other vehicles. This category includes crashes in which there was a collision on the roadway prior to a vehicle entering the median, crashes in which the vehicle that

Table 4-2. Summary of driver workload levels and contributing factors by site.

Site number	Driver workload level	Contributing factors
CA01	Low-Moderate	On-ramp Long tangent On-ramp located after 12-mi level tangent
CA02	Low-Moderate	Horizontal curve Truck stopping area on wide shoulder
CA04	Low-Moderate	Off-ramp On-ramp Bridge
CA05	High	On-ramp Upgrade Bridge On-ramp on upgrade with short acceleration lane upstream of bridge Low-speed merge due to upgrade
CA07	Moderate-High	On-ramp Off-ramp Closely spaced on-ramp followed by off-ramp (short weaving area) Closely spaced on-ramps
CA10	Low	Off-ramp
CA11	Moderate-High	On-ramp Off-ramp Closely spaced on-ramp followed by off-ramp (short weaving area) Limited sight-distance to on-ramp Mainline lane drop
CA13	High	On-ramp Tight radius curve on on-ramp Low-speed merge due to on-ramp curve Off ramp Sag vertical curve
CA14	Moderate-High	On-ramp Off-ramp Bridge Closely spaced on-ramp followed by off-ramp with bridge in short weaving area Tight radius horizontal curve on on-ramp Low-speed merge due to on-ramp curve
CA15	Moderate	Off-ramp On-ramp Low-speed merge due to short on-ramp
MO01	Low	Downgrade Bridge Horizontal curve
MO02	Moderate	Horizontal curve Upgrade Off-ramp On-ramp Crest vertical curve Off-ramp with crest vertical curve that limits sight-distance near start of taper On-ramp on upgrade Low-speed merge due to grade
MO03	Moderate	Curve Intersections Intersection on curve
MO04	Low	Horizontal curve Long tangent Horizontal curve after long tangent At-grade intersections
MO05	Low-Moderate	On-ramp Horizontal curve Downgrade On-ramp on horizontal curve on downgrade Low-speed merge due to mainline curve
MO06	Low	Horizontal curve Downgrade Horizontal curve on downgrade
MO07	Low-Moderate	Off-ramp On-ramp High truck volume on on-ramp
MO08	Very Low	No contributing factors noted

Table 4-2. (Continued).

Site number	Driver workload level	Contributing factors
MO09	Very Low	No contributing factors noted
MO10	Moderate	Horizontal curve Off-ramp On-ramp Trees block sight-distance to on-ramp
MO11	High	Off-ramp On-ramp Horizontal curve Downgrade On-ramp with multilane entrance (three entering lanes) on slight curve on downgrade (curve has influence even though slight) Closely spaced on-ramps Off-ramp with lane-drop exit Bridge
MO12	High	Off-ramp On-ramp Left-side on-ramp Closely spaced on-ramps (one left-side, one right-side) Closely spaced on-ramp followed by off-ramp (short weaving area)
OH01	Low	Bridge
OH02	Low	No contributing factors noted
OH03	Low	No contributing factors noted
OH04	High	On-ramp Off-ramp Off-ramp with short deceleration lane Downgrade Bridge Closely spaced on-ramp followed by off-ramp with bridge between (within full cloverleaf interchange)
OH05	Low	Bridge
OH06	High	On-ramp Horizontal curve Major merge area (two freeways merge) Mainline lane drop On-ramp with tight horizontal curve Low-speed merge due to on-ramp curve Closely spaced on-ramps
OH07	Moderate	Off-ramp On-ramp Bridge Downgrade
OH08	Moderate	Upgrade Bridge Horizontal curve Crest vertical curve Off-ramp Off-ramp at crest vertical curve on horizontal curve On-ramp
OH09	Low	No contributing factors noted
OH10	Moderate	Sharp horizontal curve Off-ramp
OH11	Low-Moderate	Off-ramp On-ramp Horizontal curve
OH12	Moderate	Off-ramp Horizontal curve
OH13	Moderate-High	Bridge On-ramp Downgrade Closely spaced on-ramps
WA02	Low-Moderate	Off-ramp On-ramp Bridge

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Table 4-2. (Continued).

Site number	Driver workload level	Contributing factors
WA03	Very High	Tunnel HOV lane Off-ramp Closely spaced off-ramps Off-ramp with multilane exit Off-ramp with lane-drop exit Horizontal curve
WA04	High	Downgrade Horizontal curve On-ramp Off-ramp Downgrade ending in horizontal curve Left-side on-ramp Closely spaced on-ramp followed by off-ramp (one left-side, one right-side)
WA05	High	On-ramp Off-ramp Left-side off-ramp Off-ramp with lane-drop exit Horizontal curve Downgrade Sag vertical curve On-ramp with merge area in sag vertical curve
WA06	High	Downgrade On-ramp Off-ramp Off-ramp with multilane exit Off-ramp with lane-drop exit Bridge Closely spaced on-ramp followed by off-ramp with two-lane lane-drop exit
WA07	Moderate	Narrow bridge Off-ramp Downgrade Off-ramp just beyond narrow bridge on downgrade Off-ramp with multilane exit On-ramp
WA08	Low-Moderate	At-grade intersections
WA10	Moderate	Downgrade On-ramp Sharp horizontal curve On-ramp with high truck volume Sharp horizontal curve on downgrade Sag vertical curve Upgrade
WA11	Moderate	On-ramp Horizontal curve Downgrade Crest vertical curve On-ramp on mainline curve on downgrade Upgrade Horizontal curve at crest vertical curve Long horizontal curve (90^{o} turn) Truck stopping area on wide shoulder
WA12	Moderate-High	Steep downgrade Horizontal curve Horizontal curve on steep downgrade Site begins downstream of an on-ramp
WA13	High	Upgrade Downgrade Sharp horizontal curve Off-ramp Off-ramp on horizontal curve on downgrade
WA14	High	Horizontal curve Off-ramp Reverse curves (four in sequence) Off-ramp on horizontal curve Downgrade

Note: Contributing factors with combined effects are noted together.

Table 4-3. Summary of driver workload levels and individual contributing factors by site.

Site number	Driver workload level	Individual contributing factors
CA01	Low-Moderate	On-ramp Long tangent
CA02	Low-Moderate	Horizontal curve Truck stopping area on wide shoulder
CA04	Low-Moderate	Off-ramp On-ramp Bridge
CA05	High	On-ramp Upgrade Bridge
CA07	Moderate-High	On-ramp Off-ramp
CA10	Low	Off-ramp
CA11	Moderate-High	On-ramp Off-ramp Mainline lane drop
CA13	High	On-ramp Off ramp Sag vertical curve
CA14	Moderate-High	On-ramp Off-ramp Bridge
CA15	Moderate	Off-ramp On-ramp
MO01	Low	Downgrade Bridge Horizontal curve
MO02	Moderate	Horizontal curve Upgrade Off-ramp On-ramp Crest vertical curve
MO03	Moderate	Horizontal curve At-grade intersections
MO04	Low	Horizontal curve Long tangent At-grade intersections
MO05	Low-Moderate	On-ramp Horizontal curve Downgrade
MO06	Low	Horizontal curve Downgrade
MO07	Low-Moderate	Off-ramp On-ramp
MO08	Very Low	No contributing factors noted
MO09	Very Low	No contributing factors noted
MO10	Moderate	Horizontal curve Off-ramp On-ramp
MO11	High	Off-ramp Off-ramp with lane-drop exit On-ramp Horizontal curve Downgrade Bridge
MO12	High	Off-ramp On-ramp
OH01	Low	Bridge
OH02	Low	No contributing factors noted
OH03	Low	No contributing factors noted
OH04	High	On-ramp Off-ramp Downgrade Bridge

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Table 4-3. (Continued).

Site number	Driver workload level	Individual contributing factors
OH05	Low	Bridge
OH06	High	On-ramp Horizontal curve Major merge area (two freeways merge) Mainline lane drop
OH07	Moderate	Off-ramp On-ramp Bridge Downgrade
OH08	Moderate	Upgrade Bridge Horizontal curve Crest vertical curve Off-ramp On-ramp
OH09	Low	No contributing factors noted
OH10	Moderate	Sharp horizontal curve Off-ramp
OH11	Low-Moderate	Off-ramp On-ramp Horizontal curve
OH12	Moderate	Off-ramp Horizontal curve
OH13	Moderate-High	Bridge On-ramp Downgrade
WA02	Low-Moderate	Off-ramp On-ramp Bridge
WA03	Very High	Tunnel HOV lane Off-ramp Off-ramp with lane-drop exit Horizontal curve
WA04	High	Downgrade Horizontal curve On-ramp Off-ramp
WA05	High	On-ramp Off-ramp Off-ramp with lane-drop exit Horizontal curve Downgrade Sag vertical curve
WA06	High	Downgrade On-ramp Off-ramp Off-ramp with lane-drop exit Bridge
WA07	Moderate	Narrow bridge Off-ramp Downgrade On-ramp
WA08	Low-Moderate	At-grade intersections
WA10	Moderate	Downgrade On-ramp Sharp horizontal curve Sag vertical curve Upgrade
WA11	Moderate	On-ramp Horizontal curve Downgrade Crest vertical curve Upgrade Truck stopping area on wide shoulder

Table 4-3. (Continued).

Site number	Driver workload level	Individual conributing factors
WA12	Moderate-High	Steep downgrade Horizontal curve Site begins downstream of an on-ramp
WA13	High	Upgrade Downgrade Sharp horizontal curve Off-ramp
WA14	High	Horizontal curve Off-ramp Downgrade

Note: This table lists all contributing factors whether those factors contribute to high driver-workload individually or in combination with other factors.

Table 4-4. Summary of driver workload levels and combined contributing factors by site.

Site number	Driver workload level	Combined contributing factors
CA01	Low-Moderate	On-ramp located after 12-mi level tangent
CA02	Low-Moderate	No combined contributing factors at this site
CA04	Low-Moderate	No combined contributing factors at this site
CA05	High	On-ramp on upgrade with short acceleration lane upstream of bridge Low-speed merge due to upgrade
CA07	Moderate-High	Closely spaced on-ramp followed by off-ramp (short weaving area) Closely spaced on-ramps
CA10	Low	No combined contributing factors at this site
CA11	Moderate-High	Closely spaced on-ramp followed by off-ramp (short weaving area) Limited sight-distance to on-ramp
CA13	High	Tight radius curve on on-ramp Low-speed merge due to on-ramp curve
CA14	Moderate-High	Closely spaced on-ramp followed by off-ramp with bridge in short weaving area Tight radius horizontal curve on on-ramp Low-speed merge due to on-ramp curve
CA15	Moderate	Low-speed merge due to short on-ramp
MO01	Low	No combined contributing factors at this site
MO02	Moderate	Off-ramp with crest vertical curve that limits sight-distance near start of taper On-ramp on upgrade Low-speed merge due to grade
MO03	Moderate	Intersection on horizontal curve
MO04	Low	Horizontal curve after long tangent
MO05	Low-Moderate	On-ramp on horizontal curve on downgrade Low-speed merge due to mainline curve
MO06	Low	Horizontal curve on downgrade
MO07	Low-Moderate	High truck volume on on-ramp
MO08	Very Low	No contributing factors noted
MO09	Very Low	No contributing factors noted
MO10	Moderate	Trees block sight-distance to on-ramp
MO11	High	On-ramp with multilane entrance (three entering lanes) on slight curve on downgrade (curve has influence even though slight) Closely spaced on-ramps
MO12	High	Left-side on-ramp Closely spaced on-ramps (one left-side, one right-side) Closely spaced on-ramp followed by off-ramp (short weaving area)

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Table 4-4. (Continued).

Site number	Driver workload level	Combined Contributing factors
OH01	Low	Bridge
OH02	Low	No contributing factors noted
OH03	Low	No contributing factors noted
OH04	High	Off-ramp with short deceleration lane Closely spaced on-ramp followed by off-ramp with bridge between (within full cloverleaf interchange)
OH05	Low	No combined contributing factors at this site
OH06	High	On-ramp with tight horizontal curve Low-speed merge due to on-ramp curve Closely spaced on-ramps
OH07	Moderate	No combined contributing factors at this site
OH08	Moderate	Off-ramp at crest vertical curve on horizontal curve
OH09	Low	No contributing factors noted
OH10	Moderate	No combined contributing factors at this site
OH11	Low-Moderate	No combined contributing factors at this site
OH12	Moderate	No combined contributing factors at this site
OH13	Moderate-High	Closely spaced on-ramps
WA02	Low-Moderate	No combined contributing factors at this site
WA03	Very High	Closely spaced off-ramps Off-ramp with multilane exit
WA04	High	Downgrade ending in horizontal curve Left-side on-ramp Closely spaced on-ramp followed by off-ramp (one left-side, one right-side)
WA05	High	Left-side off-ramp On-ramp with merge area in sag vertical curve
WA06	High	Off-ramp with multilane exit Closely spaced on-ramp followed by off-ramp with two-lane lane-drop exit
WA07	Moderate	Off-ramp just beyond narrow bridge on downgrade Off-ramp with multilane exit
WA08	Low-Moderate	No combined contributing factors at this site
WA10	Moderate	On-ramp with high truck volume Sharp horizontal curve on downgrade
WA11	Moderate	On-ramp on mainline curve on downgrade Horizontal curve at crest vertical curve Long horizontal curve (90^{o} turn)
WA12	Moderate-High	Horizontal curve on steep downgrade
WA13	High	Off-ramp on horizontal curve on downgrade
WA14	High	Reverse curves (four in sequence) Off-ramp on horizontal curve

Note: Contributing factors with combined effects are noted together.

entered the median was trying to avoid collision with another vehicle, and other crashes in which vehicle–vehicle interactions contributed to the crash. Crashes that involve a vehicle swerving to avoid being cut off by another vehicle changing lanes or swerving to avoid another vehicle stopping suddenly were classified as vehicle-interaction crashes. Thus, vehicle-interaction crashes involve all multiple-vehicle collisions and some single-vehicle crashes that involve avoiding a collision with another vehicle. A total of 27 percent of all median-related crashes were classified as vehicle-interaction crashes. Approximately one-third of vehicle-interaction crashes did not involve a collision with a second vehicle.

4.6.2 Pavement Surface Condition

Pavement surface condition was classified based on the pavement surface condition at the time of the crash, as reported by the investigating officer. The category of dry-pavement crashes includes all crashes for which the investigating officer reported dry-pavement conditions at the time of the crash. The category of wet pavement, snow, and ice crashes includes all other pavement surface conditions, consisting primarily of crashes for which the officer explicitly reported wet-pavement conditions at the time of the crash, but also including muddy, snow-, ice-, or slush-covered roadways.

In three of the four states, loss of control on wet or snow-covered roads resulting in single-vehicle crashes were the most frequent precursor to median-related crashes, accounting for 39 percent of median-related crashes in Missouri, 58 percent in Ohio, and 63 percent in Washington. In contrast, only 16 percent of median-related crashes in California involved single-vehicle loss of control on wet or snow-covered roads. This observed difference likely reflects exposure to wet and snow-covered roads—there is proportionately more dry

Table 4-5. Frequency distribution of individual and combined contributing factors.

Description of contributing factor	**Total**	**Contributing factors by driver workload level**						
		Very low	**Low**	**Low-moderate**	**Moderate**	**Moderate-high**	**High**	**Very high**
RAMPS	**80**	**0**	**4**	**8**	**22**	**9**	**34**	**3**
On Ramps	**44**	**0**	**2**	**5**	**14**	**5**	**18**	**0**
On ramp	22		2	3	9	1	7	
Closely spaced on ramps	5					2	3	
Left-side on-ramp	2						2	
Multilane entrance	1						1	
Merge area in sag vertical curve	1						1	
Downstream of on-ramp	1					1		
High truck volume on on-ramp	2			1	1			
Major merge	1						1	
Short acceleration lane	1						1	
Low-speed merge due to curve on ramp	3					1	2	
Low-speed merge due to mainline curve	1			1				
Low-speed merge due to short ramp	1				1			
Low-speed merge due to grade	1				1			
Limited sight-distance to on ramp	2				2			
Off Ramps	**29**	**0**	**2**	**3**	**8**	**1**	**12**	**3**
Off ramps	20		2	3	7		8	
Closely spaced off ramps	1							1
Multilane exit	2				1			1
Off-ramp with lane drop	3						2	1
Left-side off ramp	1						1	
Short deceleration lane	1						1	
Limited sight-distance to off ramp	1					1		
On- and Off-Ramps	**7**	**0**	**0**	**0**	**0**	**3**	**4**	**0**
Closely spaced on- and off-ramp	7					3	4	
HORIZONTAL CURVES	**25**	**0**	**4**	**4**	**10**	**1**	**5**	**1**
Horizontal curves	**17**		4	4	5	1	2	1
Sharp horizontal curve	3				2		1	
Long horizontal curve	1				1			
Sequence of reverse curves	1						1	
Downgrade ending in curve	1						1	
Crest vertical curve on horizontal curve	2				2			
VERTICAL ALIGNMENT	**21**	**0**	**2**	**1**	**8**	**2**	**8**	**0**
Downgrade	13		2	1	4	1	5	
Steep downgrade	1					1		
Upgrade	5				3		2	
Sag vertical curve	2				1		1	
OTHER	**24**	**0**	**5**	**3**	**7**	**2**	**5**	**2**
Bridge	12		4	1	2	1	4	
Narrow bridge	1				1			
At-grade intersection	3		1	1	1			
At-grade intersection on curve	1				1			
Mainline lane drop	2					1	1	
Tunnel	1							1
HOV lane	1							1
Widened shldr/truck stopping area	3			1	2			
Total Observations	**150**	**0**	**15**	**16**	**47**	**14**	**52**	**6**
Percentage of Observations		0.0	10.0	10.7	31.3	9.3	34.7	4.0

Table 4-6. Frequency distribution of contributing factors by major categories.

Description of contributing factor	Total	Contributing factors by driver workload level						
		Very low	Low	Low-moderate	Moderate	Moderate-high	High	Very high
On-ramp	28			6	8	5	9	
Off-ramp	26		1	4	8	3	9	1
Horizontal curve	19		3	3	6	1	5	1
Sharp horizontal curve	3				2		1	
Bridge	13		3	2	2	2	4	
Narrow bridge	1				1			
Downgrade	15		2	1	4	1	7	
Steep downgrade	1					1		
Upgrade	6				4		2	
Crest vertical curve	3				3			
Sag vertical curve	3				1		2	
Long tangent	2		1	1				
Mainline lane drop	2					1	1	
Lane drop at exit	4						3	1
At-grade intersections	3		1	1	1			
Major merge (two freeways merge)	1						1	
Tunnel	1							1
HOV lane	1							1
Truck stopping area on wide shoulder	2			1	1			
No contributing factors noted	5	2	3					

weather in California in contrast to the other three states, and much more snow, ice, and slush in Ohio and Washington than in Missouri.

Table 4-8 compares the mean number of days with precipitation for California, Missouri, Washington, and Ohio based on data from the U.S. National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center. Days of precipitation encompass days with 0.01 inch of precipitation or more. The averages provided in the table were calculated from the mean number of days of precipitation from a range of cities across the state to provide a representation of the various weather conditions throughout the region. The following cities were used for deriving the averages for each state:

- California: Bishop, Los Angeles, Santa Barbara, Sacramento, San Francisco, Blue Canyon, Mount Shasta, and Eureka;
- Ohio: Dayton, Toledo, Columbus, Akron, Cleveland, and Youngstown;
- Missouri: Kansas City, St. Louis, and Columbia; and
- Washington: Yakima, Spokane, Seattle.

The number of years over which the weather data have been collected ranges from 25 to 101 years prior to 2011.

As might be expected, the greater the percent of days per year with precipitation, the greater the percent of median crashes that were on wet and snow-covered roads.

It should be noted though that the percent of days per year with 0.01 inch of precipitation or more ranged from 16 percent to 39 percent. On those days with precipitation, some of the time the road would be dry. In other words, considering days with no precipitation as well as there being only part of the day with wet or snow-covered road conditions, the majority of the time roads would have been dry. However, combining the results for all four states, there were more crashes on wet and snow-covered roads (average 44 percent) than would be suggested by a very conservative estimate of exposure to wet and snow-covered road conditions—days per year with at least 0.01 inch of precipitation (average 30 percent).

More than twice as many single-vehicle loss-of-control median-related crashes occurred on wet and snow-covered roads (49 percent) than on dry roads (23 percent), despite dry-road conditions being present at least 2.3 times (70 percent vs. 30 percent) more often than wet and snow-covered roads. Thus, wet and snow-covered roads are overinvolved in single-vehicle loss-of-control median-related crashes by a factor of at least 4.6, given that days with 0.01 inch of precipitation likely have dry hours.

This finding suggests that wet and snow-covered roads are a major risk factor for single-vehicle loss-of-control median-related crashes. A meta-analysis based on 34 published studies reports average increases in crash rates of 71 percent for rain and 84 percent for snow (*52*). The data reviewed here would suggest a much higher risk for single-vehicle loss-of-control median-related crashes as compared to other crash types.

A total of 19 percent of all median-related crashes were vehicle-interaction crashes that occurred on dry roads, while 9 percent were vehicle-interaction crashes on wet and snow-covered roads. In other words, vehicle-interaction crashes

Table 4-7. Crash frequency by site for median-related crashes.

Site number	Number of crashes in a 5-year period by crash type and pavement surface condition					Length (mi)	Directional AADT (veh/day)	Crash rate	
	Single-vehicle loss of control		Vehicle interaction		Total				
	Dry roads	Wet roads[a]	Dry roads	Wet roads[a]				per mile per year	per MVMT
California Sites									
CA01	8	0	5	0	13	2.0	39000	1.30	0.091
CA02	10	0	4	0	14	2.0	39000	1.40	0.098
CA04	5	4	4	0	13	2.0	58000	1.30	0.061
CA05	8	0	9	0	17	1.0	61000	3.40	0.153
CA07	1	5	3	0	9	2.0	61000	0.90	0.040
CA10	7	0	4	0	11	1.0	75000	2.20	0.080
CA11	2	1	5	1	9	1.0	72000	1.80	0.068
CA13	6	10	6	4	26	1.0	67000	5.20	0.213
CA14	5	1	4	1	11	1.0	67000	2.20	0.090
CA15	4	1	10	1	16	1.0	64000	3.20	0.137
Missouri Sites									
MO01	4	8	3	4	19	2.0	15000	1.90	0.347
MO02	14	27	14	11	66	3.0	17000	4.40	0.709
MO03	9	1	3	0	13	2.0	7500	1.30	0.475
MO04	4	0	3	0	7	3.6	7000	0.39	0.152
MO05	16	25	11	4	56	10.7	20000	1.05	0.143
MO06	5	9	3	0	17	2.0	17000	1.70	0.274
MO07	10	8	10	3	31	2.0	15000	3.10	0.566
MO08	16	2	7	0	25	2.0	11000	2.50	0.623
MO09	6	3	4	1	14	2.0	11000	1.40	0.349
MO10	7	1	8	0	16	2.0	15000	1.60	0.292
MO11	8	66	10	15	99	2.1	80000	9.43	0.323
MO12	13	2	7	0	22	3.0	36400	1.47	0.110
Ohio Sites									
OH01	3	7	1	0	11	1.0	42000	2.20	0.144
OH02	2	16	10	7	35	1.0	97000	7.00	0.198
OH03	0	6	3	4	13	1.0	97000	2.60	0.073
OH04	5	10	5	0	20	1.0	57000	4.00	0.192
OH05	1	8	3	2	14	1.0	57000	2.80	0.135
OH06	3	10	3	4	20	2.1	40000	1.90	0.130
OH07	4	9	1	12	26	1.0	96000	5.20	0.148
OH08	4	18	2	2	26	1.0	104000	5.20	0.137
OH09	5	9	3	3	20	1.0	104000	4.00	0.105
OH10	12	10	4	1	27	1.0	104000	5.40	0.142
OH11	8	17	3	3	31	1.0	40000	6.20	0.425
OH12	5	39	4	0	48	1.0	39000	9.60	0.674
OH13	4	27	1	1	33	1.0	40000	6.60	0.452
Washington Sites									
WA02	49	7	0	4	60	7.2	45000	1.68	0.102
WA03	14	9	3	11	37	1.1	229000	6.67	0.080
WA04	9	6	6	5	26	0.7	208000	7.54	0.099
WA05	21	6	3	11	41	1.5	211000	5.66	0.073
WA06	3	5	8	5	21	2.2	129000	1.89	0.040
WA07	4	3	8	1	16	2.3	62000	1.42	0.063
WA08	5	10	0	1	16	5.5	19000	0.58	0.084
WA10	9	12	2	2	25	2.8	56000	1.77	0.086
WA11	2	21	1	1	25	3.5	56000	1.45	0.071
WA12	9	41	2	2	54	3.9	30000	2.78	0.254
WA13	2	22	1	2	27	1.0	30000	5.19	0.474
WA14	7	55	1	2	65	1.3	30000	9.85	0.899
Total	358	557	215	131	1261	97.4			
Percent of Total	28%	45%	17%	10%					

[a] Includes all crashes for which the pavement surface condition is reported as other than dry, including wet, muddy, snow-, ice-, or slush-covered roads.

Table 4-8. Differences in precipitation frequency by state compared to proportion of crashes on wet and snow-covered roads.

State	Average number of days per year with precipitation	Percentage of days per year with precipitation	Percentage of median crashes that occurred on wet and snow-covered roads
California	57.5	16%	16%
Missouri	103.0	28%	39%
Ohio	140.6	39%	58%
Washington	136.4	37%	63%

were only half as likely to occur on wet and snow-covered roads as on dry roads. If it was assumed that road condition was affected the entire day on days in which 0.01 inch of precipitation or more was recorded, one would expect about 30 percent of the vehicle-interaction crashes to occur on wet and snow-covered roads. The fact that approximately 32 percent occur in such conditions suggests that wet and snow-covered roads raise the risk of a vehicle-interaction crash much less than is the case for single-vehicle loss-of-control crashes.

4.6.3 Driver Contributing Factors as Classified by Investigating Officers

Much of the analysis performed was based on contributing factors to median-related crashes, as classified by the interdisciplinary team based on review of the crash reports and the field sites. Consideration also was given to the driver contributing factors as classified on the crash reports by the investigating officers.

Speed-Related Crashes—The most frequent driver contributing factor for single-vehicle loss-of-control median-related crashes under wet and snow-covered road conditions, as noted by the investigating officers in the crash reports, was speed (91 percent of single-vehicle loss-of-control crashes on wet and snow-covered roads in Missouri, 71 percent in Ohio, 84 percent in Washington). In contrast, speed was much less frequently cited as a factor in single-vehicle loss-of-control crashes involving dry roads (26 percent of single-vehicle loss-of-control crashes on dry roads in Missouri, 34 percent in Ohio, 30 percent in Washington).

With respect to vehicle-interaction crashes on wet and snow-covered roads, speed was less frequently cited than in single-vehicle loss-of-control crashes on wet and snow-covered roads (62 percent of vehicle-interaction crashes on wet and snow-covered roads in Missouri, 16 percent in Ohio, 54 percent in Washington). In vehicle-interaction crashes on dry as compared to wet and snow-covered roads, speed was even less frequently cited (Missouri 12 percent vs. 62 percent, Ohio 2 percent vs. 16 percent, Washington 21 percent vs. 54 percent).

Given that the investigating officer completing a crash report is generally not in a position to determine what the speed was or how it compared to surrounding vehicles, the attribution of speed as the cause of the crash is generally an assumption rather than being based on evidence. Nevertheless, research indicates that while drivers slow down, they do so less than is appropriate given the loss of friction and reduction in visibility that makes vehicle handling more difficult (*53*). Thus, speed is generally likely to contribute more to wet and snow-covered road crashes, but how large a factor it is cannot really be determined from crash reports. This is particularly evident from the very different findings from Ohio as compared to Missouri and Washington with respect to the percent of various types of crashes involving speed (e.g., Missouri, 62 percent vs. Washington, 54 percent vs. Ohio, 16 percent of vehicle-interaction crashes on wet and snow-covered roads).

Inattention/Distraction-Related Crashes—After speed, inattention was the most frequently cited driver contributing factor in median-related crashes. Inattention was much more likely to be cited on dry than on wet and snow-covered roads (12 percent of dry-road crashes vs. 2 percent of wet and snow-covered road crashes), and far more likely to be cited in Missouri than Ohio (10 percent vs. 1 percent of all crashes).

Crashes with No Contributing Factor Cited—Overall investigating officers in Ohio and Missouri were less likely to cite a driver contributing factor than police in Washington. This finding suggests differences in police culture with respect to assigning contributing factors that may bias findings. Given how little evidence police have to depend on to make attributions of speed, inattention, etc., some subjectivity and reliance on assumptions is to be expected.

Understanding and utilizing all of the collected data allowed the team to classify each of the field investigation sites by workload level. Table 4-9 presents the site-by-site crash frequency data grouped into the seven driver workload categories.

4.6.4 Cross-Median Collisions

The 1,261 crashes shown in Table 4-9 each involved a median encroachment. Most of those crashes involved a vehi-

Table 4-9. Crash frequency by site for median-related crashes for specific driver workload levels.

Site number	Driver workload	Number of crashes in a 5-year period by crash type and pavement surface condition					Length (mi)	Directional AADT (veh/day)	Crash rate	
		Loss of control		Vehicle interaction		Total				
		Dry roads	Wet roads[a]	Dry roads	Wet roads[a]				per mile per year	per MVMT
Very low driver workload										
MO08	Very low	16	2	7	0	25	2.0	11000	2.50	0.623
MO09	Very low	6	3	4	1	14	2.0	11000	1.40	0.349
Subtotal	Very low	22	5	11	1	39	4.0		1.95	0.486
		56%	13%	28%	3%					
Low driver workload										
CA10	Low	7	0	4	0	11	1.0	75000	2.20	0.080
MO01	Low	4	8	3	4	19	2.0	15000	1.90	0.347
MO04	Low	4	0	3	0	7	3.6	7000	0.39	0.152
MO06	Low	5	9	3	0	17	2.0	17000	1.70	0.274
OH01	Low	3	7	1	0	11	1.0	42000	2.20	0.144
OH02	Low	2	16	10	7	35	1.0	97000	7.00	0.198
OH03	Low	0	6	3	4	13	1.0	97000	2.60	0.073
OH05	Low	1	8	3	2	14	1.0	57000	2.80	0.135
OH09	Low	5	9	3	3	20	1.0	104000	4.00	0.105
Subtotal	Low	31	63	33	20	147	13.6		2.16	0.144
		21%	43%	22%	14%					
Low-moderate driver workload										
CA01	Low-moderate	8	0	5	0	13	2.0	39000	1.30	0.091
CA02	Low-moderate	10	0	4	0	14	2.0	39000	1.40	0.098
CA04	Low-moderate	5	4	4	0	13	2.0	58000	1.30	0.061
MO05	Low-moderate	16	25	11	4	56	10.7	20000	1.05	0.143
MO07	Low-moderate	10	8	10	3	31	2.0	15000	3.10	0.566
OH11	Low-moderate	8	17	3	3	31	1.0	40000	6.20	0.425
WA08	Low-moderate	5	10	0	1	16	5.5	19000	0.58	0.084
Subtotal	Low-moderate	62	64	37	11	174	25.2		1.38	0.144
		36%	37%	21%	6%					
Moderate driver workload										
CA15	Moderate	4	1	10	1	16	1.0	64000	3.20	0.137
MO02	Moderate	14	27	14	11	66	3.0	17000	4.40	0.709
MO03	Moderate	9	1	3	0	13	2.0	7500	1.30	0.475
MO10	Moderate	7	1	8	0	16	2.0	15000	1.60	0.292
OH07	Moderate	4	9	1	12	26	1.0	96000	5.20	0.148
OH08	Moderate	4	18	2	2	26	1.0	104000	5.20	0.137
OH10	Moderate	12	10	4	1	27	1.0	104000	5.40	0.142
OH12	Moderate	5	39	4	0	48	1.0	39000	9.60	0.674
WA02	Moderate	49	7	0	4	60	7.2	45000	1.68	0.102
WA07	Moderate	4	3	8	1	16	2.3	62000	1.42	0.063
WA10	Moderate	9	12	2	2	25	2.8	56000	1.77	0.086
WA11	Moderate	2	21	1	1	25	3.5	56000	1.45	0.071
Subtotal	Moderate	123	149	57	35	364	28		2.63	0.151
		34%	41%	16%	10%					

(continued on next page)

Table 4-9. (Continued).

Site number	Driver workload	Number of crashes in a 5-year period by crash type and pavement surface condition					Length (mi)	Directional AADT (veh/day)	Crash rate	
		Loss of control		Vehicle interaction		Total				
		Dry roads	Wet roads[a]	Dry roads	Wet roads[a]				per mile per year	per MVMT
Moderate-high driver workload										
CA07	Moderate-high	1	5	3	0	9	2.0	61000	0.90	0.040
CA11	Moderate-high	2	1	5	1	9	1.0	72000	1.80	0.068
CA14	Moderate-high	5	1	4	1	11	1.0	67000	2.20	0.090
OH13	Moderate-high	4	27	1	1	33	1.0	40000	6.60	0.452
WA06	Moderate-high	3	5	8	5	21	2.2	129000	1.89	0.040
WA12	Moderate-high	9	41	2	2	54	3.9	30000	2.78	0.254
Subtotal	Moderate-high	24	80	23	10	137	11.1		2.47	0.107
		18%	58%	17%	7%					
High driver workload										
CA05	High	8	0	9	0	17	1.0	61000	3.40	0.153
CA13	High	6	10	6	4	26	1.0	67000	5.20	0.213
MO11	High	8	66	10	15	99	2.1	80000	9.43	0.323
MO12	High	13	2	7	0	22	3.0	36400	1.47	0.110
OH04	High	5	10	5	0	20	1.0	57000	4.00	0.192
OH06	High	3	10	3	4	20	2.1	40000	1.90	0.130
WA04	High	9	6	6	5	26	0.7	208000	7.54	0.099
WA05	High	21	6	3	11	41	1.5	211000	5.66	0.073
WA13	High	2	22	1	2	27	1.0	30000	5.19	0.474
WA14	High	7	55	1	2	65	1.3	30000	9.85	0.899
Subtotal	High	82	187	51	43	363	14.7		4.94	0.187
		23%	52%	14%	12%					
Very high driver workload										
WA03	Very high	14	9	3	11	37	1.1	229000	6.67	0.080
Subtotal	Very high	14	9	3	11	37	1.1		6.67	0.080
		38%	24%	8%	30%					
Total		358	557	215	131	1261	97.4			
Percent of Total		28%	45%	17%	10%					

[a] Includes all crashes for which the pavement surface condition is reported as other than dry, including wet, muddy, snow-, ice-, or slush-covered roads.

cle striking an object, overturning, or coming to rest before crossing the median. Indeed, only 12 percent of the 97.4 miles of interdisciplinary field review sites had traversable medians where it is physically possible to cross the median without encountering a median barrier, fixed objects, or nontraversable terrain.

During the 5-year study period, the 47 interdisciplinary field review sites experienced only two CMC crashes in which a vehicle crossed the entire median, entered the opposing roadway, and collided with an opposing direction vehicle. In addition, there were three NCMC crashes in which a vehicle crossed the entire median and entered the opposing roadway, but did not collide with an opposing direction vehicle. It should be noted that, at the one site that experienced both a CMC and an NCMC crash, the state highway agency has since installed a cable median barrier.

4.7 Summary of Contributing Factors

Based on the interdisciplinary field reviews and crash reviews, the following contributing factors appear most involved in determining driver workload and potentially contributing to the initiation of median-related crashes:

- On-ramps (especially closely spaced on-ramps), on-ramps with low-speed merges, on-ramps with high entering truck volume, left-side on-ramps, and on-ramps with limited sight-distance to the mainline;
- Off-ramps, especially off-ramps with lane drops and multilane exits;
- Closely spaced on- and off-ramps;
- Sharp horizontal curves;
- Steep grades, especially steep downgrades, but also including steep upgrades; and
- Wet or snow-covered road conditions.

SECTION 5

Crash Data Analyses to Investigate Contributing Factors

This section of the report presents crash data analyses conducted to investigate the key factors contributing to driver workload identified in Section 4 and to confirm their role in median-related crashes. The key contributing factors addressed are ramps, sharp curves, and steep grades.

5.1 Crash Analysis Approach

The investigation of the key contributing factors was necessarily conducted with a much larger set of sites and crashes than was available for the interdisciplinary field reviews presented in Section 4. The interdisciplinary field review sites, which were selected to be studied in detail, included 97.4 miles of divided highways that experienced 1,261 crashes in 5 years. This new crash data analysis was conducted using data for 5 years for the entire rural freeway system in Washington. Although the analysis of interdisciplinary field review sites intentionally focused on sites with high crash frequencies, this analysis looked at the entire freeway system, including sites with high, average, and low crash frequency. Analyses addressed 923.56 miles of directional rural freeway segments that experienced 3,080 median-related crashes in 5 years. The FHWA HSIS data for Washington were used for this analysis because this is the only available database with curve and grade data for the entire roadway system. The 5-year period used for the analyses was the same 5-year period (2004 to 2008) used for the Washington interdisciplinary field reviews in Section 4 of this report.

The analyses compared the crash frequencies and crash rates for freeway sections adjacent to off-ramps, adjacent to on-ramps, on sharp curves (with radii of 4,500 feet or less), on steep grades (with grades of 4 percent or more), and with none of these features. Combinations of features (ramps and sharp curves, ramps and steep grades, and sharp curves and steep grades) also were considered.

Freeway segments adjacent to off-ramps were defined as extending from 0.05 miles upstream of the beginning of the deceleration lane to 0.19 miles (1,000 feet) downstream of the gore area. Freeway segments adjacent to on-ramps were defined as extending from 0.05 miles upstream of the gore area to 0.19 miles downstream of the end of the acceleration lane. The downstream area was included because there might be ramp-related turbulent flow in this area that could lead to median-related crashes.

Sharp curves were defined as curves with radii of 4,500 feet or less. The freeway system was divided, based on curvature, into the following categories for analysis:

- Curve to left with radius less than 2,000 feet;
- Curve to right with radius less than 2,000 feet;
- Curve to left with radius from 2,000 feet to less than 3,000 feet;
- Curve to right with radius from 2,000 feet to less than 3,000 feet;
- Curve to left with radius from 3,000 to 4,500 feet;
- Curve to right with radius from 3,000 to 4,500 feet; and
- No sharp curve.

The limiting value of 4,500 feet for radius of curvature was chosen because this represents a curve that would require a 4 percent superelevation rate on a 70 mph horizontal curve designed with a maximum superelevation rate (e_{max}) of 6 percent (*50*). Consideration of several ranges for curve radius less than 4,500 feet allowed assessment of which ranges should be included in design guidance.

Steep grades were defined as grades of 4 percent or more. The freeway system was divided into the following categories for analysis:

- Downgrade of more than 5 percent,
- Downgrade of 4 to 5 percent,
- Upgrade of more than 5 percent,
- Upgrade of 4 to 5 percent, and
- No steep grade.

Generally, the Interstate Highway System in the United States has been designed with a maximum grade of 3 percent, except that grades up to 6 percent are permitted in rolling or mountainous terrain (*54*). The maximum grade for a 70 mph Interstate freeway in rolling terrain is 4 percent. Therefore, grades steeper than 4 percent were considered in this analysis. Grades above 4 percent were subdivided into categories of 4 to 5 percent and more than 5 percent for assessment of which ranges should be included in design guidance.

The next section presents the results from analysis of these curve and grade data. Although no analysis was conducted to determine the statistical significance of the differences shown, the results are meaningful because the data include all crashes that occurred on the entire rural freeway system of a state during a 5-year period.

5.2 Analysis Results for Median-Related Crashes on Rural Freeways

Table 5-1 presents a comparison of median-related crash frequencies and crash rates for freeway segments adjacent to and not adjacent to ramps. The table shows that the median-related crash rates for segments adjacent to off- and on-ramps are both higher than the crash rates for segments where there is no ramp present. Off-ramps have slightly higher median-related crash rates than on-ramps, although the observed difference is minimal when the comparison is based on crash rate per million vehicle-miles of travel. Table 5-1 confirms that both off- and on-ramps are associated with elevated median-related crash rates and are confirmed as contributing factors to median-related crashes.

Table 5-2 presents a comparison of median-related crash frequencies and crash rates for freeway segments by curvature categories. The table shows that median-related crash rates are highest for the sharpest curves (radius less than 2,000 feet) and that median-related crash rates decrease as the curve radius increases. Median-related crash rates are lowest of all for freeway segments where no sharp curve is present; such sections may be either tangent sections or curves with radius greater than 4,500 feet. However, there is very little difference in median-related crash rates for freeway segment curves in the 3,000 to 4,500 feet radius category and freeway segments with no sharp curve. Therefore, a decision was reached that design guidance for sharp horizontal curves should apply to curve radii less than 3,000 feet. For a given curve radius category, the difference in median-related crash rates between curves to the left and curves to the right is small, although curves to the right have slightly higher crash rates than curves to the left. This result is logical, because motorists are most likely to run off the outside of sharp curves and the median is on the outside of a curve to the right.

Table 5-3 presents a comparison of median-related crash frequencies and rates for freeway segments by grade categories. The table shows that median-related crash rates are highest for the steepest grades (more than 5 percent), lower for 4- to 5-percent grades, and lowest for grades less than 4 percent. Based on this finding, a decision was reached to include both the 4 to 5 percent grade category and the more than 5 percent grade category in design guidance for steep grades. The differences in median-related crash rates between downgrades and upgrades are small, particularly for fatal-and-injury median-related crashes.

Table 5-4 shows the median-related crash frequencies and rates for specific combinations of ramp and curve categories. The results in Table 5-4 generally confirm the results presented in Tables 5-1 and 5-2. There do not appear to be any circumstances in which specific combinations of ramps and curves have substantially higher or lower crash rates than suggested by their independent effects. However, it should be noted that the sample sizes for specific ramp and curve combinations are generally very small.

Table 5-5 shows the median-related crash frequencies and rates for specific combinations of ramp and grade categories. The results in Table 5-5 generally confirm the results presented in Tables 5-1 and 5-3. There do not appear to be any circumstances in which specific combinations of ramps and grades have substantially higher or lower crash rates than suggested by their independent efforts. However, as for the analysis of ramp and curve combinations, the sample sizes for specific ramp and grade combinations are small. The sample sizes for specific combinations of sharp curves and steep grades are generally too small to provide meaningful results.

Table 5-1. Crash frequencies and rates by ramp category for rural freeways in Washington.

	Freeway segments		Number of median-related crashes (2004–2008)			Total crash rate		FI crash rate	
Ramp category	Cumulative length (mi)	Exposure (MVMT)	Total	FI	PDO	per mi per year	per MVMT	per mi per year	per MVMT
Off-ramp	92.91	2544.00	404	144	260	0.870	0.159	0.310	0.057
On-ramp	69.76	1983.92	289	105	184	0.829	0.146	0.301	0.053
No ramp present	760.89	17344.07	2387	903	1484	0.627	0.138	0.237	0.052
All segments combined	923.56	21871.99	3080	1152	1928	0.667	0.141	0.249	0.053

Table 5-2. Crash frequencies and rates by curve category for rural freeways in Washington.

	Freeway segments		Number of median-related crashes (2004–2008)			Total crash rate		FI crash rate	
Curve category (radius/direction)	Cumulative length (mi)	Exposure (MVMT)	Total	FI	PDO	per mi per year	per MVMT	per mi per year	per MVMT
Radius < 2,000 ft (left)	12.27	295.81	145	57	88	2.363	0.490	0.929	0.193
Radius < 2,000 ft (right)	12.27	295.81	155	67	88	2.526	0.524	1.092	0.226
Radius 2,000 to < 3,000 ft (left)	20.49	494.91	104	40	64	1.015	0.210	0.390	0.081
Radius 2,000 to < 3,000 ft (right)	20.49	494.91	108	53	55	1.054	0.218	0.517	0.107
Radius 3,000 to 4,500 ft (left)	23.45	526.72	79	25	54	0.674	0.150	0.213	0.047
Radius 3,000 to 4,500 ft (right)	23.45	526.72	66	26	40	0.563	0.125	0.222	0.049
All curves < 2,000 ft	24.54	591.62	300	124	176	2.445	0.507	1.011	0.210
All curves 2,000 to < 3,000 ft	40.98	989.82	212	93	119	1.035	0.214	0.454	0.094
All curves 3,000 to 4,500 ft	46.90	1053.44	145	51	94	0.618	0.138	0.217	0.048
All left curves	56.21	1317.44	328	122	206	1.167	0.249	0.434	0.093
All right curves	56.21	1317.44	329	146	183	1.171	0.250	0.519	0.111
All sharp curves	112.42	2634.88	657	268	389	1.169	0.249	0.477	0.102
No sharp curve	811.14	19237.11	2423	884	1539	0.597	0.126	0.218	0.046

Table 5-3. Crash frequencies and rates by grade category for rural freeways in Washington.

	Freeway segments		Number of median-related crashes (2004–2008)			Total crash rate		FI crash rate	
Grade category (percent grade/direction)	Cumulative length (mi)	Exposure (MVMT)	Total	FI	PDO	per mi per year	per MVMT	per mi per year	per MVMT
5%+ downgrade	14.80	256.66	87	27	60	1.176	0.339	0.365	0.105
4% to 5% downgrade	24.68	499.26	117	37	80	0.948	0.234	0.300	0.074
5%+ upgrade	14.80	256.66	71	27	44	0.959	0.277	0.365	0.105
4% to 5% upgrade	24.68	499.66	102	39	63	0.827	0.204	0.316	0.078
All 5%+ grades	29.60	513.32	158	54	104	1.068	0.308	0.365	0.105
All 4% to 5% grades	49.36	998.92	219	76	143	0.887	0.219	0.308	0.076
All steep downgrades	39.48	755.92	204	64	140	1.033	0.270	0.324	0.085
All steep upgrades	39.48	756.32	173	66	107	0.876	0.229	0.334	0.087
All steep grades	78.96	1512.24	377	130	247	0.955	0.249	0.329	0.086
No steep grade	844.60	20359.75	2703	1022	1681	0.640	0.133	0.242	0.050

Table 5-4. Crash frequencies and rates by ramp and curve category combinations for rural freeways in Washington.

Ramp/curve combination (ramp type/radius/ direction)	Freeway segments		Number of median-related crashes (2004–2008)			Total crash rate		FI crash rate	
	Cumulative length (mi)	Exposure (MVMT)	Total	FI	PDO	per mile per year	per MVMT	per mile per year	per MVMT
Off-ramp/< 2,000 ft (left)	0.59	22.85	9	5	4	3.051	0.394	1.695	0.219
Off-ramp/< 2,000 ft (right)	1.19	40.22	27	9	18	4.538	0.671	1.513	0.224
Off-ramp/2,000 to < 3,000 ft (left)	1.82	38.31	12	6	6	1.319	0.313	0.659	0.157
Off-ramp/2,000 to < 3,000 ft (right)	2.58	65.94	15	8	7	1.163	0.227	0.620	0.121
Off-ramp/all < 2,000 ft curves	1.78	63.07	36	14	22	4.045	0.571	1.573	0.222
Off-ramp/all 2,000 to < 3,000 ft curves	3.01	78.53	39	15	24	2.591	0.497	0.997	0.191
Off-ramp/no sharp curve	86.73	2376.68	341	116	225	0.786	0.143	0.267	0.049
On-ramp/< 2,000 ft (left)	1.41	38.79	20	8	12	2.837	0.516	1.135	0.206
On-ramp/< 2,000 ft (right)	1.11	35.43	18	9	9	3.243	0.508	1.622	0.254
On-ramp/2,000 to < 3,000 ft (left)	2.29	63.04	19	4	15	1.659	0.301	0.349	0.063
On-ramp/2,000 to < 3,000 ft (right)	1.85	59.16	12	4	8	1.297	0.203	0.432	0.068
On-ramp/all < 2,000 ft curves	2.52	74.22	38	17	21	3.016	0.512	1.349	0.229
On-ramp/all 2,000 to < 3,000 ft curves	3.40	98.47	37	13	24	2.176	0.376	0.765	0.132
On-ramp/no sharp curve	63.10	1787.50	220	80	140	0.697	0.123	0.254	0.045

Table 5-5. Crash frequencies and rates by ramp and grade category combinations for rural freeways in Washington.

Ramp/grade combination (ramp type/percent grade/direction)	Freeway segments		Number of median-related crashes (2004–2008)			Total crash rate		FI crash rate	
	Cumulative length (mi)	Exposure (MVMT)	Total	FI	PDO	per mile per year	per MVMT	per mile per year	per MVMT
Off-ramp/5%+ downgrade	0.00	0.00	0	0	0	--	--	--	--
Off-ramp/5%+ upgrade	0.39	9.35	12	5	7	6.154	1.283	2.564	0.535
Off-ramp/4% to 5% downgrade	1.10	21.80	8	1	7	1.455	0.367	0.182	0.046
Off-ramp/4% to 5% upgrade	0.74	21.06	7	3	4	1.892	0.332	0.811	0.142
Off-ramp/all 5%+ grades	0.39	9.35	12	5	7	6.154	1.283	2.564	0.535
Off-ramp/all 4% to 5% grades	1.84	42.86	15	4	11	1.630	0.350	0.435	0.093
Off-ramp/no steep grade	92.52	2534.65	392	139	253	0.847	0.155	0.300	0.055
On-ramp/5%+ downgrade	0.06	21.16	17	5	12	56.667	0.803	16.667	0.236
On-ramp/5%+ upgrade	0.23	3.20	1	1	0	0.870	0.313	0.870	0.313
On-ramp/4% to 5% downgrade	0.92	28.76	3	0	3	0.652	0.104	0.000	0.000
On-ramp/4% to 5% upgrade	1.19	26.26	8	3	5	1.345	0.305	0.504	0.114
On-ramp/all 5%+ grades	0.29	24.36	18	6	12	12.414	0.739	4.138	0.246
On-ramp/all 4% to 5% grades	2.11	55.02	11	3	8	1.043	0.200	0.284	0.055
On-ramp/no steep grade	69.47	1959.56	271	99	172	0.780	0.138	0.285	0.051

5.3 Comparison of Results for Median-Related Crashes to Other Crash Types

Table 5-6 summarizes the crash data for rural freeways in Washington by crash type (median-related crashes, run-off-road right crashes, and on-road crashes). The table shows that the overall proportions of total crashes, ramp crashes, and grade crashes for these crash types are very similar (roughly 28 percent median-related crashes, 28 percent run-off-road right crashes, and 44 percent on-road crashes). The corresponding proportions for fatal-and-injury (FI) crashes on ramps, steep grades, and all site types combined are roughly 32 percent median-related crashes, 38 percent run-off-road crashes, and 30 percent on-road crashes. There is a more even distribution of crash types for total crashes on sharp curves (roughly 34 percent median-related crashes, 32 percent run-off-road crashes, and 34 percent on-road crashes) than for ramps and steep grades. The proportions for FI crashes on sharp curves (roughly 36 percent median-related crashes, 29 percent run-off-road crashes, and 35 percent on-road crashes) vary slightly more than for total crashes on sharp curves. Furthermore, it is evident that, as the curve radius decreases, the proportion of median-related crashes increases and the proportion of on-road crashes decreases, for crashes of all severity levels combined, as follows:

- Curve radius from 3,000 to 4,500 feet (25 percent median-related crashes);
- Curve radius from 2,000 to less than 3,000 feet (33 percent median-related crashes); and
- Curve radius less than 2,000 feet (40 percent median-related crashes).

Table 5-7 compares crash rates by crash type for crash rate per mile per year and crash rate per million vehicle-miles of travel on rural freeways in Washington.

Table 5-6. Comparison of crash type distributions by ramp category, curve category, and grade category.

	Number of crashes by crash type (2004–2008)				Percent of crashes by crash type		
Type of segment	Median related	ROR right	On road	Total	Median related	ROR right	On road
Ramp Category							
Off ramp	404	391	730	1525	26.5	25.6	47.9
On ramp	289	297	488	1074	26.9	27.7	45.4
No ramp present	2387	2442	3788	8617	27.7	28.3	44.0
All segments combined	3080	3130	5006	11216	27.5	27.9	44.6
Curve Category							
Radius < 2,000 ft (left)	145	101	111	357	40.6	28.3	31.1
Radius < 2,000 ft (right)	155	142	94	391	39.6	36.3	24.0
Radius 2,000 to < 3,000 ft (left)	104	85	91	280	37.1	30.4	32.5
Radius 2,000 to < 3,000 ft (right)	108	122	124	354	30.5	34.5	35.0
Radius 3,000 to 4,500 ft (left)	79	80	116	275	28.7	29.1	42.2
Radius 3,000 to 4,500 ft (right)	66	99	135	300	22.0	33.0	45.0
All curves < 2,000 ft	300	243	205	748	40.1	32.5	27.4
All curves 2,000 to < 3,000 ft	212	207	215	634	33.4	32.6	33.9
All curves 3,000 to 4,500 ft	145	179	251	575	25.2	31.1	43.7
All left curves	328	266	318	912	36.0	29.2	34.9
All right curves	329	363	353	1045	31.5	34.7	33.8
All sharp curves	657	629	671	1957	33.6	32.1	34.3
No sharp curve	2423	2501	4335	9259	26.2	27.0	46.8
Grade Category							
5%+ downgrade	87	84	129	300	29.0	28.0	43.0
4% to 5% downgrade	117	149	169	435	26.9	34.3	38.9
5%+ upgrade	71	83	123	277	25.6	30.0	44.4
4% to 5% upgrade	102	100	156	358	28.5	27.9	43.6
All 5%+ grades	158	167	252	577	27.4	28.9	43.7
All 4% to 5% grades	219	249	325	793	27.6	31.4	41.0
All steep downgrades	204	233	298	735	27.8	31.7	40.5
All steep upgrades	173	183	279	635	27.2	28.8	43.9
All steep grades	377	416	577	1370	27.5	30.4	42.1
No steep grade	2703	2714	4429	9846	27.5	27.6	45.0

Table 5-7. Comparison of crash rates by type of segment and crash type for rural freeways in Washington.

	Crash rate per mile per year (2004–2008)				Crash rate per MVMT (2004–2008)			
Type of segment	**Median-related crashes**	**ROR right crashes**	**On-road crashes**	**Total crashes**	**Median-related crashes**	**ROR right crashes**	**On-road crashes**	**Total crashes**
Ramp Category								
Off ramp	0.870	0.842	1.571	3.283	0.1588	0.154	0.287	0.599
On ramp	0.829	0.851	1.399	3.079	0.1457	0.150	0.246	0.541
No ramp present	0.627	0.642	0.996	2.265	0.1376	0.141	0.218	0.497
All segments combined	0.667	0.678	1.084	2.429	0.1408	0.143	0.229	0.513
Curve Category								
Radius < 2,000 ft (left)	2.363	1.646	1.809	5.819	0.490	0.341	0.375	1.207
Radius < 2,000 ft (right)	2.526	2.315	1.532	6.373	0.524	0.480	0.318	1.322
Radius 2,000 to < 3,000 ft (left)	1.015	0.830	1.201	3.045	0.210	0.172	0.249	0.630
Radius 2,000 to < 3,000 ft (right)	1.054	1.191	1.210	3.455	0.218	0.247	0.251	0.715
Radius 3,000 to 4,500 ft (left)	0.674	0.682	0.989	2.345	0.150	0.152	0.220	0.522
Radius 3,000 to 4,500 ft (right)	0.563	0.844	1.151	2.559	0.125	0.188	0.256	0.570
All curves < 2,000 ft	2.445	1.980	1.671	6.096	0.507	0.411	0.347	1.264
All curves 2,000 to < 3,000 ft	1.035	1.010	1.205	3.250	0.214	0.209	0.250	0.673
All curves 3,000 to 4,500 ft	0.618	0.763	1.070	2.452	0.138	0.170	0.238	0.546
All left curves	1.167	0.946	1.245	3.359	0.249	0.202	0.266	0.717
All right curves	1.171	1.292	1.256	3.718	0.250	0.276	0.268	0.793
All sharp curves	1.169	1.119	1.251	3.539	0.249	0.239	0.267	0.755
No sharp curve	0.597	0.617	1.061	2.275	0.126	0.130	0.224	0.480
Grade Category								
5%+ downgrade	1.176	1.135	1.743	4.054	0.339	0.327	0.503	1.169
4% to 5% downgrade	0.948	1.207	1.370	3.525	0.234	0.298	0.339	0.871
5%+ upgrade	0.959	1.122	1.662	3.743	0.277	0.323	0.479	1.079
4% to 5% upgrade	0.827	0.810	1.264	2.901	0.204	0.200	0.312	0.716
All 5%+ grades	1.068	1.128	1.703	3.899	0.308	0.325	0.491	1.124
All 4% to 5% grades	0.887	1.009	1.317	3.213	0.219	0.249	0.325	0.794
All steep downgrades	1.033	1.180	1.510	3.723	0.270	0.308	0.394	0.972
All steep upgrades	0.876	0.927	1.413	3.217	0.229	0.242	0.369	0.840
All steep grades	0.955	1.054	1.461	3.470	0.249	0.275	0.382	0.906
No steep grade	0.640	0.643	1.049	2.332	0.133	0.133	0.218	0.484

5.4 Involvement of Road Surface Condition in Median-Related Crashes and Other Crash Types

The percentage of crashes on wet and snow-covered pavements was compared for median-related crashes and other crash types on rural freeways in Washington. The climate in Washington includes both extremely wet and extremely dry regions, and rural freeways are found in both environments.

Table 5-8 shows that median-related and run-off-road right crashes include a substantially higher percentage of crashes on wet or snow-covered pavements than on-road crashes (62 and 60 percent vs. 35 percent). This clearly implies that loss of control on wet or snow-covered pavements has a more important role in crashes in which a vehicle leaves the road than in on-road crashes.

For median-related crashes, the table indicates that

- The percentage of median-related crashes on wet or snow-covered pavements is slightly higher for off-ramps than for on-ramps or locations where no ramp is present.
- For sites with curves, the percentage of median-related crashes on wet and snow-covered pavements increases as the curve radius decreases.
- Sites with steep grades experience a higher percentage of median-related crashes on wet or snow-covered pavement than sites not on steep grades.

5.5 Discussion of Contributing Factors

The crash analysis for rural freeways in Washington confirmed that the following contributing factors, identified in the interdisciplinary field reviews, are, in fact, overrepresented in median-related crashes:

- On- and off-ramps;
- Sharp curves (with radii of less than 3,000 feet);
- Steep grades (4 percent or more); and
- Wet and snow-covered pavement conditions.

Other contributing factors, including combinations of the factors noted here, did not have sufficient sample sizes for their contributions to be formally tested.

Table 5-8. Comparison of percent of crashes on wet or snow-covered pavement by crash type for rural freeway crashes in Washington.

	Percent of crashes on wet or snow-covered pavement by crash type		
Type of segment	**Median related**	**ROR right**	**On road**
Ramp Category			
Off ramp	68.1	62.7	39.3
On ramp	58.8	57.9	37.5
No ramp present	61.8	59.7	33.3
All segments combined	62.3	59.9	34.6
Curve Category			
Radius < 2,000 ft (left)	82.1	63.4	51.3
Radius < 2,000 ft (right)	70.3	75.4	57.5
Radius 2,000 to < 3,000 ft (left)	69.2	60.0	45.3
Radius 2,000 to < 3,000 ft (right)	48.2	58.2	28.8
Radius 3,000 to 4,500 ft (left)	73.4	57.5	36.2
Radius 3,000 to 4,500 ft (right)	50.0	57.6	29.6
No sharp curve	61.0	59.1	33.6
Grade Category			
5%+ downgrade	73.6	61.9	51.9
4% to 5% downgrade	71.8	56.4	31.1
5%+ upgrade	77.5	74.7	37.4
4% to 5% upgrade	73.5	82.0	39.1
No steep grade	60.8	58.7	33.7

SECTION 6

Guidelines for Geometric Design and Countermeasure Implementation to Reduce Median-Related Crashes

Guidelines for reducing median-related crashes can be classified into three general approaches:

- Design guidance to reduce consequences of median encroachments,
- Design guidance to reduce likelihood of median encroachments, and
- Countermeasures to reduce likelihood of median encroachments.

Highway agency efforts to improve median safety on divided highways have focused primarily on the first approach presented above—designing or retrofitting medians of divided highways to reduce the consequences of median encroachments. The AASHTO *Roadside Design Guide* (*55*) and other resources provide guidance on implementing this approach. While this research encourages the first approach, it also directs highway agency attention to the second and third approaches, which are intended to reduce the likelihood that motorists will run off the road into the median in the first place. An effective program to reduce median-related crashes should consider a mix of these three approaches.

Table 6-1 summarizes the design guidance and countermeasures that should be considered in median safety programs. The table includes both general objectives for implementing each of the three approaches to reducing median-related crashes identified above and specific design guidance or countermeasures that should be considered for implementation.

Appendix D presents detailed guidelines for reducing median-related crashes. The guidelines address the three overall approaches for reducing median-related crashes, the objectives of highway agency actions, and the specifics of design guidelines and countermeasures for implementation. The discussion of each guideline or countermeasure describes the guideline or countermeasure and presents what is known about its effectiveness. The appendix is in a form that could be used as a stand-alone guide.

Table 6-1. Design guidelines and crash countermeasures to reduce median-related crashes.

Objective	Design guidance/countermeasure
Design guidance to reduce consequences of median encroachments	
Minimize potential for collision with fixed objects	Relocate or remove fixed objects in median
Reduce consequences of collision with fixed objects	Provide barrier to shield objects in median
Reduce likelihood of cross-median collisions	Provide wider medians Provide continuous median barrier
Reduce likelihood of vehicle overturning	Flatten median slopes Provide U-shaped (rather than V-shaped) median cross section Provide barrier to shield steep slopes
Design guidance to reduce likelihood of median encroachments	
Improve design of geometric elements	Provide wider median shoulder Minimize sharp curves with radii less than 3,000 feet Minimize steep grades of 4 percent or more
Improve design of mainline ramp terminals	Increase separation between on- and off-ramps Minimize left-hand exits Improve design of merge and diverge areas by lengthening speed-change lanes Simplify design of weaving areas Increase decision sight-distance to on-ramps
Countermeasures to reduce likelihood of median encroachments	
Reduce driver inattention	Provide edgeline or shoulder rumble strips
Decrease side friction demand	Improve/restore superelevation at horizontal curves
Increase pavement friction	Provide high-friction pavement surfaces
Improve drainage	Improve road surface or cross-slope for better drainage
Reduce high driver workload	Improve visibility and provide better advance warning for on-ramps Improve visibility and provide better advance warning for curves and grades Improve delineation
Encourage drivers to reduce speeds	Provide transverse pavement markings
Minimize weather-related crashes	Provide weather-activated speed signs Provide static signs warning of weather conditions (e.g., bridge freezes before road surface) Apply sand or other materials to improve road surface friction Apply chemical de-icing or anti-icing as a location-specific treatment Improve winter maintenance response times Install snow fences Raise the state of preparedness for winter maintenance

SECTION 7

Conclusions and Recommendations

The conclusions of the research are as follows:

1. Median encroachments are initiated both from loss of control by drivers of single vehicles and by vehicle–vehicle interactions that result in one or more vehicles leaving the roadway and entering the median. Review of crash data for sites with high frequencies of median-related crashes found that 73 percent of median-related crashes began with a single vehicle losing control, while 27 percent resulted from vehicle–vehicle interactions.
2. Review of crash data for sites with high frequencies of median-related crashes found that 55 percent of median-related crashes occurred under wet or snow-covered pavement conditions, while 45 percent of median-related crashes occurred under dry pavement conditions. Wet and snow-covered pavements appear to be overrepresented in median-related crashes, since the proportion of days with precipitation of 0.01 inches or more ranges from 16 to 39 percent for the four states studied (California, Missouri, Ohio, and Washington).
3. Based on interdisciplinary field studies for sites in California, Missouri, Ohio, and Washington with high median-related crash frequencies, the following factors were found to contribute to the occurrence of median-related crashes on divided highways:
   - On-ramps,
   - Off-ramps,
   - Closely spaced on- and off-ramps,
   - Sharp horizontal curves,
   - Steep grades,
   - Bridges,
   - At-grade intersections, and
   - Wet and snow-covered pavement conditions.

   These factors were found to contribute to median-related crashes both individually and in combination.
4. Countermeasures recommended to reduce the likelihood of median encroachments include the following:
   - Provide edgeline or shoulder rumple strips;
   - Improve/restore superelevation at horizontal curves;
   - Provide high-friction pavement surfaces;
   - Improve road surface or cross-slope for better drainage;
   - Improve visibility and provide better advance warning for on-ramps;
   - Improve visibility and provide better advance warning for curves and grades;
   - Improve delineation;
   - Provide transverse pavement markings;
   - Provide weather-activated speed signs;
   - Provide static signs warning of weather conditions (e.g., bridge freezes before road surface);
   - Apply sand or other materials to improve road surface friction during winter storms;
   - Apply chemical de-icing or anti-icing as a location-specific treatment;
   - Install snow fences; and
   - Raise the state of preparedness for winter maintenance.
5. Appendix D provides recommended guidelines for reducing the consequences and likelihood of median-related crashes. The guidelines address the application of each design treatment or countermeasure together with known information on the effectiveness of each design treatment of countermeasure. Appendix D presents effectiveness measures for each design treatment or countermeasures whose effect on crash frequency or severity is known. Further research would be desirable to establish effectiveness measures for other design treatments and countermeasures.
6. A separate analysis of crash data for rural freeways in Washington confirmed that the following factors are overrepresented in median-related crashes:
   - On-ramps;
   - Off-ramps;

- Sharp horizontal curves (particularly curves with radii of less than 3,000 feet);
- Steep grades (particularly grades of 4 percent or more, including both upgrades and downgrades); and
- Wet and snow-covered pavement conditions.

Other potential contributing factors and combinations of contributing factors could not be verified as contributing to median-related crashes either because of limited sample sizes of sites and crashes or because of lack of systemwide data. Although no separate confirmation could be developed for some factors, the interdisciplinary field studies, by themselves, provide evidence that all of the factors listed in Conclusion 3 contribute to median-related crashes.

7. Conclusions 3 and 4 indicate that improvements to the contributing factors listed there have the potential to reduce the frequency of median-related crashes and can supplement traditional median safety programs that focus on reducing the consequences of leaving the roadway and encroaching on the median.
8. Crash data analysis found that as the radius of a horizontal curve decreases (i.e., as a curve gets sharper), the proportion of median-related crashes increases and the proportion of on-road crashes decreases.

The following recommendations were developed in the research:

1. The traditional approach to improving median safety involves design improvements to reduce the consequences of median encroachments. The following design improvements are recommended to implement this approach to improving median safety:
   - Remove, relocate, or use breakaway design for fixed objects in medians;
   - Provide barrier to shield objects in medians;
   - Provide wide medians;
   - Provide continuous median barrier;
   - Flatten median slopes;
   - Provide U-shaped (rather than V-shaped) median cross sections; and
   - Provide barrier to shield steep slopes in median.
2. The research confirms that median safety also can be improved by design treatments and countermeasures to reduce the likelihood of median encroachments (i.e., using design treatments and countermeasures to make it less likely that motorists will run off the roadway into the median).
3. Design treatments recommended to reduce the likelihood of median encroachments include the following:
   - Provide wider median shoulders;
   - Minimize the use of sharp horizontal curves with radii less than 3,000 feet;
   - Minimize use of steep grades of 4 percent or more;
   - Increase separation between on- and off-ramps;
   - Minimize left-hand exits;
   - Improve design of merge and diverge areas by lengthening speed-change lanes;
   - Simplify design of weaving areas; and
   - Increase decision sight-distance to on-ramps.

   High-cost treatments, such a realigning curves or grades, may be impractical for existing roadways and may be applicable primarily in design of new construction projects.
4. Countermeasures recommended to reduce the likelihood of median encroachments include the following:
   - Provide edgeline or shoulder rumble strips;
   - Improve/restore superelevation at horizontal curves;
   - Provide high-friction pavement surfaces;
   - Improve road surface or cross-slope for better drainage;
   - Improve visibility and provide better advance warning for on-ramps;
   - Improve visibility and provide better advance warning for curves and grades;
   - Improve delineation;
   - Provide transverse pavement markings;
   - Provide weather-activated speed signs;
   - Provide static signs warning of weather conditions (e.g., bridge freezes before road surface);
   - Apply sand or other materials to improve road surface friction during winter storms;
   - Apply chemical de-icing or anti-icing as a location-specific treatment;
   - Install snow fences; and
   - Raise the state of preparedness for winter maintenance.
5. Appendix D provides recommended guidelines for reducing the consequences and likelihood of median-related crashes. The guidelines address the application of each design treatment or countermeasure together with known information on the effectiveness of each design treatment or countermeasure. Appendix D presents effectiveness measures for each design treatment or countermeasure whose effect on crash frequency or severity is known. Further research would be desirable to establish effectiveness measures for other design treatments and countermeasures.

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Abbreviations

AADT	Average annual daily traffic
ADT	Average daily traffic
B/C	Benefit-cost
CMC	Cross-median collision
CMF	Crash modification factor/function
EB	Empirical Bayes
FI	Fatal-and-injury
HMMS	Highway Maintenance Management System
HSIS	Highway Safety Information System
HSM	*Highway Safety Manual*
MoDOT	Missouri Department of Transportation
MVMT	Million vehicle-miles traveled
NB	Negative binomial
NCMC	Non-collision cross-median crash
NM	Negative multinomial
NOAA	National Oceanic and Atmospheric Administration
PDO	Property-Damage-Only
RENB	Random-effects negative binomial
RSA	Road Safety Audit
RSAP	Roadside Safety Analysis Program
SE	Standard errors
SVROR	Single-vehicle run-off-the-road
TMS	Transportation Management System
TOPS	Traffic Operations and Safety

APPENDIXES A THROUGH C

Appendixes A through C of the contractor's final report are not published herein but are available on the TRB website and can be found by searching for NCHRP Report 790.

APPENDIX D

Guidelines for Reducing the Frequency and Severity of Median-Related Crashes on Divided Highways

Introduction

This appendix describes methods to reduce the frequency and severity of median-related crashes on divided highways.

Guidelines for reducing median-related crashes can be classified into three general approaches:

1. Design guidance to reduce consequences of median encroachments,
2. Design guidance to reduce likelihood of median encroachments, and
3. Countermeasures to reduce likelihood of median encroachments.

Highway agency efforts to improve median safety on divided highways have focused primarily on the first approach presented above—designing or retrofitting medians of divided highways to reduce the consequences of median encroachments. The AASHTO *Roadside Design Guide* and other resources provide guidance on implementing this approach. Although this research encourages the first approach, it also directs highway agency attention to the second and third approaches, which are intended to reduce the likelihood that motorists will run off the road into the median in the first place. An effective program to reduce median-related crashes should consider a mix of these three approaches.

Table D-1 summarizes the design guidance and countermeasures that should be considered in median safety programs. This table includes both general objectives for implementing each of the three approaches to reducing median-related crashes and specific design guidance or countermeasures that should be considered for implementation.

The following sections review specific design guidelines and countermeasures and include, where available, estimates of their safety effectiveness. The safety effectiveness of design guidelines and countermeasures is based on three general sources: the Roadside Safety Analysis Program (RSAP) model (Mak and Sicking, 2003); the new safety prediction procedure for freeways developed in NCHRP Project 17-45 (Bonneson et al., 2012) for implementation in the AASHTO *Highway Safety Manual* (HSM) (AASHTO, 2010); and other individual sources in the literature. Both RSAP and the HSM include safety prediction models and cost-effectiveness/benefit-cost procedures for assessing design treatments and countermeasures. Unfortunately, the RSAP and HSM safety prediction models are based on inconsistent assumptions, since RSAP is based on estimated median encroachment frequencies and the HSM is based on reported crash frequencies. Research is under way in NCHRP Project 17-54 to try to make the RSAP and HSM more compatible, but no results are yet available.

Design Guidance to Reduce Consequences of Median Encroachments

The consequences of median encroachments can be reduced through the following design treatments:

- Remove, relocate, or use breakaway design for obstacles in median;
- Provide barrier to shield objects in median;
- Provide wider medians;
- Provide continuous median barrier;
- Flatten median slopes;
- Provide U-shaped (rather than V-shaped) median cross sections; and
- Provide barrier to shield steep slopes in medians.

All of these design improvements have the potential to reduce crash severity for motorists who run off the road into the median. Current design guidance for these treatments is presented in the AASHTO *Green Book* (AASHTO, 2011a) and the AASHTO *Roadside Design Guide* (AASHTO, 2011b). The

Table D-1. Design guidelines and crash countermeasures to reduce median-related crashes.

Objective	Design guidance/countermeasure
Design guidance to reduce consequences of median encroachments	
Minimize potential for collision with fixed objects	Relocate or remove fixed objects in median
Reduce consequences of collision with fixed objects	Provide barrier to shield objects in median
Reduce likelihood of cross-median collisions	Provide wider medians Provide continuous median barrier
Reduce likelihood of vehicle overturning	Flatten median slopes Provide U-shaped (rather than V-shaped) median cross section Provide barrier to shield steep slopes
Design guidance to reduce likelihood of median encroachments	
Improve design of geometric elements	Provide wider median shoulder Minimize sharp curves with radii less than 3,000 ft Minimize steep grades of 4% or more
Improve design of mainline ramp terminals	Increase separation between on- and off-ramps Minimize left-hand exits Improve design of merge and diverge areas by lengthening speed-change lanes Simplify design of weaving areas Increase decision sight-distance to on-ramps
Countermeasures to reduce likelihood of median encroachments	
Reduce driver inattention	Provide edgeline or shoulder rumble strips
Decrease side friction demand	Improve/restore superelevation at horizontal curves
Increase pavement friction	Provide high-friction pavement surfaces
Improve drainage	Improve road surface or cross-slope for better drainage
Reduce high driver workload	Improve visibility and provide better advance warning for on-ramps Improve visibility and provide better advance warning for curves and grades Improve delineation
Encourage drivers to reduce speeds	Provide transverse pavement markings
Minimize weather-related crashes	Provide weather-activated speed signs Provide static signs warning of weather conditions (e.g., bridge freezes before road surface) Apply sand or other materials to improve road surface friction Apply chemical de-icing or anti-icing as a location-specific treatment Improve winter maintenance response times Install snow fences Raise the state of preparedness for winter maintenance

following discussion reviews each design treatment and documents known effectiveness measures for those treatments. Several of these treatments, by their nature, have high costs and may be most appropriate for consideration in new construction and reconstruction projects, rather than for application to existing roadways.

Remove, Relocate, or Use Breakaway Design for Obstacles in Median

A key strategy for improving median safety is to remove or relocate fixed objects located within the median in positions were they may be struck by vehicles that leave the roadway and enter the median. Such objects may include trees, utility poles, luminaire supports, signs and sign bridge supports, culverts and their appurtenances, bridge abutments and bridge supports, and other miscellaneous fixed objects. For any median fixed object that is reviewed, all three potential treatments—removing the object completely, relocating it to a less exposed position (farther from the roadway or less likely to be struck), or converting the object to a breakaway design—should be considered. Another potential alternative is providing guardrail to shield objects in the median (see next section on shielding). The AASHTO *Roadside Design Guide* (AASHTO, 2011b) provides detailed guidance on treatment of roadside obstacles.

The RSAP model provides a benefit-cost analysis tool to assess roadside design issues, including the location and type of roadside fixed objects (Mak and Sicking, 2003). RSAP is intended for analysis of the roadside on the outside of the roadway, but analysis of the equivalent fixed objects provides the best available method to analyze objects in the median.

Provide Barrier to Shield Objects in Median

Another alternative for consideration where objects in the median of a divided highway cannot be removed, relocated, or converted to breakaway design is to provide a guardrail or other barrier to prevent vehicles that run off the road into the median from striking the objects. This approach is generally less desirable than removing, relocating, or converting the object to breakaway design because guardrail is itself a roadside obstacle that can kill or injure drivers and passengers in vehicles that strike the guardrail. Thus, guardrail is generally provided for roadside obstacles only when removing, relocating, or converting the object to breakaway design is impractical and only when it is verified that the risk to vehicle occupants from striking the guardrail is less that the risk of striking the object. Tradeoff analyses of the relative risks of striking guardrails or obstacles are generally performed with the RSAP model (Mak and Sicking, 2003; RoadSafe LLC, 2012a; RoadSafe LLC, 2012b). Concrete barriers and cable barriers can be considered as an alternative to metal guardrail in these situations.

Provide Wider Medians

Wider medians generally reduce the severity of median encroachments by making it less likely that vehicles that run off the road and enter the median will cross the entire median, enter the opposing roadway and become involved in a cross-median collision (CMC) crash or a non-collision cross-median crash (NCMC). A wider median should provide more opportunity for drivers of vehicles entering the median to be able to recover control of the vehicle or come safely to rest.

Design guidelines for median width are presented in the AASHTO *Green Book* (AASHTO, 2011a). The design guidance in the AASHTO *Roadside Design Guide* (AASHTO, 2011b) focuses specifically on design criteria for median barriers (which are, in part, influenced by median width) and design criteria for fixed objects in the median.

Pennsylvania research has quantified the influence of median width on CMC crashes as follows (Mason et al., 2001):

$$N_{CMC} = 0.2 \times e^{-18.203} \times L \times AADT^{1.770} \times e^{-0.0165MW} \tag{D-1}$$

where

N_{CMC} = number of CMC crashes per year for one direction of travel
L = segment length (mi)
ADT = average daily traffic (veh/day)
MW = median width (ft)

New HSM procedures for freeways developed in NCHRP Project 17-45 (Bonneson et al., 2012) include the following crash modification functions (CMFs) for median width:

$$\begin{aligned} \mathrm{CMF} = {} & (1.0 - P_{ib}) \exp(a[W_m - 2W_{is} - 48]) \\ & + P_{ib} \exp(a[2W_{icb} - 48]) \end{aligned} \tag{D-2}$$

where

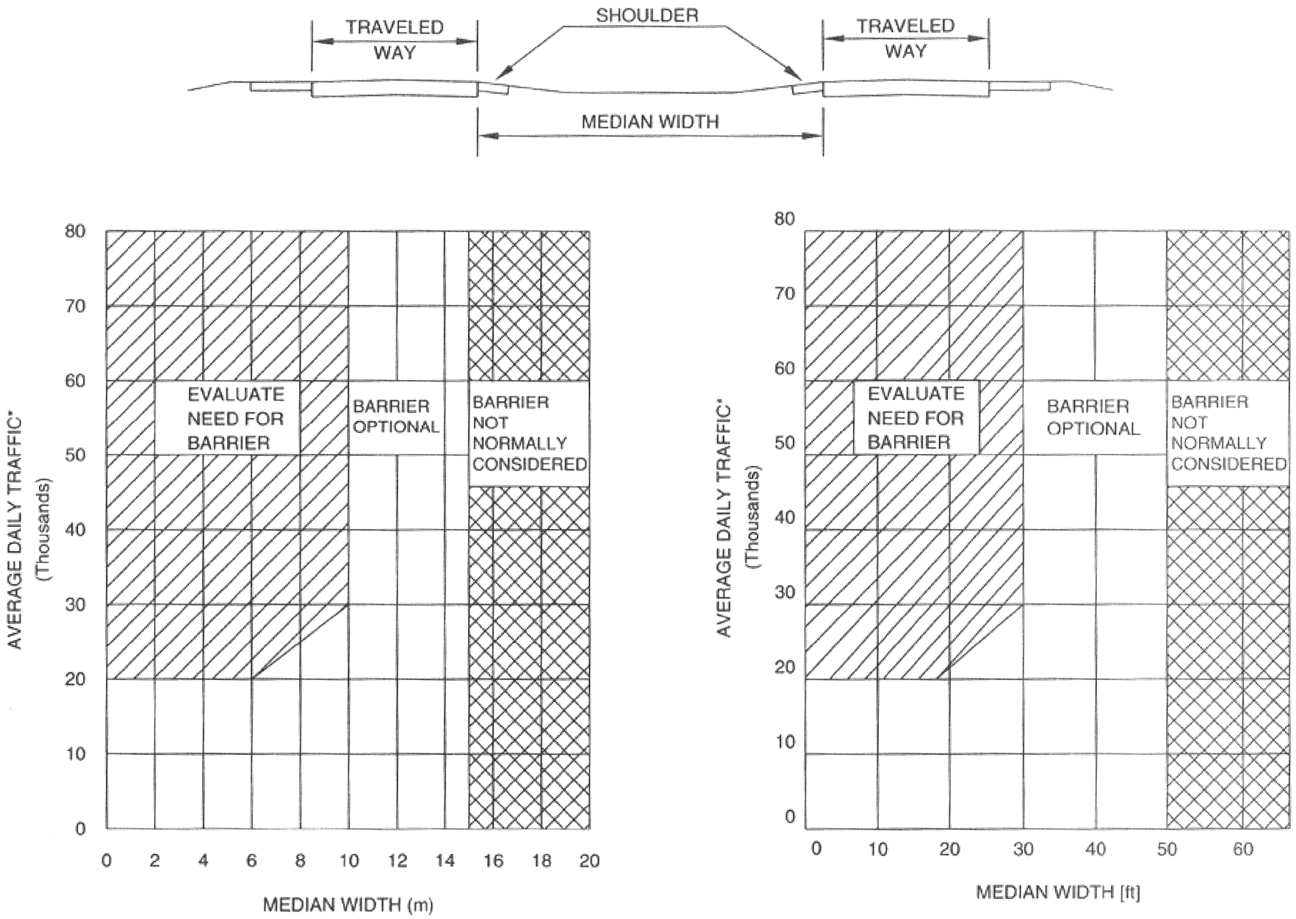
P_{ib} = proportion of segment length with a barrier present in the median
W_m = median width (measured between the inside edges of the traveled way) (ft)
W_{icb} = distance from edge of inside shoulder to barrier face
W_{is} = width of inside shoulder (ft)
a = regression coefficient:
–0.00302 for multiple-vehicle FI crashes
–0.00291 for multiple-vehicle PDO crashes
0.00102 for single-vehicle FI crashes
–0.00289 for single-vehicle PDO crashes

Provide Continuous Median Barrier

Highway agencies often provide continuous median barrier to reduce the risk of vehicles running across the median—CMC and NCMC crashes—to near zero. The AASHTO *Roadside Design Guide* (AASHTO, 2011b) provides guidance on situations in which a median barrier should be considered on divided highways as a function of median width and traffic volume (see Figure D-1). The figure shows that median barriers are considered warranted in specific design situations where the traffic volume on the divided highway exceeds 30,000 vehicles per day.

Three types of median barrier are in general use: concrete barrier, metal guardrail, and cable barrier. Concrete barrier is generally placed at the center of a median. Metal guardrail is generally placed in the center of the median only in relatively narrow medians; in wider medians, metal guardrail may be placed near the edge of the inside shoulder so that any vehicles that strike the guardrail will do so at a relatively shallow angle. Cable barrier has typically been placed in the center of the median, but some highway agencies have begun placing cable barrier just outside the shoulder on one side of the median or on the median slope toward one side of the median. NCHRP Project 22-22 has been charged with developing placement guidelines for median barriers, but is not yet complete.

Research by Graham et al. (2011) found that cable barriers may be cost-effective in some divided highway medians with average daily traffic volumes as low as 10,000 vehicles per day.



*Based on a 5-year projection

Figure D-1. Guidelines for median barriers on high-speed, fully controlled access roadways (AASHTO, 2011b).

New HSM procedures for freeways developed in NCHRP Project 17-45 (Bonneson et al., 2012), include the following CMFs for placement of continuous median barrier:

$$\mathrm{CMF} = (1.0 - P_{ib}) + \left(P_{ib} \exp\left(\frac{a}{W_{icb}} \right) \right) \qquad \text{(D-3)}$$

where

a = regression coefficient (0.240 for FI crashes and 0.169 for PDO crashes)

Flatten Median Slopes

Providing flatter median slopes can reduce the likelihood that drivers of vehicles that run off the road into the median will be able to avoid overturning and will be able to regain control of their vehicles or come to a stop before crossing the median or striking a fixed object. The AASHTO *Green Book* (AASHTO, 2011a) recommends the use of 1V:6H slopes in design of medians. Recent research in NCHRP Project 22-21 (Graham et al., 2011) has recommended that flatter 1V:8H slopes be considered instead.

Provide U-Shaped (Rather than V-Shaped) Median Cross-Sections

The AASHTO Green Book (AASHTO, 2011a) does not provide specific guidance on the overall shape of median cross sections. However, many highway agencies build divided highway medians with V-shaped cross sections, as continuous slopes from the edge of each inside shoulder meet at the center of the median. Recent research in NCHRP Project 22-21 (Graham et al., 2011) recommended that U-shaped median cross sections be considered in preference to V-shaped medians. The flat area in the center of the median appears to create a preferable design.

Provide Barrier to Shield Steep Median Slopes

Just as guardrail and other barriers can be used to shield fixed objects in the median from being struck by vehicles that run off the road, guardrail or other barriers also can be used to ensure that vehicles that run off the road do not encounter steep slopes on which they might overturn. As in the case of barrier to shield fixed objects, the most applicable tools of barrier to shield steep slopes in median areas are the RSAP model (Mak and Sicking, 2003; RoadSafe LLC, 2012a; RoadSafe LLC, 2012b) and the new freeway models for the HSM (AASHTO, 2010) developed in NCHRP Project 17-45 (Bonneson et al., 2012).

Design Guidance to Reduce Likelihood of Median Encroachments

The likelihood of median encroachments can be reduced through the following design treatments:

- Provide wider median shoulder,
- Minimize use of sharp curves with radii less than 3,000 feet,
- Minimize use of steep grades of 4 percent or more,
- Increase separation between on- and off-ramps,
- Minimize left-hand exits,
- Improve design of merge and diverge areas by lengthening speed-change lanes,
- Simplify design of weaving areas, and
- Increase decision sight-distance to on-ramps.

The importance of these design treatments to the likelihood of median-related crashes is not well addressed in current design guidance and, therefore, is addressed here.

Provide Wider Median Shoulder

The median or inside shoulder of a divided highway is intended as a primary recovery area for vehicles that begin to leave the roadway and, in some cases, as a primary stopping and recovery area. This distinction is made because many highway agencies prefer to provide relatively narrow (4-foot) median shoulders to discourage motorists from stopping on the median shoulder; a wider shoulder is provided on the right side of the roadway and often highway agencies prefer that motorists that need to stop use the right or outside shoulder for that purpose.

The new HSM freeway procedure developed in NCHRP Project 17-45 includes the following CMF for inside or median shoulder width:

$$\mathrm{CMF} = \exp(a[W_{is} - 6]) \qquad \text{(D-4)}$$

where

a = regression coefficient (−0.0172 for FI crashes and −0.0153 for PDO crashes)

Table D-2 shows the crash modification factor (CMF) for converting from one inside shoulder width to another, based on Equation D-4. These CMFs apply to all crash types, not specifically to median-related crashes. There are no equivalent CMFs for divided highways that are not freeways.

It should be noted that the CMFs in Table D-2 do not show any reason to discourage wider inside shoulders—the wider the inside shoulder, the lower the resulting crash rate. It should be recognized, however, that crash prediction models are not necessarily good tools to reflect such design guidance. Nothing in the new HSM material should be taken as implying that highway agency preferences for using narrow insider

Table D-2. CMFs for changing inside shoulder width on freeways (computed from results of Bonneson et al., 2012).

Inside Shoulder Width (ft) (Before)	Inside Shoulder Width (ft) (After)					
	2	4	6	8	10	12
Fatal-and-Injury Crashes (FI)						
2	1.00	0.97	0.93	0.90	0.87	0.84
4	1.03	1.00	0.97	0.93	0.90	0.87
6	1.07	1.03	1.00	0.97	0.93	0.90
8	1.11	1.07	1.03	1.00	0.97	0.93
10	1.15	1.11	1.07	1.03	1.00	0.97
12	1.19	1.15	1.11	1.07	1.03	1.00
Property-Damage-Only Crashes (PDO)						
2	1.00	0.97	0.94	0.91	0.88	0.86
4	1.03	1.00	0.97	0.94	0.91	0.88
6	1.06	1.03	1.00	0.97	0.94	0.91
8	1.10	1.06	1.03	1.00	0.97	0.94
10	1.13	1.10	1.06	1.03	1.00	0.97
12	1.17	1.13	1.10	1.06	1.03	1.00

shoulders and wider outside shoulders necessarily needs to be changed.

Minimize Use of Sharp Curves with Radii Less Than 3,000 Feet

Research by Harwood et al. (2014) identified sharp curves with radii less than 3,000 feet as a key contributing factor to median-related crashes. This finding was suggested in interdisciplinary field reviews of crash history and roadway characteristics at selected divided highway sites and confirmed in crash data analyses for rural freeways in Washington.

To minimize median-related crashes, it is recommended that curve radii less than 3,000 feet be avoided on divided highways, whenever practical. It is clearly impractical to change the curve radii for existing roadways and it may be impractical to avoid designing sharp curves in mountainous terrain, so this design guideline applies to new divided highways that may be constructed in the future.

The role of sharp curves in median-related crashes also suggests that where median improvements to reduce crash severity (like those discussed above) are being considered, it may be appropriate to apply those treatments to curves with radii less than 3,000 feet, even when they are not applied along the full length of the roadway.

Minimize Use of Steep Grades of 4 Percent or More

Research by Harwood et al. (2014) identified steep grades of 4 percent or more as a key contributing factor to median-related crashes. This finding was suggested in interdisciplinary field reviews of crash history and roadway characteristics at selected divided highway sites and confirmed in crash data analyses for rural freeways in Washington.

To minimize median-related crashes, it is recommended that steep grades of 4 percent or more be avoided on divided highways, whenever practical. It is clearly impractical to change the curve radii for existing roadways, and it may be impractical to avoid designing steep grades in mountainous terrain, so this design guideline applies to new divided highways that may be constructed in the future. It should be noted that the design guidelines for the Interstate Highway System generally limit grades to 3 percent, except in mountainous terrain.

The role of steep grades in median-related crashes also suggests that, where median improvements to reduce crash severity (like those discussed above) are being considered, it may be appropriate to apply those treatments to steep grades of 4 percent or more, even when they are not applied along the full length of the roadway.

Increase Separation Between On- and Off-Ramps

Research by Harwood et al. (2014) found that short separation distances between ramps are a contributing factor to median-related crashes. Divided highway sections adjacent to both on- and off-ramps were found to have higher crash rates than divided highway sections not located adjacent to ramps. Interdisciplinary field reviews concluded that short separations between adjacent ramps were a contributing factor to median-related crashes.

Most interchanges consist of an off-ramp followed by an on-ramp. Other ramp combinations, with ramps spaced less than 0.3 miles apart (gore-to-gore spacing), within the same interchange or adjacent interchanges, appear to be contributing factors to median-related crashes, including:

- On-ramp followed by off-ramp,
- On-ramp followed by on-ramp, and
- Off-ramp followed by off-ramp.

It is clearly impractical to reconstruct existing interchanges solely to reduce median-related crashes, so this design guideline applies to new divided highways that may be constructed in the future.

The role of on- and off-ramps in median-related crashes also suggests that, where median improvements to reduce crash severity (like those discussed above) are being considered, it may be appropriate to apply those treatments in the vicinity of ramps—especially closely spaced ramps—even when they are not applied along the full length of the roadway.

Minimize Left-Hand Exits

Research by Harwood et al. (2014) suggests that left-hand exits are a contributing factor to median-related crashes. It is clearly impractical to reconstruct existing interchanges solely to reduce median-related crashes, so this design guideline applies to new divided highways that may be constructed in the future.

Equations D-5 and D-6 show CMFs indicating that left-hand ramps experience substantially more crashes than do right-hand ramps. These CMFs, of course, apply to all crash types and not only to median-related crashes.

The role of left-hand exits in median-related crashes also suggests that, where median improvements to reduce crash severity (like those discussed above) are being considered, it may be appropriate to apply those treatments in the vicinity of left-hand exits—especially closely spaced ramps—even when they are not applied along the full length of the roadway.

Improve Design of Merge and Diverge Areas by Lengthening Speed-Change Lanes

Research by Harwood et al. (2014) highlighted on- and off-ramps as key contributing factors in median-related crashes. A key element that affects the operation of on- and off-ramps is the design of the merge and diverge areas and their associated speed-change lanes (acceleration and deceleration lanes).

A study of driver physiological workload suggested that the physiological stress associated with merging onto a freeway was 2.2 times as high as in a "basic driving section," peaking at 260 feet beyond the gore for a ramp posted at 50 km/h (31 mph) and a freeway posted at 80 km/h (50 mph), and subsiding 4 seconds after merging (Chang et al., 2001). An acceleration lane that does not allow drivers a comfortable amount of time to reach freeway speed is likely to increase this stress.

HSM Part D indicates that lengthening the speed change lane by 100 feet from a base condition of 690 feet is associated with a 7 percent reduction in crashes (AASHTO, 2010). However, the confidence interval is large and includes the possibility of a crash increase.

The new HSM freeway procedure developed in NCHRP Project 17-45 includes the following CMF for ramp exits (deceleration lanes):

$$\text{CMF} = \exp\left(a\, I_{left} + \frac{b}{L_{ex}}\right) \qquad \text{(D-5)}$$

where

I_{left} = side of road for ramp (1 for left-side ramp; 0 for right-side ramp)

L_{ex} = length of deceleration lane (ft) (range: 160 to 1,600 ft)

a = regression coefficient (0.594 for FI crashes and 0.824 for PDO crashes)

b = regression coefficient (0.0116 for FI crashes and 0.0 for PDO crashes)

The comparable equation for ramp entrances (acceleration lanes) is

$$\text{CMF} = \exp\left(a\, I_{left} + \frac{b}{L_{en}} + d \ln\left[c\, AADT_r\right]\right) \qquad \text{(D-6)}$$

where

L_{en} = length of acceleration lane (ft) (range: 370 to 1,600 ft)

$AADT_r$ = average daily traffic volume for ramp crashes (veh/day)

a = regression coefficient (0.594 for FI crashes and 0.824 for PDO crashes)

b = regression coefficient (0.0318 for FI crashes and 0.0252 for PDO crashes)

c = regression coefficient (0.001 for all crashes)

d = regression coefficient (0.198 for FI crashes and 0.0 for PDO crashes)

Equations D-5 and D-6 illustrate that longer speed-change lanes result in lower crash frequencies. These CMFs apply to all crash types, not specifically to median-related crashes.

Simplify Design of Weaving Areas

Some short weaving areas require drivers to make two lane-change maneuvers to complete a merge or diverge maneuver. Driver workload can be substantially reduced by modifying the design or the marking plan so that only one lane-change maneuver is required.

Driver lane-change distance requirements, including the time to search for and recognize gaps, were studied by McGee et al. (1978). They found that in low-volume conditions a single lane change requires 8 seconds, and, in high volume conditions, 9.8 seconds are required. These data were based on observed single lane change times from a freeway study combined with very limited data on gap search and recognition time from 12 young male drivers.

There are better data available on times for two lane changes, based on time and distance recorded for 20 subjects driving an instrumented vehicle on a multi-lane highway in light (725 vehicles/hour or less), medium (726 to 1,225 vehicles/hour), and heavy (> 1,225 vehicles/hour) traffic. The posted speed limit was 55 mph. Distance was calculated according to the speed traveled and the time taken from signaling to turn from the left-most lane until all four wheels had crossed into the right-most lane. On high-speed roadways (55 mph and above), the average time to complete two lane changes was 15 seconds in medium traffic and 17 seconds in heavy traffic (McNees, 1982). At a design speed of 120 km/h (75 mph), time for one and two lane changes corresponds to travel distances of 1,080 feet and 1,870 feet, respectively.

The reduced workload by means of reducing a merge from two to one lane change is associated with a crash risk reduction of 32 percent for crashes in the merging lane (AASHTO, 2010).

The design of weaving areas also can be improved by providing collector-distributor roads so that weaving maneuvers do not occur adjacent to the mainline roadway. Redesign of interchanges in this way is, of course, very expensive.

Increase Decision Sight-Distance to On-Ramps

Research by Harwood et al. (2014) suggests that limited-sight-distance for traffic approaching on-ramps at some sites is a contributing factor to median-related crashes.

Decision sight-distance is defined as the sight distance that should allow drivers to detect an unexpected or difficult-to-perceive information source or condition, recognize the condition or its potential threat, select an appropriate speed and path, and initiate and complete the maneuver safely and efficiently (Alexander and Lunenfeld, 1975). Examples of traffic control devices and road geometric elements that are high priority with respect to the need to apply or consider decision sight-distance so that drivers can change lanes comfortably include the following among others:

- A guide sign;
- Lane markings indicating a change in cross-section; and
- A change in cross-section (two-lane to four-lane, four-lane to two-lane, passing lane, climbing lane, lane drop, optional lane split, deceleration lane, channelization) (Lerner et al., 2004).

On a freeway, drivers are assisted in identifying the exit or entrance if the gore area has good sight-distance. It has been shown that a significant proportion of drivers wait until they can see the road layout before changing lanes (McGee et al., 1978).

The best data on the amount of sight distance that drivers require is probably the data on decision sight-distance collected by McGee et al. (1978). Drivers were observed as they responded to unusual highway features such as lane drops at an exit or a lane split. Despite warning devices of various kinds, in approximately half the approaches, subjects did not start responding until they actually saw the feature in question. Detection and recognition times varied from a minimum of 1.5 to 3.0 seconds depending on the complexity of the change in the roadway. Decision and response initiation, which includes time to search for a gap prior to changing lanes, took 4.2 to 7.0 seconds and lane change required 3 to 4.5 seconds. On the basis of this work, a decision sight-distance of 11 to 14 seconds at the operating speed is recommended.

Countermeasures to Reduce Likelihood of Median Encroachments

The likelihood of median encroachments can be reduced through the following traffic control and weather-related countermeasures:

- Provide edgeline or shoulder rumble strips;
- Improve/restore superelevation at horizontal curves;
- Provide high-friction pavement surfaces;
- Improve road surface or cross-slope for better drainage;
- Improve visibility and provide better advance warning for on-ramps;
- Improve visibility and provide better advance warning for curves and grades;
- Improve delineation;
- Provide transverse pavement markings;
- Provide weather-activated speed signs;
- Provide static signs warning of weather conditions (e.g., bridge freezes before road surface);
- Apply sand or other materials to improve road surface friction;
- Apply chemical de-icing or anti-icing as a location-specific treatment;
- Improve winter maintenance response times;
- Install snow fences; and
- Raise the state of preparedness for winter maintenance.

The importance of these countermeasures is supported by the results of research by Harwood et al. (2014). That research found wet and snow-covered pavements to be a key contributing factor in median-related crashes. Therefore, any countermeasures that reduce the likely duration of exposure of motorists to adverse pavement conditions or the consequences of that exposure should help reduce median-related crashes. With the exception of the first countermeasure discussed, shoulder rumble strips, the role of these countermeasures in reducing the likelihood of median-related crashes is not well addressed in current design guidance and, therefore, is addressed here.

Provide Edgeline or Shoulder Rumble Strips

The most widely known countermeasure for reducing the likelihood of median encroachments is providing edgeline and shoulder rumble strips. Fatigue and distraction are commonly experienced by drivers and easily can lead to momentary inattention to the road path and, thus, to a median encroachment. Edgeline and shoulder rumble strips alert drivers that they are about to leave the paved roadway and help drivers correct their maneuvers before encroaching on the median.

Shoulder edge rumble strips have been shown to decrease single-vehicle run-off-road crashes by 18 percent on rural and urban freeways combined and by 21 percent on rural freeways (Griffith, 1999).

Torbic et al. (2009) provided the following estimates on the safety effectiveness of shoulder rumble strips on freeways:

Urban/Rural Freeways

Rolled shoulder rumble strips

- 18 percent reduction in single-vehicle run-off-the-road (SVROR) crashes (Standard Error [SE] = 7) and
- 13 percent reduction in SVROR fatal and injury (FI) crashes (SE = 12).

Rural Freeways

Shoulder rumble strips

- 11 percent reduction in SVROR crashes (SE = 6) and
- 16 percent reduction in SVROR FI crashes (SE = 8).

Improve/Restore Superelevation at Horizontal Curves

Appropriate superelevation is important in helping motorists maintain control of their vehicles on horizontal curves. Given the importance of wet pavement conditions as a contributing factor in median-related crashes, as found by Harwood et al. (2014), providing or restoring design superelevation on horizontal curves so that pavements on curves drain properly, may be particularly important. There are no crash-reduction effectiveness estimates for restoring superelevation of divided highway curves.

Provide High-Friction Pavement Surfaces

High-friction pavement is best implemented in areas where drivers are expected to be braking (e.g., in weaving areas, in areas where queuing regularly occurs, on downgrades, and at the entrance to sharp curves). Elvik and Vaa (2004) state that when the friction coefficient is initially higher than 0.7, improvements in friction have no effect on crashes. When the friction coefficient is less than around 0.7, a reduction of the total number of crashes on bare roads of the order of magnitude of 5 to 10 percent can be achieved. This reduction is entirely attributable to fewer crashes on wet and snow-covered road surfaces.

FHWA has encouraged the provision of high-friction pavement surfaces at high-friction-demand areas, such as horizontal curves. To minimize median-related crashes, use of high-friction pavement surfaces at all areas where median-related crashes are most common—on-ramps, off-ramps, sharp curves (radius less than 3,000 feet), and steep grades greater than 4 percent—should be considered.

Improve Road Surface or Cross-Slope for Better Drainage

Just as superelevation was noted as important in maintaining proper drainage to minimize crashes on wet and snow-covered roads, maintenance of the road surface and the normal pavement cross slope (typically 1.5 to 3 percent) also is important. There are no formal crash reduction measures for road surface condition or normal pavement cross slope.

Improve Visibility and Provide Better Advance Warning for On-Ramps

It was noted in the previous section that limited sight-distance to on-ramps for mainline drivers can lead to median-related crashes. Geometric realignment to correct the limitedsight-distance may be impractical for existing sites, but pavement markings and signing may be improved to make the on-ramp more visible. No formal effectiveness measures for this treatment are available.

Improve Visibility and Provide Better Advance Warning for Curves and Grades

It was noted in the previous section that sharp curves (radius less than 3,000 feet) and steep grades (4 percent or more) are associated with increased levels of median-related crashes. Geometric realignment to flatten the curves or reduce the grades is likely to be impractical for existing sites, but advance signing may assist drivers to anticipate the curves and grades. No formal effectiveness measures for this treatment are available.

Improve Delineation

Improvements to delineation improve driver path preview in poor weather and at night. This in turn increases driver confidence, and reduces driver workload. In some geometric conditions, improved delineation reduces crash risk. In other conditions, improved delineation can lead to higher speeds and increased crashes.

A study in Finland examined the impact of post-mounted delineators on roads of various standards, those with higher standards posted at 100 km/h (62 mph) and those with lower standards posted at 80 km/h (50 mph) (Kallberg, 1993). Twenty pairs of road sections were selected, and one of each pair was randomly assigned to have post-mounted delineators, thus avoiding a potential regression-to-the-mean effect. Improved guidance with post-mounted delineators had minimal effects on nighttime speed or on crashes on 100 km/h (62 mph) roads. On the 80 km/h (50 mph) roads; however, the speeds increased at night, with a highly significant 40 to 60 percent increase in nighttime injury crashes.

An NCHRP evaluation of raised pavement markers on undivided highways and freeways applied Empirical Bayes (EB) statistical techniques to data from several hundred miles of roadway (Bahar et al., 2004). The results strongly confirmed Kallberg's findings that improving path delineation on lower standard roadways (i.e., sharper curves) leads to more crashes. Raised pavement markers placed on sharp curves—that is, with greater than 3.5 degrees of curvature—on low-volume roadways with an average annual daily traffic (AADT) of less than 5,000 vehicles per day were associated with a 43 percent increase in crashes when compared to the number of crashes when the pavement markers were not present. The best effect is on freeways with traffic volumes of more than 60,000 veh/day—the number of crashes on roads equipped with raised pavement markers is 67 percent of the number of crashes on roads not so equipped.

In 2005 and 2006, the Missouri Department of Transportation (MoDOT) undertook a major program to improve both the rideability and the visibility of over 2,300 miles of major roadways in Missouri, including most of the Interstate Highway System in Missouri, as well as freeways and expressways; some multilane and two-lane undivided roads were included. The striping and delineation improvements included the following:

- Wider and higher visibility lane lines;
- Wider edgelines with rumble strips;
- Centerline rumble strips (on undivided highways only);
- Barrier-mounted delineators (on concrete barriers, guardrails, and cable barriers); and
- Emergency reference marker signs (on interstate highways only).

A before/after evaluation was performed using the EB method (Potts et al., 2011). The striping and delineation program was found to have resulted in an overall reduction of 16 percent in fatal-and-disabling-injury crashes and 11 percent in fatal-and-all-injury crashes. The evaluation results for total crashes (all crash severity levels combined) show a statistically significant 4 percent reduction. The program appears to be particularly effective in reducing multiple-vehicle crashes on improved roadways. By contrast, single-vehicle crashes appear to have increased. This increase was considered likely to have resulted from a statewide trend of increases in lane-departure crashes rather than from an effect of the striping and delineation improvements. The program was associated with consistent crash reductions for all road types in daytime, but there was a statistically significant 24 percent increase in nighttime fatal-and-disabling-injury crashes on urban freeways.

Human factors studies are needed to explain the interaction of road geometry, delineation, confidence, visibility, road condition, and speed. But Kallberg's findings that speed increased at night when post-mounted delineators were installed, as well as older research by Allen showing that higher contrast lane markings led to higher speeds both in simulators and on real roads, indicate a likely explanation for findings that, in some circumstances, speed increases when the road is better delineated (Allen et al., 1977). On roads with little room for error, and potentially on wet and snow-covered road surfaces, even small increases in speed can greatly increase the risk of a crash.

Provide Transverse Pavement Markings

Transverse pavement markings are best implemented in areas where drivers may be travelling faster than desirable (e.g., on the entry to a tight off-ramp). A driver's main cue for speed comes from the streaming of information or "optical flow" in peripheral vision. After driving long distances, drivers become "speed-adapted" and have difficulty in reducing speed, even when they are aware of the adaptation and try to counter it. Thus, stimulating peripheral vision with close-by stimuli should lead to a modest decrease in speed. Progressively closer transverse lane markings have been successfully used to accomplish this. Progressively closer transverse bars and converging chevron patterns have been applied at entries to roundabouts, approaches to intersections, the end of freeway ramps, and other hazardous locations. Results found have been an immediate reduction in speed with reduced effectiveness over time and a small reduction in overall crash risk (Griffin and Reinhardt, 1996). A more recent study has shown greater effects on roads expected to have the greatest proportion of unfamiliar drivers. After the implementation of transverse bars, Katz et al. (2006) found the following reduction in average speeds after 4 months:

- 2.4 mph for off-ramps,
- 1.2 mph for sharp curves on highways, and
- 0.2 mph for sharp curves on local roads.

Godley et al. (1999) found that constant spacing was as effective as progressively closer spacing and peripheral transverse lines were almost as effective as full transverse lines. Constant spaced peripheral markings are preferable, as they are easier to implement and maintain.

Provide Weather-Activated Speed Signs

Weather-activated signs may be most appropriate on downgrades and curve approaches where inappropriately high speed is most likely to lead to loss of control. A study of activated speed signs at an arterial road lane drop with speed limit reduction found a significant drop in mean speed and a 40 percent drop in the proportion of vehicles travelling 9 mph over the speed limit (Maroney and Dewar, 1987). A study in a construction zone found a 4-mph drop in mean speed and 4 percent drop in the proportion of vehicles traveling 16 km/h over the speed limit (McCoy et al., 1995). A study by Van Houten and Nau (1981) found a 46 percent reduction in crashes of all types, although the HSM (AASHTO, 2010) (pp. 13–31) indicates that there is considerable variability in this reduction estimate.

A Finnish study investigated the effects of weather controlled speed limits and signs for slippery road conditions on driver behavior. In winter, with a lowering of the speed limit from 100 km/h to 80 km/h (62 to 50 mph), the signs were associated with a 2.1 mph reduction in speed, on top of the 3.9 mph reduction related to the road and weather conditions. A somewhat lesser effect was found when poor road conditions were difficult to detect. In both cases speed variance decreased; however, headway was not affected (Rämä, 1999).

Provide Static Signs Warning of Weather Conditions

A static sign (e.g., bridge freezes before road surface) may change driver behavior at the location where it is posted. It also serves to educate drivers about the problem. This countermeasure is listed in HSM Part D, but the HSM indicates that the crash-reduction effects of this treatment are unknown.

Apply Sand or Other Materials to Improve Road Surface Friction

This countermeasure is listed in HSM Part D, but the HSM indicates that the crash-reduction effects of this treatment are unknown.

Apply Chemical De-Icing or Anti-Icing as a Location-Specific Treatment

Chemical de-icing (e.g., application of salt) prevents snow from sticking to the road surface and is only effective above 21° F. Preventative de-icing, also known as anti-icing, involves applying salt or other chemicals to the road before the storm begins. Based on Elvik and Vaa (2004), the HSM states that anti-icing appears to reduce injury crashes.

Improve Winter Maintenance Response Times

Based on several international studies cited by the HSM, the crash-reduction effect of raising winter maintenance response times standards (based on traffic volume and road function) by one class level is a potential reduction of 11 percent in injury crashes and 27 percent in all crash types.

Install Snow Fences

Based on Elvik and Vaa (2004), the HSM states that installing snow fences on mountainous highways appears to reduce all types of crashes of all severities. However, the magnitude of the crash-reduction effect is uncertain (AASHTO, 2010).

Raise the State of Preparedness for Winter Maintenance

Based on Elvik and Vaa (2004), the HSM states that limited research suggests that such measures as putting maintenance crews on standby or having inspection vehicles drive around the road system may reduce the number of crashes in some cases but not others. The research suggests the measure may be more effective in the early morning hours.

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation