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Cable Median Barrier Guidelines

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Cable Median Barrier Guidelines

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16. Abstract (Limit: 200 words)

A detailed examination of accidents in Kansas was undertaken in order to evaluate the need for cable median barrier. Hard copies of all accident reports from Kansas controlled-access freeways from 2002 through 2006 were reviewed. A total of 525 cross-median events and 115 cross-median crashes were identified. Cross-median encroachment rates were found to be linearly related to traffic volume, while cross-median crash rates appeared to have second-order relationship with volume. Cross median crashes were found to be much more frequent during winter months, and the severity of wintertime crashes was found to be lower. This finding indicates that median barrier guideline criteria may need to be adjusted to accommodate regional climate differences. This is especially true for guidelines based upon cross-median crash rates. A relationship was developed between cross-median crash rate and traffic volume for Kansas freeways with median widths of 60 feet (18.3 meters). This relationship was then combined with encroachment rate and lateral extent of encroachment data from Cooper to develop general guidelines for the use of cable median barriers along Kansas freeways, which typically have 6:1 or flatter slopes.

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1 INTRODUCTION

1.1 Background

Caltrans has led the way in the analysis of median barrier effectiveness and development of guidelines for median barrier implementation (1-6). Caltrans began studying median related accidents in the 1950s by comparing the accident histories of flat traversable medians to those from "deterring" medians with ditches, berms, or barriers (1-2). These studies led Caltrans to begin conducting before and after studies of highways where median barriers were installed (3-6). Caltrans used the findings from these before and after studies to develop the first guidelines for the application of median barriers. Due to the relatively low frequency of cross-median crashes, the accident data was insufficient to consider any characteristics beyond median width and traffic volume. These width-volume guidelines were eventually adapted for nationwide application and, with only minor changes, were employed from the 1970s through the 1990s (7-10).

Although Caltrans continued to study the need for median barriers and examine its guidelines, no major changes were recommended throughout the 1970s, 1980s, and most of the 1990s (11-13). During this period, traffic volumes increased dramatically across the nation, especially in suburban and rural regions where open medians are commonly found. Operating speeds actually declined during the 70s when the national speed limit law was enacted. However, the elimination of this law in the 90s led to significant increases in operating speeds on rural and suburban freeways. In 1997, Caltrans conducted additional accident data analysis of the benefits of implementing median barrier (14). This study indicated that median barriers were warranted in medians as wide as 75 ft (22.9 m) when traffic volumes exceed 62,000 ADT. Other states have conducted similar studies (15-16). Although there have been variations in the findings, these studies

have generally indicated that barrier can be justified in wider medians than previously recommended in national guidelines (10). For example, a North Carolina study recommended installing cable median barrier in all median widths of 70 ft (21.3 m) or less, regardless of traffic volume. Median barrier studies have also produced guidelines for installing barriers on existing highways based upon cross-median accident frequency. For example, a study of cross-median crashes (CMCs) in Texas concluded that barrier should be installed where the historical cross-median crash rate reaches a threshold value of 0.7 accidents per mile (0.43 accidents per kilometer) per year (16).

A number of accident studies have shown that median encroachments and crossover accidents are much more likely to occur on horizontal curves and near interchanges (17-18). These studies clearly indicate that highway alignment and interchange frequency and/or configuration can influence the need for a median barrier. Median geometry is also believed to affect the frequency of CMCs. Depressed medians with steep foreslopes allow encroaching vehicles to become airborne for approximately half of the median traversal. While airborne, drivers have no opportunity to take any corrective action. Further, full-scale crash testing has shown that vehicles tend to climb up steep back slopes rather than steer back toward the center median (19). Thus, median cross-section design is believed to have an impact on CMC frequency.

Much of the nation’s rural and suburban freeway system was originally constructed in the 1950s and 1960s as part of the interstate highway system. Most states incorporated relatively consistent alignment, interchange, and cross-section designs during construction of the rural interstate system. These historical design standards greatly affect the geometrics of the today's highway system across most states. Further, design standards for these freeways varied widely across the nation. Many Midwestern states chose to invest in safety by acquiring additional right-of-way

and providing additional fill material to produce both wider and flatter medians. Further, many plains states benefitted from flat terrain and were able to produce long straight sections of freeway. Low population densities in many states also reduced the frequency of interchanges. Rolling terrain, costly right of way, and high population density forced other states to construct rural freeways with narrow, depressed medians, uneven alignment, and closely spaced interchanges. These differences in freeway geometrics are believed to have a significant effect on the need for median barriers. National median barrier guidelines based upon median width and traffic volume cannot account for system wide variations in median and roadway geometrics that are encountered from one state to the next.

Climate is another factor that is believed to have an impact on cross-median crash rates. Median related accidents spike upward during winter driving conditions, and a Pennsylvania study showed that icy conditions were over represented in cross-median crashes (20). However, winter driving conditions often cause drivers to slow down, which may reduce the severity of cross-median accidents. Thus, it is reasonable to believe that winter driving conditions could affect both the number and severity of cross-median crashes. Climate variation from north to south is another reason to question the merit of implementing uniform median barrier guidelines across the nation. For example, barrier guidelines developed from accident data collected in California, Texas, or North Carolina would not be expected to accurately reflect the effects of winter driving conditions across the Midwest (14-16).

In recognition of the potential for significant differences in cross-median crash experience arising from variations in roadway geometrics and climatic conditions from one state to the next, the Midwest States' Pooled Fund Program funded a study to develop cable median barrier guidelines.

1.2 Objective

The objective of the study was to use accident data from a Midwestern state to develop cable median barrier guidelines that might be applicable to a number of states in the region.

1.3 Research Approach

The Kansas Department of Transportation volunteered to supply accident data for the study. Unfortunately, Kansas accident reports do not contain a specific descriptor to identify median related crashes. Thus, it was necessary to obtain all accident reports from controlled-access freeways in the state of Kansas in order to assure that median related crashes were identified. Accident reports from the start of 2002 through the end of 2006 were collected for inclusion in the study.

A total of 43,435 accident records were manually reviewed to identify median related crashes. A total of 8,233 crashes involving a vehicle entering the median were identified. An accident involving a vehicle traveling completely across the median and entering opposing lanes was identified as a cross-median event (CME). When a CME resulted in a multiple vehicle collision in the opposing travel way, the accident was classified as a cross-median crash (CMC). A total of 525 CMEs and 115 CMCs were identified.

During the process of reviewing the accident reports, a number of crash scenarios were identified that should not be classified as a CMC. These accident scenarios included vehicles traveling in the wrong direction, crashes in work zones, cross-median impacts involving parked cars, ramp related crashes, and debris related impacts. Several accidents involving head-on crashes appeared to result from a vehicle traveling the wrong direction on a divided highway. If there was evidence that the vehicle was traveling on the wrong side of the road, either from witness statements or telephone reports to emergency personnel, the accident was not classified as a CMC. Further, all

accidents and highway sections associated with continuous median barrier were omitted from the study.

A number of CMEs and CMCs were reported to have occurred in construction zones. Unless there was clear evidence, either from the accident scene sketch or narrative description, to indicate that the freeway was operating in a two-lane, two-way condition, the accident was recorded as a cross median event. A large number of crashes involved an encroaching vehicle striking another vehicle parked in the median or on the median shoulder. Most of these crashes occurred under winter driving conditions. These accidents were not classified as CMCs.

Many of the crashes initially identified as cross-median events proved to be ramp related crashes wherein a vehicle went out of control on a ramp and crossed a roadside area onto another ramp or the main lanes of the freeway. Most of these crashes were omitted from the study. Only those ramp related accidents, wherein the vehicle crossed into through lanes and then proceeded across the median, were included in the study. Finally, any crash involving vehicles impacting debris, such as vehicle components or payload, were omitted from the study, because cable barrier would not be expected to capture many vehicle or payload elements that become detached from impacting vehicles.

The remaining crash data were then modeled to estimate CMC frequencies. Average CMC costs were also estimated using accident severities gleaned from accident reports. Estimated CMC rates and average costs were then utilized to estimate societal costs associated with freeways without median barrier.

Initially, an attempt was made to identify median related crashes in terms of the percentage of median traversed. It was hoped that this information would be useful in identifying the frequency

of barrier crashes that could be expected if a barrier was placed in the center of the median. A total of 3,053 encroachments were initially identified as having crossed 50 percent or more of the median. A random sample of these 3,053 crash reports were examined to assure data quality. Unfortunately, it was discovered that only a small proportion of the accident reports associated with non-injury median encroachments contained sufficient evidence to accurately determine the portion of the median traversed. Students reviewing accident reports had attempted to assign a value to the portion of the median crossed based upon the investigating officers narrative. There was literally no evidence to indicate the extent of travel in the median for approximately half of the more than 3,000 encroachments initially identified as crossing 50 percent or more of the median. As a result, it was necessary to abandon this approach to determining barrier impact frequencies.

Note that almost all of Kansas' installed median barriers are constructed from concrete and are typically placed very near the travelway. Thus, it was not possible to determine cable median barrier crash costs from Kansas accident records. In order to determine cable barrier crash cost, it was necessary to estimate the impact frequency and the average cost of a crash. Because of the unavailability of barrier accident frequencies from the Kansas accident records system, it was necessary to estimate barrier impact frequencies using encroachment probability procedures. Average cable barrier crash costs were then identified from a study of cable median barrier crashes in Missouri (21). Average cable median barrier installation and repair costs were obtained from statewide bid tabulations from several states in the region. Benefit-cost ratios for cable median protection were then estimated using modeled CMC frequencies and average costs and the costs associated with cable barrier installation, repair, and crashes.

2 ACCIDENT DATA

2.1 Data Collection

Kansas controlled-access freeway system includes 761 miles (1,225 kilometers) of freeway without median barrier. The median width distribution for freeways without median barrier in Kansas is shown in Table 1. Note that less than 10 percent of the freeways without median barrier have a width of less than 58 ft (17.7 m) and less than 5 percent have median widths greater than 60 ft (18.3 m). A total of 672.4 miles (1,082.1 kilometers) of freeways without median barrier, or 88 percent of the entire system, is classified as having a median width of 60 ft (18.3 m). With this overwhelming representation of 60 ft (18.3 m) wide medians, it was impossible to utilize accident data to model CME or CMC rates as a function of median width. Therefore, it was necessary to utilize Kansas accident data to develop relationships between CME and CMC rates and traffic volumes for a 60-ft (18.3-m) wide median. CMC and CME rates would then have to be extrapolated to other median widths using lateral extent of movement distributions from historical encroachment or accident data.

A total of 525 CMEs and 115 CMCs were identified in the five years of accident data from the start of 2002 through the end of 2006. The distribution of CME and CMC events by median width is shown in Table 2. When viewed in conjunction with Table 1, this chart indicates that narrow medians were over represented and wide medians were under represented in both CME and CMC events. Note that 429 CMEs and 81 CMCs occurred on highways with a median width of 60 ft (18.3 m).

Table 1. Width of Open Medians in Kansas

Median Width ft (m)	Length miles (kilometers)
0 – 30 (0 – 9.1)	5.2 (8.37)
30 – 40 (9.1 – 12.2)	9.2 (14.81)
40 – 50 (12.2 – 15.2)	27.2 (43.77)
50 – 59 (15.2 – 18.0)	17 (27.36)
60 (18.3)	672.4 (1082.12)
61 – 90 (18.6 – 27.4)	22.4 (36.05)
> 90 (> 27.4)	7.9 (12.71)
Total	761.3 (1225.20)

Table 2. CMC and CME Distribution by Median Width

Median Width ft (m)	Length miles (kilometers)	Number of CMEs	Number of CMCs
0 – 30 (0 – 9.1)	5.2 (8.37)	18	7
30 – 40 (9.1 – 12.2)	9.2 (14.81)	16	4
40 – 50 (12.2 – 15.2)	27.2 (43.77)	41	11
50 – 59 (15.2 – 18.0)	17 (27.36)	4	0
60 (18.3)	672.4 (1082.12)	429	81
61 – 90 (18.6 – 27.4)	22.4 (36.05)	14	11
> 90 (> 27.4)	7.9 (12.71)	3	1
Total	761.3 (1225.20)	525	115

Both CME and CMC occurrences were found to be more frequent during the winter months of December, January, and February, as shown in Figure 1. Approximately one third of all CME and CMC events occurred under snow and ice conditions, as shown in Figure 2. Although winter comprises a fourth of the calendar year, winter driving conditions are not present throughout the winter. In order to assess the frequency of winter driving conditions, the entire data file of accidents on all access controlled roadways in Kansas was examined to identify days when ice or snow was present during any freeway accident. Note that this approach assumes that whenever winter driving

conditions exist somewhere in the state, all highways are affected throughout the day. This assumption would tend to overstate the time that snow or ice is present on the driving surface. At least one snow or ice related accident was reported on a Kansas controlled access roadway during only 228 days out of a possible 1,826 days included in the study. During these 228 days where at least one snow or ice related accident occurred, 143 CME and 42 CMC crashes were recorded out of totals of 525 and 115 occurrences, respectively. Thus, winter driving conditions are present for less than an eighth of the days in the study and accounted for more than a quarter of CME and a third of CMC occurrences. A two-tailed, Chi-square evaluation showed that the frequency of both CME and CMC occurrences were found to be significantly over represented during winter driving conditions at the p=0.0001 (0.01 percent) level. Clearly, snow and ice has a major impact on CME and CMC rates.

The severity of CMCs was also found to be significantly affected by snow and ice, as shown in Table 3. Only 7 percent of the cross-median crashes associated with snow and icy conditions were found to involve a fatality, while 22 percent of non-snow and ice CMCs were classified as fatal. A similar effect was found when combining disabling injury and fatality crashes (A+K). Twenty-three percent of snow and ice related crashes fell into the A+K category, while 42 percent of non-snow and ice CMCs had a similar classification. These findings indicate that the effectiveness of median barrier is likely to be influenced by regional climate conditions, and a single set of median barrier guidelines may not be appropriate for implementation across the entire nation.

Most medians without barrier are located in rural and suburban regions. It is known that suburban freeways experience higher traffic volumes. Further, it may seem reasonable that more accidents would occur in the later portion of the day. The distribution of CMCs from the available

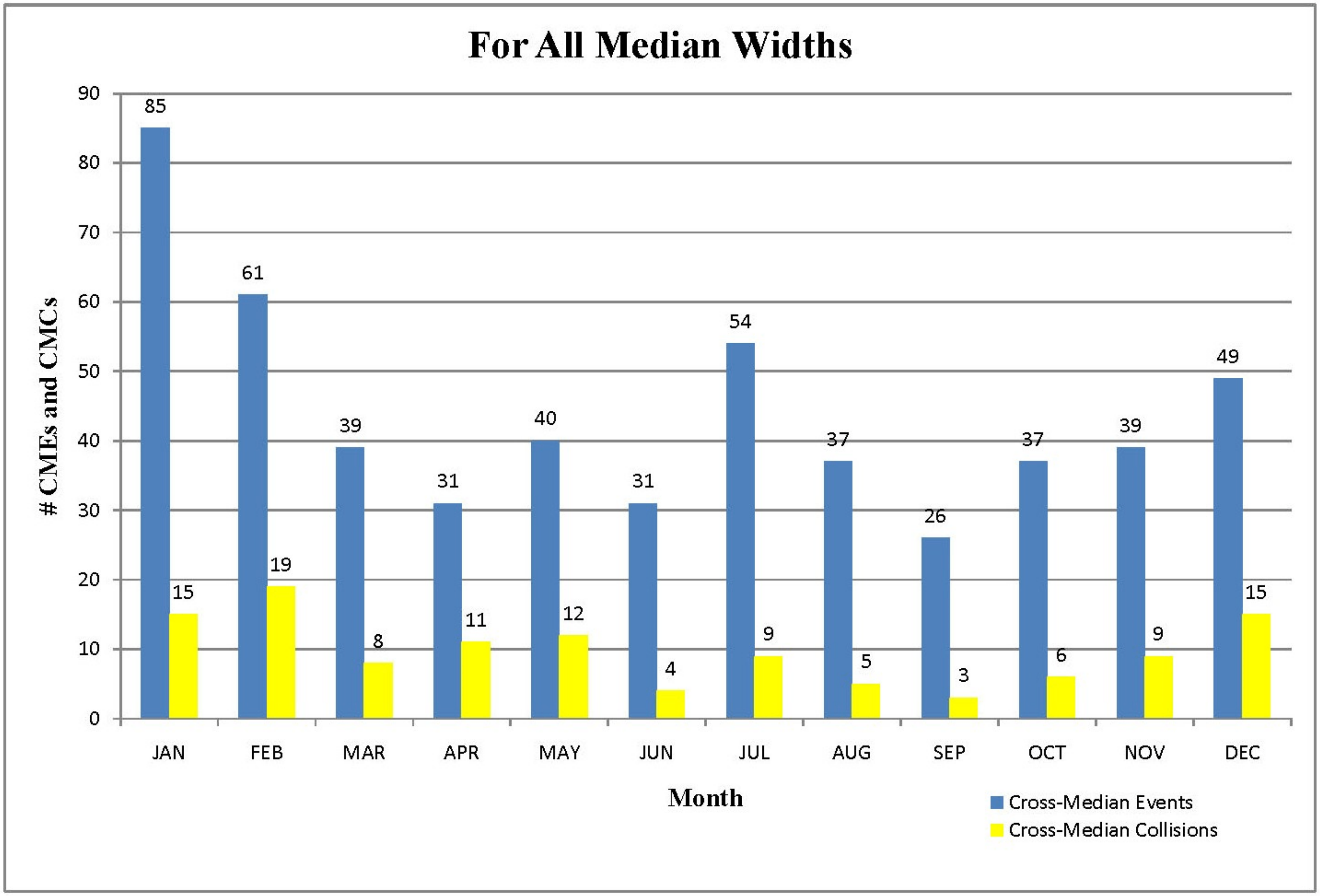

Figure 1. CME and CMC Distribution by Month

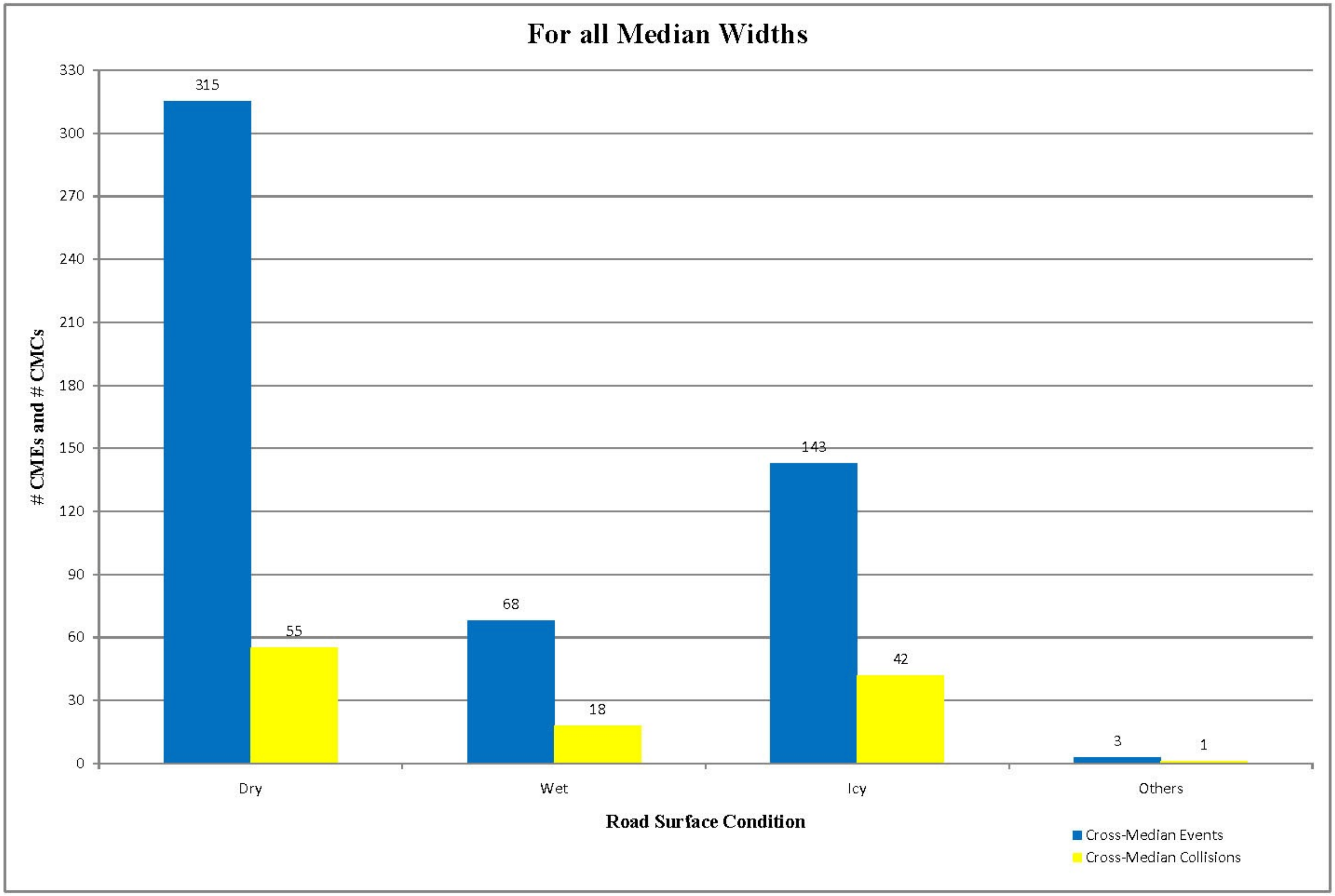

Figure 2. CME and CMC Distribution by Road Surface Condition

data is shown in Figure 3. This data indicated that there was a slight increase in afternoon crashes over morning crashes, but due to the small data set, this does not pass the statistical test for significance.

Table 3. CMC Severity by Road Surface Condition

	Road Surface Condition				
Severity Level	Dry	Wet	Snow& Ice	Other	Sub-Total
PDO	11	4	14	0	29
Injury	31	10	25	1	67
Fatal	12	4	3	0	19
Sub-Total	54	18	42	1	115

2.2 Accident Models

CME and CMC rates were modeled as a function of traffic volume for 60-ft (18.3-m) wide medians. The modeling effort attempted to develop relationships for predicting CME and CMC in terms of both events/crashes per mile per year and events/crashes per 100 million vehicle miles (100MVM). All of these modeling efforts showed the common trend that CME rates were relatively linear, and that CMC rates were best modeled with a nonlinear equation. This finding is not surprising. Cross-median events should be somewhat proportional to the primary exposure term of traffic volume. However, cross-median crashes have two exposure terms related to traffic volume. The risk of a vehicle crossing the median is strongly related to the number of vehicles exposed to the median and the risk of striking another vehicle in the opposing lanes is affected by the number of vehicles exposed to any encroaching vehicle. Plots of CME rates versus traffic volume measured in terms of events per mile per year and events per hundred million vehicle miles (100MVM) are

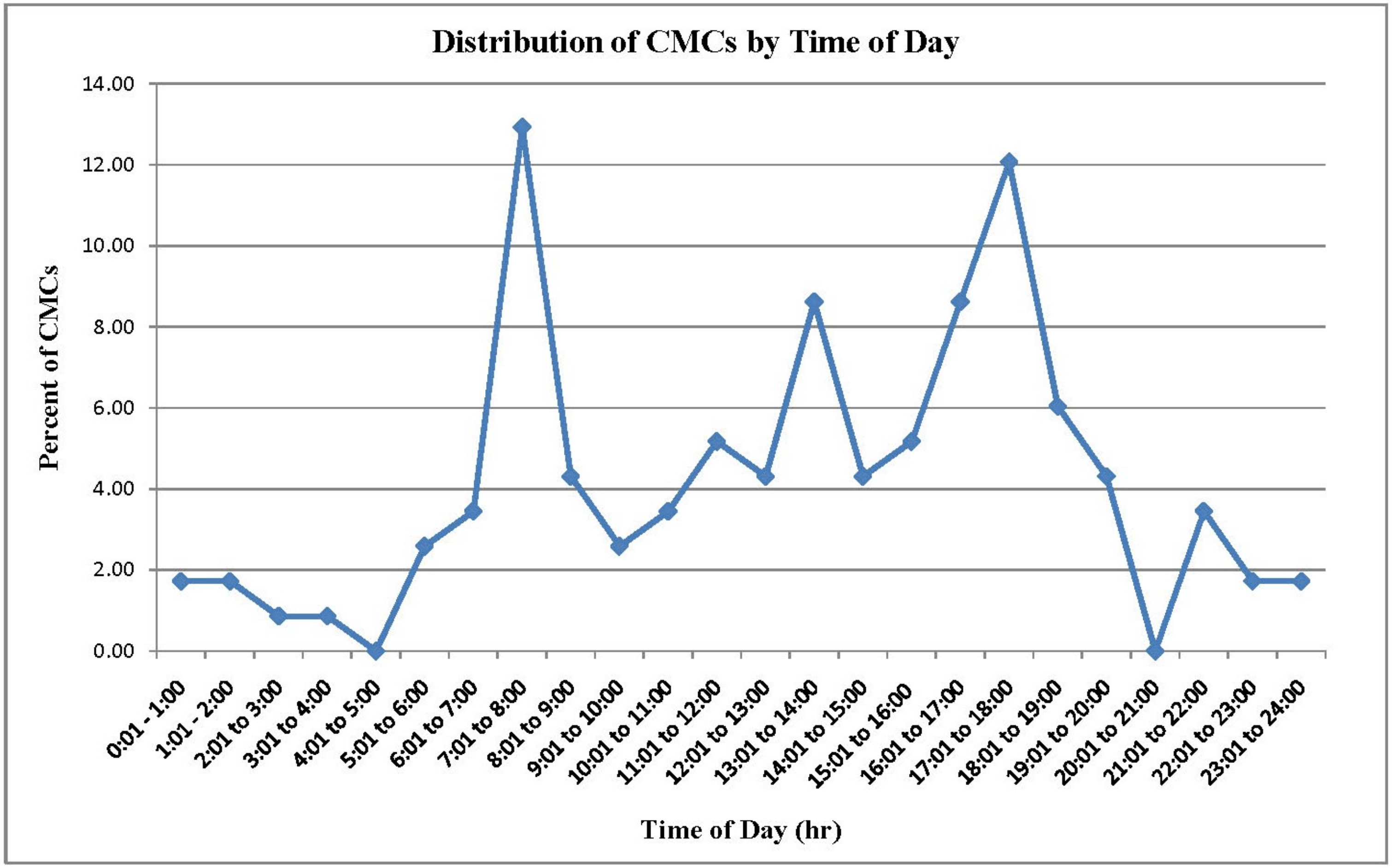

Figure 3. CMC Distribution by Time of Day

shown in Figures 4 and 5, respectively. Notice that when the CME rate is measured in terms of events/mile/year, it is relatively linear, as shown in Figure 4. If the CME rate is linearly related to traffic volume, the relationship between CMC and traffic volume should be of a higher order. Notice that when CMEs are measured in terms of events per 100MVM, the relationship is more or less constant at 2.2 CME per 100MVM. It should be noted that all figures presented show one-way traffic volumes. Total roadway volumes are double those values shown in Figures 4 and 5.

Cross-median crash rate as a function of crashes per 100MVM is shown in Figure 6. This crash rate was found to be relatively linearly related to traffic volume. This finding indicates that CMC crash rate measured in terms of accidents per mile per year should have generally a second-order relationship with traffic volume. CMC measured in terms of crashes per mile per year as a function of traffic volume is shown in Figure 7. CMC data was modeled using a variety of traffic volume ranges, equal exposure length ranges, and equal number of crashes ranges. Because of the sensitivity of nonlinear functions to the highest traffic volumes and the fact that CMC rates for the higher traffic volumes were developed from fewer highway miles, there was a concern about the stability of the modeled equations. In order to explore this concern, the last two data points of each modeled equation were combined into a single traffic volume or highway length range, and a new equation was developed. All models that proved to be relatively stable were found to be very similar. The data were fit with a simple polynomial function of the form $y = ax^2$, as shown in Figure 7. The equation relating CMC rates for 60-ft (18.3-m) wide medians was found to be:

$$CMC = 1.71x10^{-10}\ ADT^2 \qquad [1]$$

where:

CMC = cross-median crash rate (crashes/mile/year).
ADT = one way traffic volume (vehicles/day).

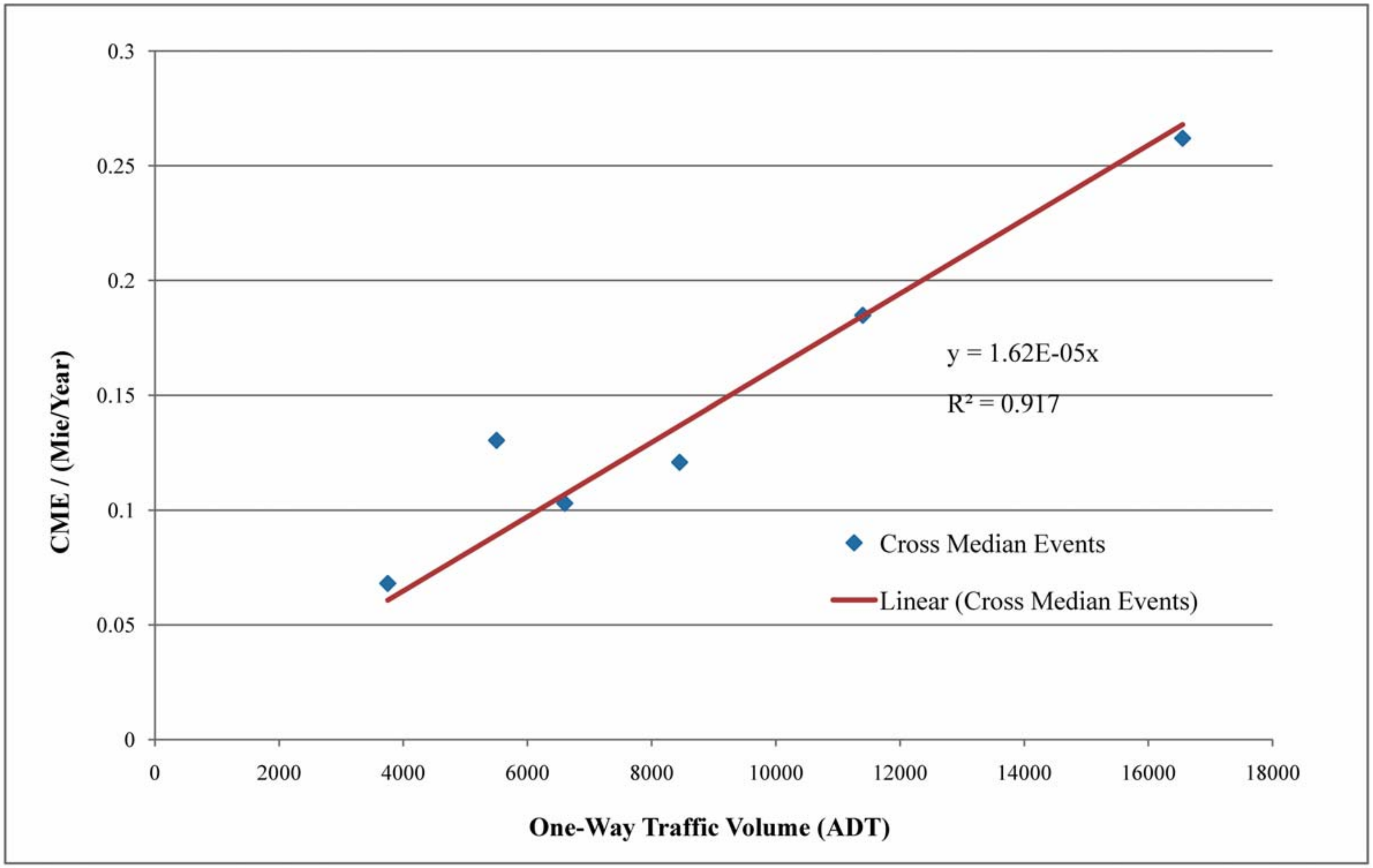

Figure 4. CME Measured per Mile per Year vs. One-Way Traffic Volume

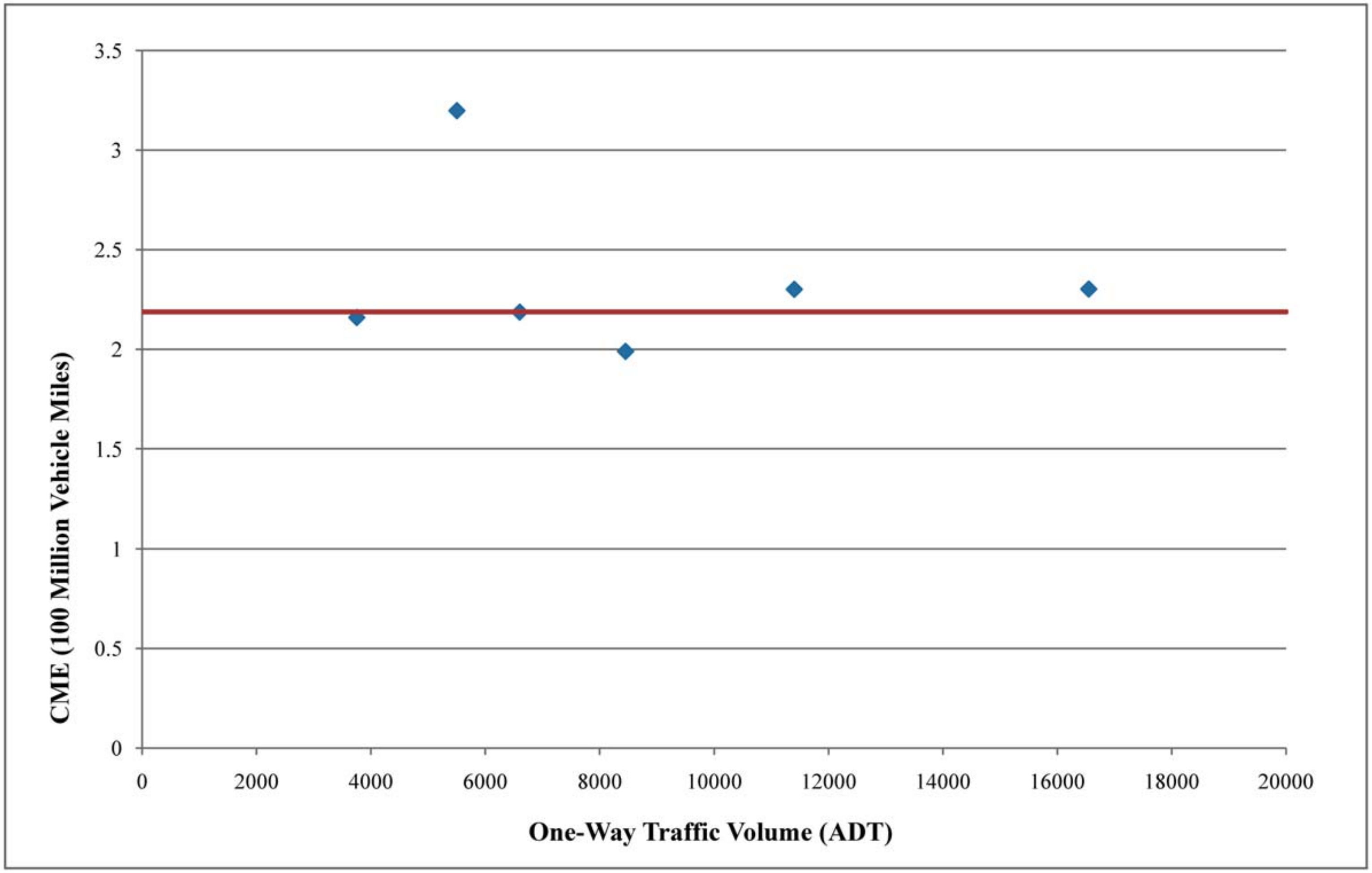

Figure 5. CME Measured per 100MVM vs One-Way Traffic Volume

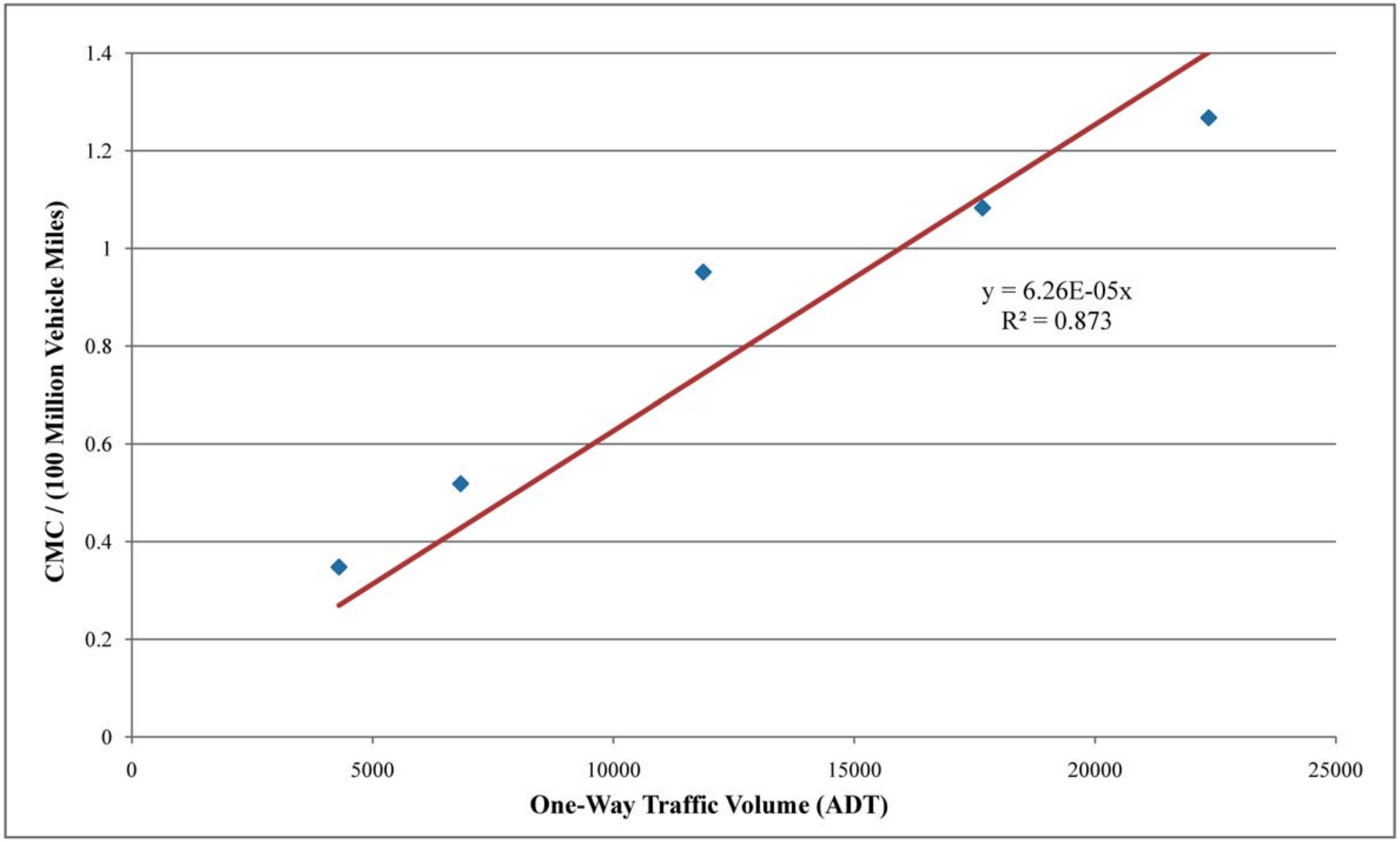

Figure 6. CMC Measured per 100MVM vs. One-Way Traffic Volume

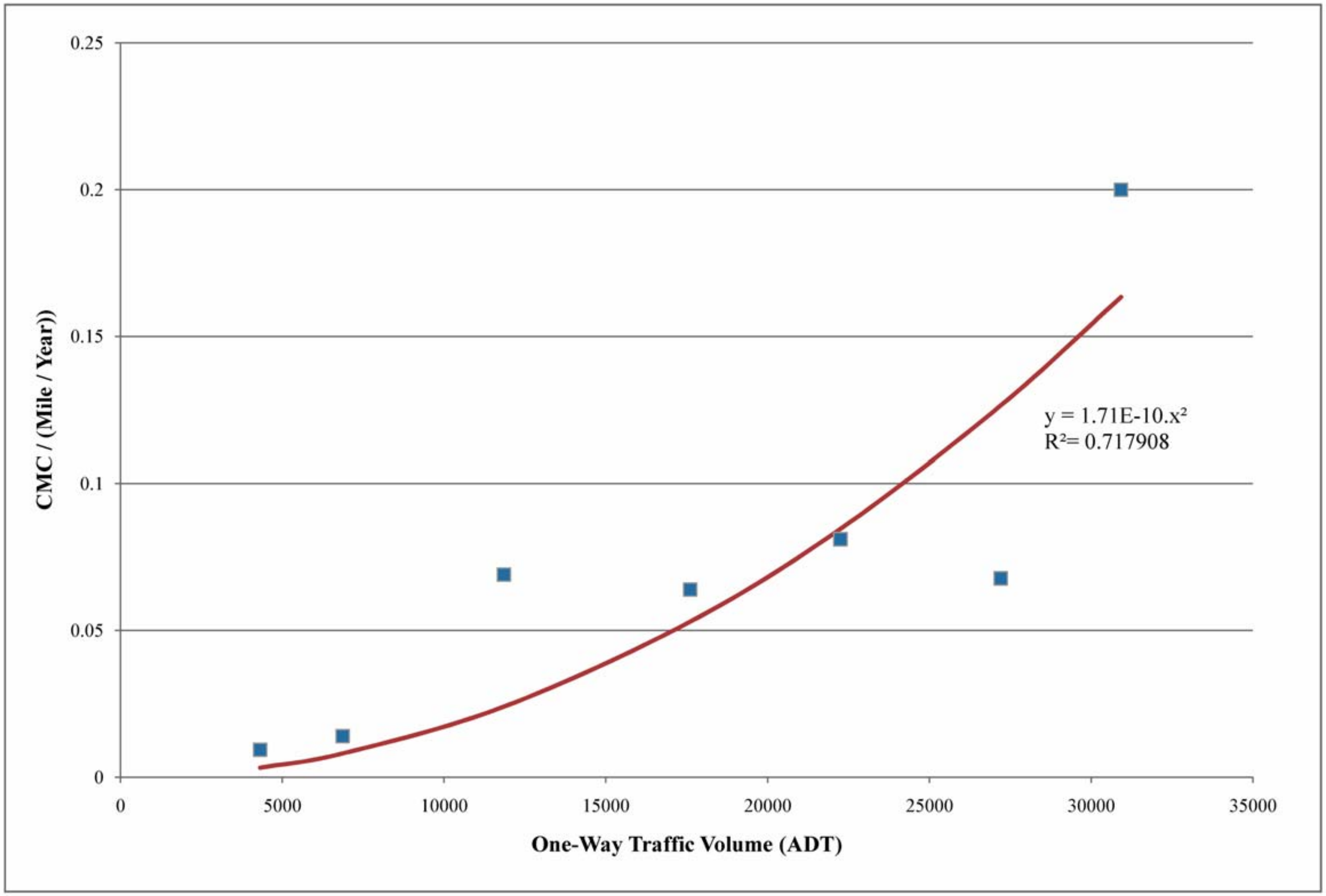

Figure 7. CMC Measured per Mile per Year vs. One-Way Traffic Volume

This model was able to explain approximately 71 percent of the variation in the data, as shown on Figure 7. At first glance, an R^2 value of 0.71 may seem low. However, recognizing the wide variations in factors such as roadway and median geometrics, driver demographics, and land use that exist across any state, this level of correlation was deemed to be relatively good.

2.3 Crash Costs

CMC costs were calculated from Kansas accident data using updated accident cost values recommended by the Federal Highway Administration. Accident costs per injury and fatality were updated to 2008 dollars and are shown in Table 4. These costs are significantly higher than those used to develop median barrier guidelines in California (14). When these costs are applied to the 115 cross median crashes identified in the Kansas accident study, the average cost of a CMC was found to be $1,022,700.

Table 4. 2008 Accident Costs Per Injury and Fatality

Accident Costs Per Injury	
PDO	$ 2,800
Possible Injury	$ 26,350
Injury	$ 49,850
Disabling Injury	$ 249,200
Fatality	$ 3,599,500

Average crash costs for a CMC during winter driving conditions were found to be $463,900 which was less than half the average cost of a CMC. The cost of a CMC on ice covered or

snowpacked surfaces was found to be only $345,400, and the cost a CMC on snow/slush covered surfaces was $898,200, only slightly below the average for all crashes. This effect may indicate that operating speeds are much lower when the pavement is ice covered or snow packed than when there is fresh snow or slush on the surface. Never-the-less, it can be concluded that although winter driving conditions increase CMC frequencies, the severity of these crashes is much lower.

Wet weather CMC accident costs were found to average $1,890,000, or almost twice the average value for all crashes. This finding may indicate that operators do not slow down significantly under wet weather, but their ability to brake after the driver loses control is greatly reduced.

Accident costs for cable median barrier crashes were estimated using accident data from Missouri (21). This study involved a detailed investigation of all cable median barrier accidents along selected sections of freeway in Missouri. Unfortunately, accident severity was only reported in terms of PDO, injury, and fatality. Neither the severity of injuries nor the number of injured or killed occupants were recorded. Average cable barrier accident costs were estimated by assigning an accident cost of $49,850 to all injury accidents and $3,599,500 to all fatal crashes. Note that this method would likely understate the average cable barrier accident costs because the additional costs associated with multiple injuries and multiple fatalities are omitted. Using this method, the average cost of a reported cable barrier accident was found to be $38,134. However, this cost does not include unreported crashes involving cable median barrier. The number of unreported cable barrier crashes was estimated by comparing the number of cable barrier repairs to the number of cable barrier accident reports. During 2006 and 2007, the State of Missouri recorded a total of 4,386 cable barrier accidents and 5,939 repairs to the cable barrier. Although some repairs were undoubtedly caused by roadside debris in highway maintenance activities such as mowing and snowplowing, it

was assumed that all barrier repairs were related to vehicular impacts. Based on this assumption, approximately 26 percent of all cable barrier collisions were unreported. After adjusting for unreported accidents, the average cost of a cable median barrier crash was estimated to be $28,894. Note that this value was believed to understate the actual cost because it did not include the possibility of disabling injuries, multiple injuries, or multiple fatalities and probably overstates the number of unreported crashes.

3 BENEFIT/COST ANALYSIS

3.1 60-ft (18.3-m) Wide Medians

A benefit/cost analysis of cable median barrier implementation requires estimates of cross-median crash costs, cable barrier crash costs, barrier installation costs, and cable barrier repair costs. Cross-median crash costs were estimated by employing the predictive equations shown in Figure 7 to obtain CMC frequency which was then multiplied by the average CMC cost of $1,022,700.

As mentioned previously, Kansas has no installed base of cable median barrier and thus, accident data cannot be used to estimate crash frequencies. Therefore, barrier crash frequencies were estimated using encroachment frequencies and lateral extent of movement data from the Roadside Safety Analysis Program (RSAP) (22). Because the median barrier is continuous and is generally placed a fixed distance from the travelway, impact frequencies can be estimated by merely multiplying encroachment frequency by the probability that an encroaching vehicle will travel halfway across the median and strike the barrier. Note that the cable barrier is assumed to be in the center of the median. Placing the barrier in this position minimizes cable barrier crashes and thereby maximizes the benefits of using the barrier. Recall, a roadside barrier should be placed as far from the travelway as possible such that an encroaching vehicle has a chance of regaining control without impacting the barrier. Therefore, barrier offset from the travelway reduces the crash rate, and center placement has been shown to reduce the probability of an encroaching vehicle impacting the barrier. Encroachment frequency and probability of lateral extent data from RSAP are presented in Figures 8 and 9, respectively. Annual cable median barrier crash costs were then calculated by multiplying impact frequency by the average cost of a cable barrier impact, $28,894.

Cable median barrier installation and repair costs were initially estimated by obtaining

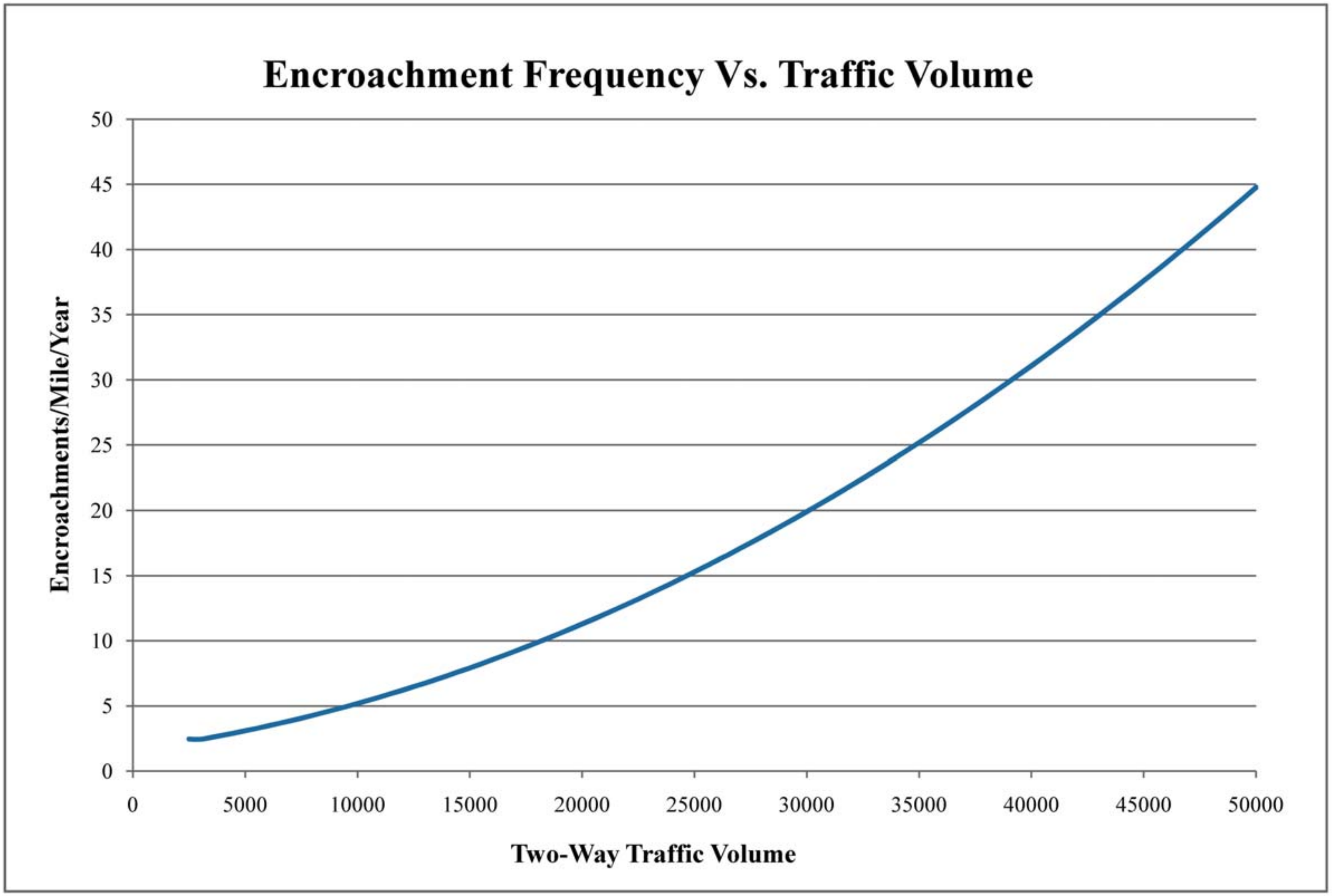

Figure 8. RSAP Encroachment Frequency vs. Traffic Volume

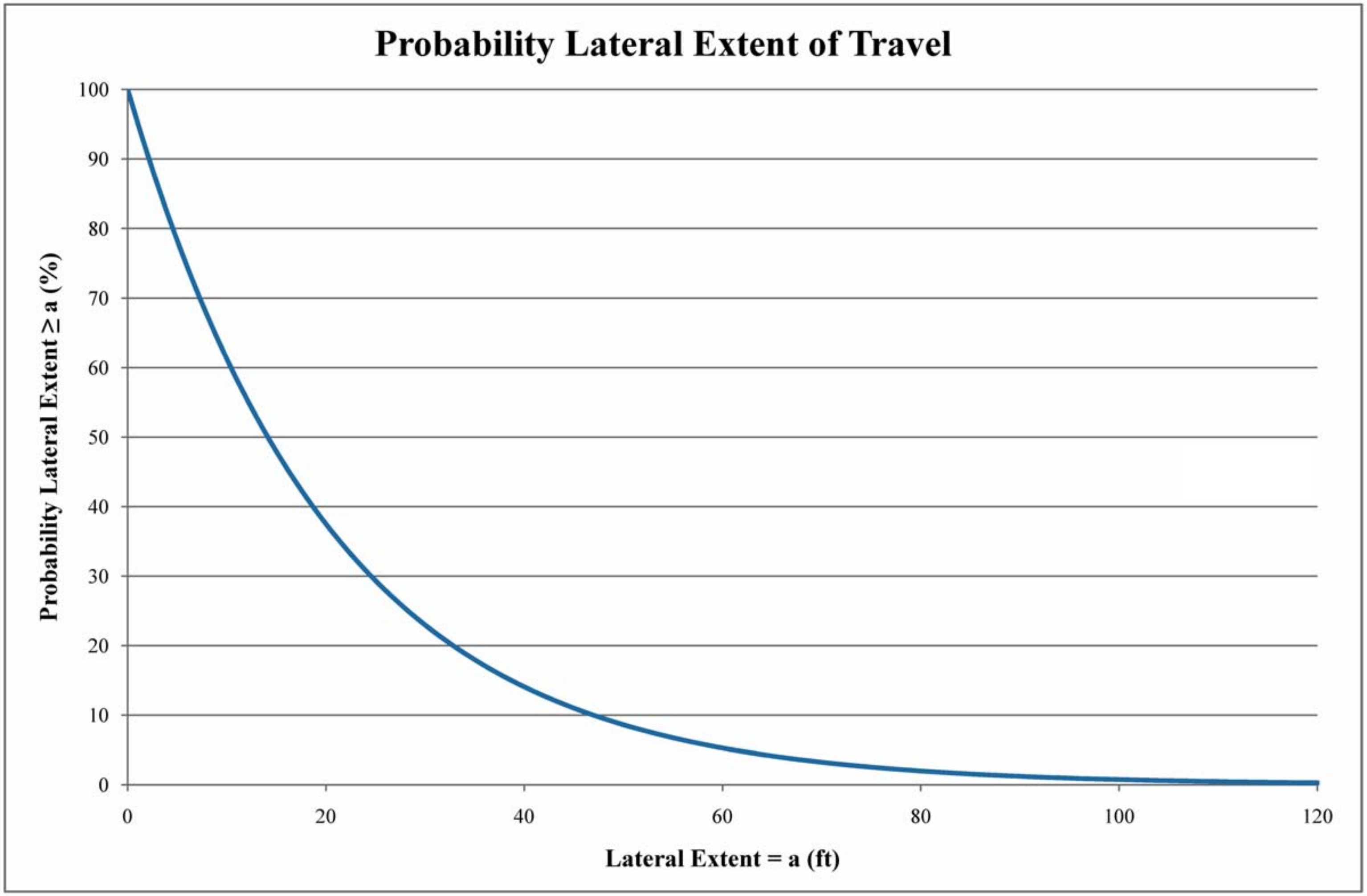

Figure 9. RSAP Probability of Lateral Extent of Encroachment.

statewide bid averages from several states as presented in Table 5. Note that barrier costs shown in Table 5 are believed to be reflective of prices for a 3-cable barrier system. Further, the values are not believed to include the recent increases in steel prices. Because most Midwest States' Pooled Fund participants are now utilizing 4-cable barrier systems and the price of raw steel increased more than 40 percent during the first five months of 2008, an average construction cost of $125,000 per mile was used in the benefit/cost (B/C) analysis. Cable repair costs are believed to be controlled largely by mobilization and labor costs and therefore were not adjusted to include the higher costs of repairing a 4-cable design or the increased cost of steel. Annualized direct costs associated with a cable median barrier installation were calculated using a 20-year life and a 4 percent discount rate. The total direct cost for a median barrier installation includes the annualized installation cost and the average repair cost multiplied by the expected impact frequency.

Table 5. Cable Barrier Construction and Repair Costs

State	Construction Cost $/mile	Construction Cost ($/kilometer)	Repair Cost $/repair
Iowa	$105,600	($65,617)	--
Colorado	$71,280	($44,291)	$1000
Louisiana	$92,400	($57,415)	--
Indiana	$125,090	($77,727)	$312
Washington	–		$733
Average	$98,593	($61,263)	$682

Benefit/cost ratios for a 60-ft (18.3-m) wide median can be calculated using the following equation:

$$\frac{B}{C} = \frac{AC_o - AC_b}{DC_b} \qquad [2]$$

where:

AC_o = Accident costs associated with an open median
AC_b = Accident costs associated with a cable median barrier
DC_b = Direct costs of using a cable median barrier

Equation 2 can be utilized in conjunction with the CMC and cable barrier crash frequency estimation procedures described previously to calculate B/C ratios for a 60-ft (18.3-m) wide median at any traffic volume. The equation can also be used to determine the traffic volume that will generate any B/C ratio. Safety projects should begin to be funded when the associated B/C ratios reach a value comparable to those associated with other types of construction projects. A B/C ratio of 1.0 indicates that the benefit to society will be become equal to the direct cost of the construction by the end of the life of the project. B/C ratios for most construction projects are much higher. A highway agency's administration must make the determination whether safety projects should be given higher priority than other types of construction. B/C ratios of a wide variety of construction projects should be estimated in order to provide administrators with the necessary information to make this decision.

As explained previously, the average cost of cable median barrier crashes is understated in this analysis. Thus, it is believed that this procedure will likely over estimate the B/C ratio for installing cable median barrier. Hence, it is recommended that barrier installation not be considered at B/C ratios below 2.0. However, it is not uncommon to find resurfacing or roadway widening

projects in the Midwest with a B/C ratio in the range of 4.0. Therefore, it is generally recommended that safety projects begin to be funded at threshold B/C ratios between 2.0 and 4.0. For a 60-ft (18.3-m) wide median, the analysis described previously indicate that traffic volumes of 57,700 and 69,200 produce B/C ratios of 2.0 and 4.0, respectively.

3.2 Other Median Widths

The equation for predicting CMC rates for 60-ft (18.3-m) wide medians can be extrapolated to other median widths using a ratio of lateral extent of motion. This approach is based on the assumption that the change in CMC rate for alternate median widths is directly related to the probability that an encroaching vehicle will travel completely across the median and enter the opposing lanes. This approach assumes that the cross median crash rate is directly proportional to the frequency that errant vehicles enter the opposing lanes. This assumption will be accurate provided encroachment velocities and angles do not change rapidly as the distance from the roadway increases. Because examination of real-world accident data found extremely weak correlations between the distance from the roadway and impact velocity and angle (23), the method for extrapolating crash rates for 60-ft (18.3-m) medians to other widths should be relatively accurate.

As an illustration of the crash rate extrapolation procedure, consider a 40-ft (12.2-m) wide median. The probability that an errant vehicle will encroach 40 feet (12.2 meters) is 14.0 percent and the probability that it will reach 60 feet (18.3 meters) is 5.3 percent, as shown in Figure 8. The predictive equation for 60-ft (18.3-m) wide medians can be adjusted to 40-ft (12.2-m) medians by multiplying the lead coefficient in the equation by the ratio of 14.0/5.3. Using this technique, traffic volumes that produce B/C ratios of 2.0 and 4.0 were calculated for a range of median widths and are presented in Table 6.

Table 6. Cable Barrier B/C Ratios

Median Width ft (m)	Traffic Volume at B/C = 2.0 (1000 ADT)	Traffic Volume at B/C = 4.0 (1000 ADT)
10 (3.0)	15	17
20 (6.1)	19	22
30 (9.1)	24	28
40 (12.2)	31	37
50 (15.2)	42	51
60 (18.3)	60	74
70 (21.3)	97	121

Traffic volumes, shown in Table 6, represent the threshold values at which implementing cable median barrier may become cost beneficial. These volumes should be considered average values over the life of the project. Note that beyond a median width of 70 ft (21.3 m), traffic volumes at which a barrier is predicted to become cost beneficial increases rapidly and exceeds 200,000 ADT at a median width of 80 ft (24.4 m). Recall that the CMC rate prediction model is based primarily upon data collected on highways with two-way traffic volumes of 60,000 ADT or less. Further, the assumed second order relationship between CMC rate and traffic volume is believed to overstate the number of cross-median crashes at high traffic volumes. Therefore, barrier is not generally recommended for use in medians wider than 70 ft (21.3 m).

The median barrier implementation guidelines from Table 5 and those shown in the most recent Roadside Design Guide (23) are compared in Figure 9. The RDG guidelines define three areas on the chart. The upper left region of the chart is described as "barrier recommended" and the middle section is identified as "barrier considered." The far right side of the figure is described as "barrier optional." The proposed median barrier guidelines shown in Table 5 include only two regions. Any

point above the appropriate line would fall into the barrier recommended category and any other point would fall into the barrier not recommended region. Notice that almost all of the barrier recommended category from the RDG guidelines falls into the same category for the guidelines proposed herein. Further, most of the "barrier considered" category from the RDG falls into the recommended region of the new guidelines. Finally, for traffic volumes above 50,000 ADT, the new guidelines extend into the RDG's barrier optional region. In summary, the guidelines described previously appear to indicate that cable median barriers are cost beneficial over a wider range of median widths and traffic volumes than indicated by the RDG's median treatment guidelines.

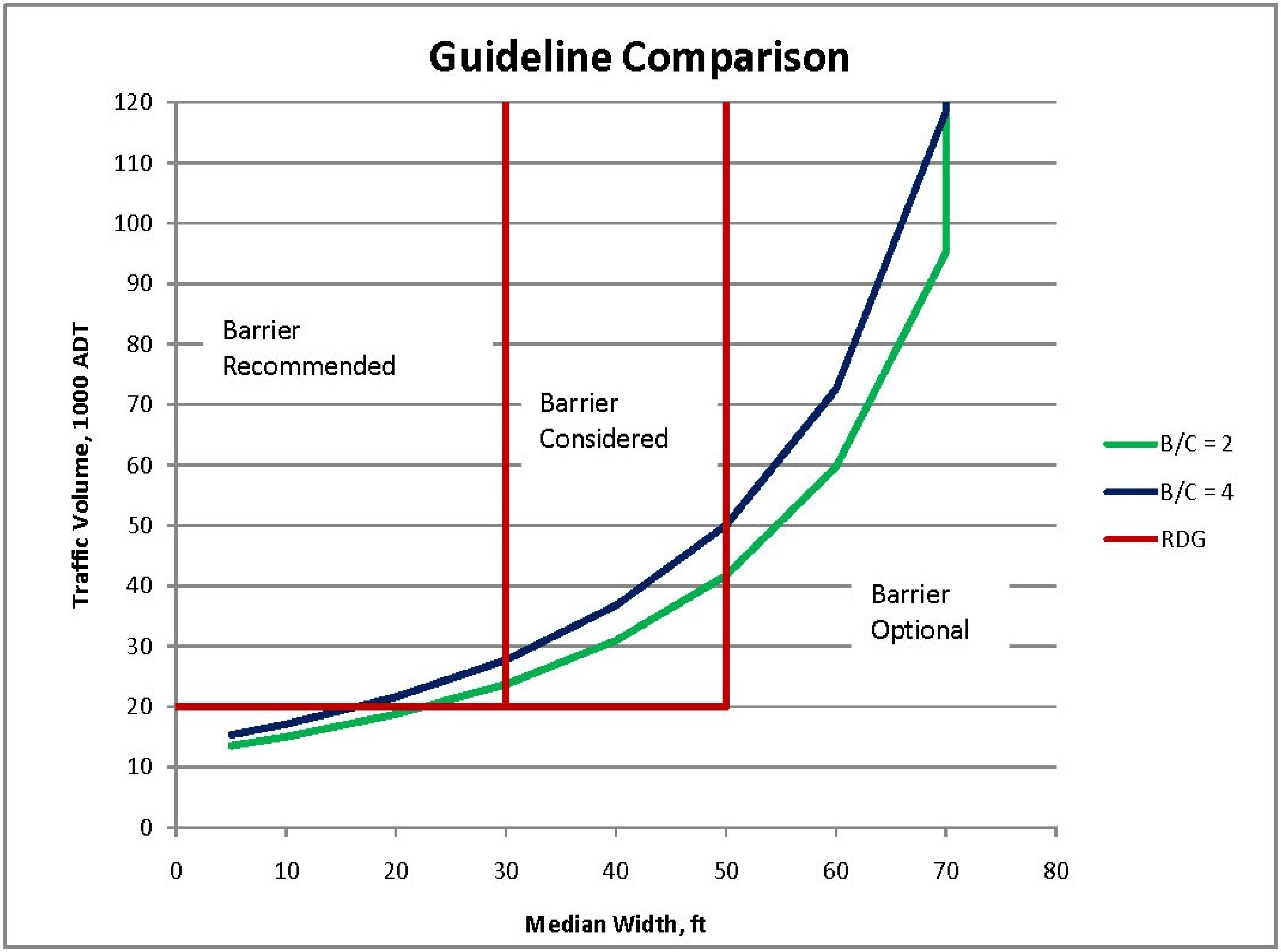

Figure 9. Comparison of Proposed Guidelines with RDG Recommendations.

4 LIMITATIONS

The most important limitation associated with the benefit/cost analysis procedure described above is the traffic volume range available for developing the CMC rate prediction model. Virtually all of the highways incorporated into this study had one-way traffic volumes below 30,000 vehicles per day. Further, the highway mileage for higher traffic volumes is relatively limited which further complicates the use of the CMC prediction model to extrapolate the accident data to higher traffic volumes. However, the crash prediction model should be accurate for most rural freeways found in the Midwest, where one-way traffic volumes are typically below 25,000 vehicles per day. Nevertheless, the confidence in this analysis could be further improved by the inclusion of additional years of crash data, especially for higher traffic-volume roadways.

The lack of cable barrier crash data is another important limitation. If Kansas had a significant amount of cable barrier installed across the state, the accident study could have been used to directly estimate barrier crash rates and impact severities. Although using encroachment data from the RSAP program is believed to provide a reasonable estimate of crash frequency, at best, these values can only be considered a national average. There is no way to incorporate the effects of Kansas geometric design policies without the needed accident data.

Accident severities incorporated from Missouri's cable median barrier crash evaluation do not include specific severity levels nor number of injuries and/or fatalities. This omission significantly understates the average severity of cable median barrier crashes and would tend to lower traffic volumes at which a barrier becomes cost beneficial.

Further, there is reason to believe cross median crash rates should begin to plateau as traffic volumes become very large. As traffic volumes begin to reach saturation levels, virtually every

vehicle reaching the opposing traffic lane will be involved in a CMC. Hence, the rate of CMC occurrence will no longer increase as the number of cars in the opposing lanes grows. Unless increases in traffic conflicts cause CME rates to grow exponentially faster in these volume ranges, the rate of growth in CMC rates will diminish. In fact, an S-curve fit the data a little better than the selected model. However, as mentioned previously, highway mileage at the higher volumes was limited and the S-curve proved to be relatively unstable. However, it is recommended that care should be taken when extrapolating the CMC predictive model much above the upper bound traffic volumes in the data set of 30,000 vehicles per day in each direction of travel.

It is also important to recognize that median barrier installation must compete for funding against other safety projects across an agency's highway system. States are encouraged to explore the magnitude of the statewide cross-median crash problem relative to other safety issues. For example, Kansas averaged 5.6 fatalities per year from CMCs for the five years included in this study. This is a relatively low number in comparison to the average of 270 fatalities per year for all types of crashes on Kansas' state maintained highway system. Safety resources should not be disproportionately assigned to mitigate cross-median crashes when they represent a relatively small portion of all crash fatalities.

Finally, the reader must be aware that cable median barriers are not problem free. Regardless of the type or design of cable median barrier, some vehicles will penetrate through, over, or under the system. Thus, even though cross median crashes should be dramatically reduced with the installation of cable median barrier, some CMCs will still occur. Accident studies have shown that cable barrier penetration rates can reach as high as five percent of reported crashes. Further, cable barriers complicate some aspects of freeway operation including, incident management and

vegetation control. Median crossovers will not be available for use by emergency response vehicles or incident management teams after a cable barrier is installed. In rural areas, this could mean significant additional delay before first responders can arrive at the scene of a serious crash. When serious crashes require closure of one set of lanes, traffic is sometimes re-routed across the median traffic flow until the roadway can be reopened. Cable barrier installations make redirecting traffic across the median as a means of incident management a difficult if not impossible proposition. Cable barriers also complicate median vegetation control and require either chemical treatments or installation of a mow strip under the barrier.

5 CONCLUSIONS AND RECOMMENDATIONS

The analysis of Kansas accident data on controlled access roadways clearly demonstrated that winter driving conditions significantly increase cross-median crash rates. The analysis also revealed that, although crash rates go up during winter driving conditions, accident severities are reduced. The same sort of effect would be anticipated for cable barrier crash rates. Hence, incorporating a single set of median safety treatment guidelines across the entire nation may not be appropriate.

B/C ratios for cable median barrier implementation shown in Table 6 can be used to develop statewide guidelines for safety treatment of open medians. These B/C ratios should be appropriate for use across most of the Midwest. State agencies are encouraged to examine B/C ratios associated with common types of construction projects and then develop median barrier guidelines that will assure comparable B/C values for cable barrier installation. If utilized in this manner, findings from the study should help state highway agencies to develop policies that provide safety for the motoring public and optimize the expenditure of safety funds.

After selecting the appropriate B/C ratio, highway agencies should examine their freeway system to identify regions where existing traffic volumes are near the threshold values indicated in Table 6. Traffic volumes for the candidate regions should then be projected forward to determine the estimated average volume over the 20 year life of the cable barrier system. Highway sections with projected average traffic volumes above values shown in Table 6 should then be analyzed further to prioritize barrier placement projects. Highway sections found to be candidates for barrier installation should then be examined to identify CMC rate in terms of crashes per mile per year. Sections with the highest CMC rate should be assigned the highest priority for barrier installation. If highway sections have similar CMC rates, barrier installation priority should be based upon the

ratio between average traffic volume and threshold volumes at which a barrier becomes recommended. Highway sections with a higher ratio should be given the higher priority.

It should be noted that Kansas medians typically have 6:1 or flatter slopes, thus the guidelines presented herein are appropriate for these condition. However, the accident data analysis procedures described above can be adapted to develop median barrier implementation guidelines appropriate for other parts of the country. In fact, most large states have sufficiently unique highway and median geometrics to merit individual studies designed to develop guidelines for cable median implementation.

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