RELATING ROADSIDE COLLISIONS TO HIGHWAY CLEAR ZONE WIDTH

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Abstract

The provision of a hazard-free 'clear zone' adjacent to roadways has been standard design practice for many years aimed at reducing the severity of run-off-the-road collisions. Nevertheless, collisions between vehicles and various elements along the roadside are still responsible for approximately one-third of all fatalities and account for approximately $80 billion in annual costs in the United States [1]. In New Brunswick, the problem is even more acute given that 55 percent of road fatalities were roadside collisions in 2002 [2].

The width of clear zone provided for a highway has a profound impact on the final cost of the project. Unfortunately, the tools that planners and designers currently use are based on very dated observations and relationships. This study provides a quantification of the relationship between clear zone width and collision reduction that should provide key input into the process of selecting highway design standards.

This study evaluated 70 highway sections in New Brunswick in order to determine how much single-vehicle run-off-road (SVROR) collision rates varied when controlling for the clear zone provided. The data used were drawn from eleven years of motor vehicle collision reports provided by the New Brunswick Department of Transportation. The results of this study show that SVROR collision rates are reduced by approximately 40% when the clear zone provided is extended from a Category 'A' (<6m) to Category 'B' (6 – 10m). Similarly, collision rates are reduced by over 60% when the clear zone provided is extended to Category 'C' (10+m).

Résumé

L'utilisation d'une zone de dégagement en bordure des routes fait partie des principes de conception depuis longtemps et vise la réduction de la gravité des collisions hors de la route. Pourtant les collisions avec des objets fixes sont encore responsables d'environ 1/3 des décès et coûtent environ 80 milliards de dollars aux États-Unis. Au Nouveau-Brunswick, le problème est encore plus important puisqu'en 2002 environ 55 % des décès étaient le résultat d'une sortie de route.

La largeur de cette zone de dégagement a un effet très important sur les coûts de construction. Malheureusement, les outils utilisés par les planificateurs et les concepteurs sont basés sur des observations et des relations qui datent. Cette étude établit une relation entre la largeur de la zone de dégagement et la réduction du nombre de collisions hors route et devrait donc être un intrant important pour le choix des normes de conception.

Soixante-dix sections de routes du Nouveau-Brunswick ont été évaluées afin de déterminer comment le taux de collision hors route était influencé par la largeur de la zone de dégagement. Les données étudiées ont été obtenues du Ministère des Transports du Nouveau-Brunswick et couvraient une période de 11 ans. L'analyse montre que le taux de collision hors route est réduit d'environ 40 % lorsque la zone de dégagement passe d'une catégorie A (<6 m) à une catégorie B (6-10 m). De même, le taux collision hors route est réduit d'environ 60 % lorsque la zone de dégagement passe à une catégorie C (10 m et plus).

INTRODUCTION

Improving roadside safety is a major issue for highway transportation agencies as roadside collisions account for approximately 14,000 (or one-third of all) highway fatalities and 100,000 injuries in the United States annually, with total costs estimated at $80 billion [1]. This is also an issue for the Province of New Brunswick, Canada, where in 2002, there were 57 fatalities (55% of total), 1252 personal injuries, and millions of dollars in property damage all resulting from roadside collisions [2]. The provision of a clear zone beyond the travel lane to reduce the severity of run-off-the-road collisions has been standard practice for many years. The width of clear zone provided for a highway has a profound impact on the final cost of the project. Unfortunately, the tools that planners and designers currently use are based on very dated observations and weak relationships. This study provides a quantification of the relationship between clear zone width and collision reduction that should provide key input into the decision-making process for highway standard selection.

1. Study Goal

The underlying goal for this study was to develop a better understanding of the relationship between the frequency/severity of single-vehicle run-off-road collisions and certain geometric/operational characteristics of the corresponding highway sections. Current methods of establishing clear zone width were developed from encroachment studies undertaken in the 1960's. While the Transportation Association of Canada (TAC) and American Association of State Highway and Transportation Officials (AASHTO) include clear zone encroachment probability curves in their design guides, questions have been raised on the adequacy of these probability curves for today's highways and vehicles.

This study examined the safety performance of a sample of rural highway sections in New Brunswick. The collision data considered for this study came from collision reports filed between 1993 and 2003. The highway sections selected for inclusion in this study were relatively uniform throughout their length in terms of speed, volumes, and geometric characteristics (in particular, clear zone width). Collisions involving all classes of vehicles were considered as part of this study; however, only single-vehicle run-off-road (SVROR) collisions were included in order to isolate the number of variables to be considered. This study could not include SVROR incidents that were not reported (e.g. vehicle recovered and drove away).

2. Background

Clear zones are the areas provided adjacent to roadways that are free of hazardous obstacles or steep slopes while providing an adequate "zone" (both in terms of slope and distance) for drivers of errant vehicles to regain control and safely stop or return to the highway. TAC assigns the term "recovery zone" to include a clear runout area if the clear zone ends where a non-recoverable slope is located. This study refers to both the "clear zone" and "recovery zone" as "Clear Zone Provided" (CZP) to reflect actual provisions in the field.

The TAC Geometric Design Guide for Canadian Roads is the primary resource used by highway designers in Canada and includes a "Roadside Safety" section as part of its overall highway design guide [3]. TAC guidelines, for the most part, are reflective of those found in the AASHTO Roadside Design Guide [4], with some alterations to better reflect Canadian conditions and practice.

The encroachment probability curve (Figure 1) from the TAC geometric design guide indicates that a minimum clear zone of 10m has been found to allow 80% of errant drivers to regain control of their vehicles without experiencing any interference from roadside features. Unfortunately, the impact of criteria such as vehicle speed, cross slope, and traffic volume are not included in this model. It is shown in Figure 1 that clear zones would have to be as wide as 20m to protect close to 100% of errant vehicles. Therefore, when designing a road and its adjacent clear zone, efforts should be made to increase the chances of recovery for errant vehicles, while realizing that virtually no practicable clear zone width guarantees 100% errant vehicle recovery.

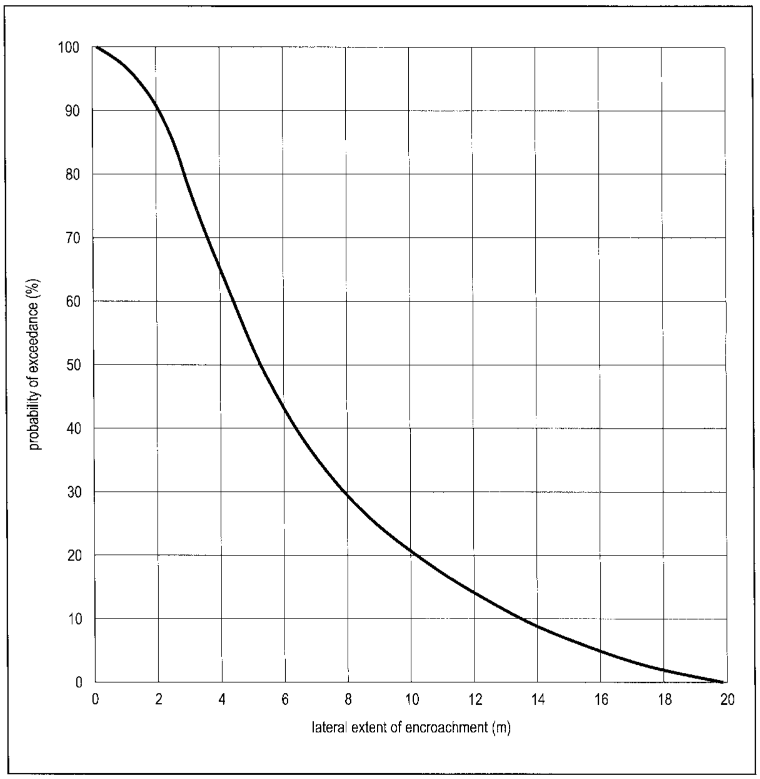

Figure 1 – TAC encroachment probability curve [5]

The AASHTO guide presents multiple probability curves accounting for variations in errant vehicle speed [6]. These curves appear to be more precise and informative than the single TAC probability curve (Figure 1) although they are both based on the same research information.

The Australian transportation authorities present their clear zone standards somewhat differently than their North American counterparts [7]. The major difference is that Australian clear zone dimensions are presented in a linear format, while North American clear zone dimensions are represented on probability curves.

To compare the standards of the three countries mentioned (Canada, the United States, and Australia), three exemplary design speeds have been chosen, and the corresponding clear zone dimension based on each country's standard is noted in Table 1.

Table 1: Comparison of international clear zone recommended dimensions*

Design Speed	Country	Clear Zone Recommended**
60 kph	Canada USA Australia	4.5 - 5.0m 4.0m 3.3m
80 kph	Canada USA Australia	6.0 - 8.0m 6.0m 5.5m
100 kph	Canada USA Australia	10. 0 -12.0m 10.0m 8.0m

*Assume Average Daily Traffic = 2500, and fill slope 1:5
** Measured from edge of traveled lane

The data in Table 1 indicate that there is a discrepancy between the three countries in terms of clear zone recommendations. Taking into consideration maximum and minimum clear zone values, the difference between recommended clear zone widths could be as much as 4 metres (in the case of a 100 kph highway). This wide range illustrates the subjectivity of roadside design and highlights the need to better understand the fundamental theory behind these recommended dimensions.

Both the TAC and AASHTO design guidelines relating to clear zones find their roots in a 1966 study by J.W. Hutchinson and T.W. Kennedy, researchers affiliated with the University of Illinois. Their final report (Illinois Cooperative Highway Research Project 59) contained the results of a large study that examined the "frequency, nature, and causes of vehicle encroachments on medians of divided highways" [8]. Although this study focused primarily on medians, the methodology and the results of the study went on to be applied directly to all highway roadside environments (both on the left and right side of divided and non-divided highways). The report's primary purpose was to provide a practical and economically feasible methodology for mitigating roadside encroachments.

Encroachment data were collected by investigating tire marks on the roadside surface, and then examined further to determine the nature of the encroachment, such as vehicle speed, type, and distance traveled. Hutchinson and Kennedy acknowledged that no information could be collected for the first three feet (0.9m) of roadside (the "stabilized shoulder") as tire marks were virtually impossible to identify. While the researchers considered other measurement techniques, such as aerial photography and electronic detection equipment, they were rejected due to limited success and reliability issues.

The report indicated that there is no simple mathematical relationship that can accurately reflect the enormous number of variables involved with vehicle encroachments, and therefore empirical data collected at encroachment sites must be used. This methodology is similar to that used in many other subsequent transportation studies. The most important conclusion of this study was the recommendation for a 30-foot (9.1m) wide obstacle-free median with moderate cross slopes, which was included in the 1974 AASHTO guide to Highway Design and Operational Practices Related to Highway Safety [9].

The encroachment model explains that those who created the clear zone tables in the AASHTO Roadside Design Guide used "roadway and traffic information to estimate the expected encroachment frequency." This involved a two-step process where highway type and traffic volumes were used to estimate a base or average encroachment frequency, and then adjustment factors were applied based on number of lanes, controlled versus uncontrolled encroachments, and other highway geometric characteristics [10].

Clear zones have been the subject of several subsequent studies. Cooper [11] built on the work by Hutchinson and Kennedy by refining encroachment measurement methodology. Graham and Hardwood [12] and Olivarez [13] contributed to the debate on treating clear zone dimensions as guidelines rather than standards, given the variability in characteristics of different highways.

Zeeger and Council [14] quantified a relationship between increasing recovery distance and a reduction in collision frequency. Specifically, they found that increasing roadside recovery distance by 1.5, 3.0, 4.6 and 6.1m yielded accident reductions of 13, 25, 35 and 44 percent. Unfortunately, these reduction factors do not reflect the extent of clear zone provided or other base conditions prior to widening/modification.

Mak, Bligh, and Ross [15] identified the roadside obstacles most frequently involved in collisions, while Sullivan and Jud [16] also discussed underlying causes for drivers to run-off-the-road. Sicking and Mak [17] concluded that the "clear zone concept is perhaps the most important contributor to roadside safety design" but that "it is difficult to develop clear zone guidelines that consider both the benefits and costs of providing wider recovery zones." This current study attempts to expand on the known relationships.

METHODOLOGY

A collision database was developed that included records of all motor vehicle collisions that have been reported to the New Brunswick enforcement agencies from 1993 to 2003, inclusive. To simplify data analysis, it was assumed that reported collisions comprise the majority of all highway collisions. It was also assumed that cross-sectional characteristics assigned to a given section of highway are constant throughout the section, on both sides of the roadway. Control sections that had fewer than 11 years of data were included, provided that data were for control sections that remained physically unchanged.

Each record contained attribute information such as the number and types of vehicles involved, the severity of the collision (injury, fatality, or property damage only (PDO)), along with many other variables describing the nature of each collision. The database was customized to only include single-vehicle run-off-road (SVROR) collisions. Since this study only considered collisions where a single vehicle was involved, both types of lane configurations (divided and undivided) were included.

With the help of engineers at the New Brunswick Department of Transportation (NBDOT) 70 sections of highway were identified and isolated based on relative uniformity of geometric characteristics including CZP. The 70 sections were separated into 27, 22, and 21 highway sections, respectively, for each of the three CZP width categories delineated. The number of width categories was kept relatively small to ensure a degree of statistical reliability when capturing results. Table 2 summarizes the CZP thresholds for each category, along with the total number of sampled control sections included in each category.

Table 2: Study control sections

Category	Clear zone provided	Number of Sample Control Sections
A	< 6m	27
B	6 – 10m	22
C	10+m	21

Data analysis first required assembling the appropriate data for each specific highway section, including relevant collision data, along with the CZP, length, posted speed, and traffic volumes for each section. Lack of available actual operating speed necessitated the use of posted speed as a proxy and some interpolation of the traffic volume data. Each section of highway was then analyzed separately. These collision rates were then normalized based on road length and traffic volume. Annual collision rates were expressed as collisions per billion vehicle-kilometres.

Overall collision rates for each highway section over the entire study period were determined by averaging the individual yearly collision rates for each section. Once average collision rates (fatalities, injuries, and PDO) were determined for each control section, and with control sections sorted into the three CZP categories (A, B, or C), average annual collision rates were determined for each category.

RESULTS

The data plotted in Figure 2 illustrate the relative differences in collision rates between the three categories of CZP. Category ‘A’ had the highest collision rates in each severity type, with ‘B’ and ‘C’ having progressively better rates. One item of note is that Category ‘C’ actually had a higher fatality rate than ‘B’ (2.8 versus 0.7 col. / billion veh-km). This may be due to excessive travel speeds on some of the four-lane facilities, which tend to be overrepresented in Category ‘C’.

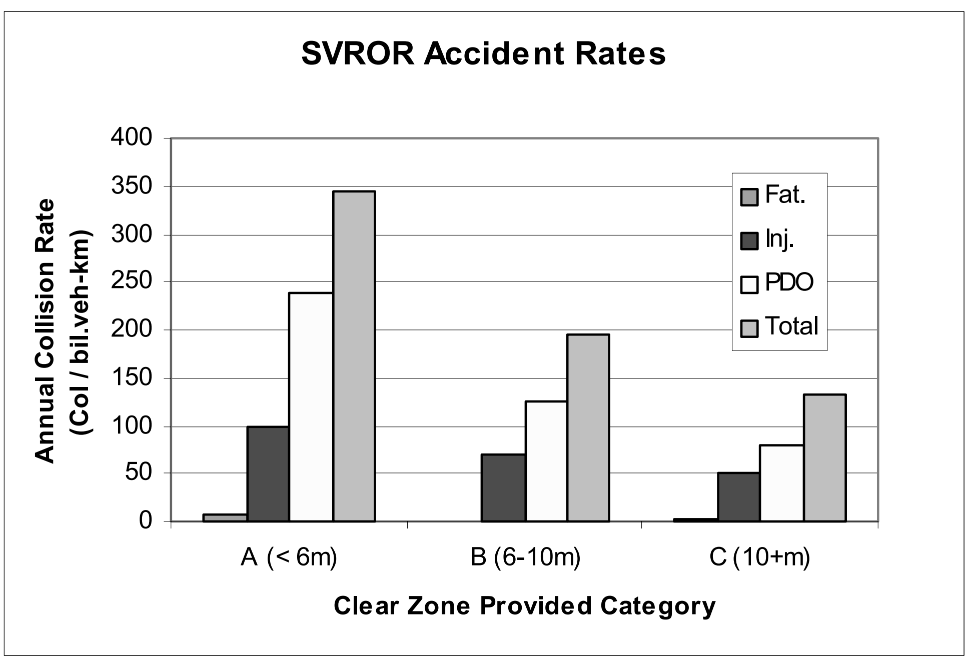

Figure 2: Collision rates for each category of clear roadside provided

The average posted speeds for CZP Categories 'A', 'B', and 'C' were calculated to be 79 kph, 90 kph, and 100 kph, respectively. Another analysis was performed on control sections that shared a posted speed of 80 kph to normalize the impact of speed so that the effect of CZP could be better isolated.

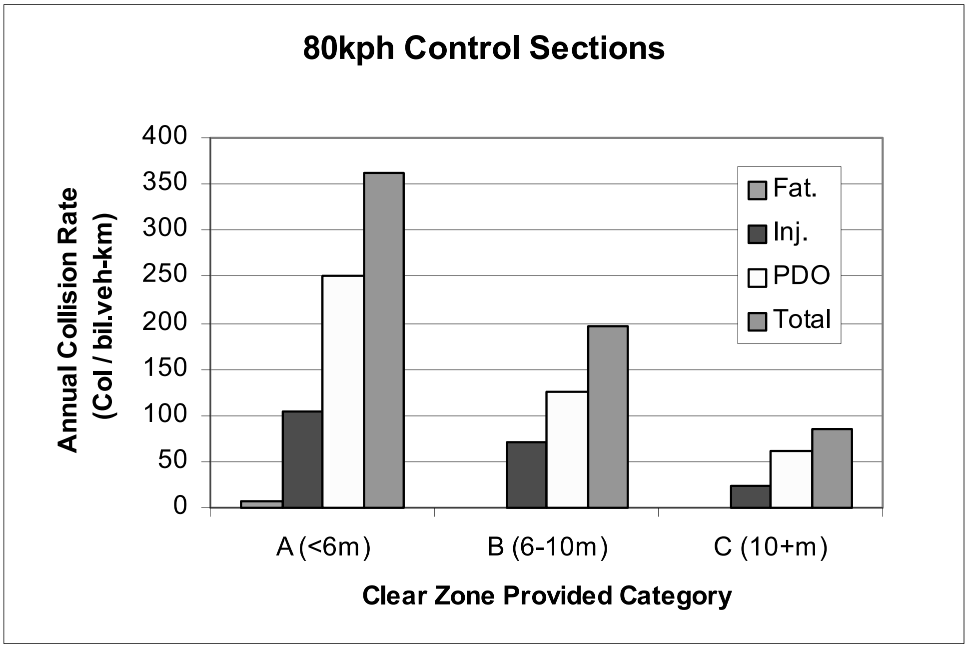

Figure 3: Collision rates for control sections with 80 kph posted speeds

The plots in Figure 3 illustrate nearly identical trends to that of the previous figure where different posted speeds were included. This suggests that the differences between collision rates among the three CZP categories are not dependent on posted speeds. It is important to note that these results demonstrate the value of establishing adequate CZP on lower posted speed roads as well as with high-speed highways. Interestingly, the relative distributions of PDO, injury and fatal collisions are also relatively consistent between CZP and width categories.

When individual control sections are compared, overall collision rate trends are reinforced. The control sections that have the three highest fatality, injury, and PDO rates are all included in Category 'A' (<6m of CZP).

To confirm the apparent significance of the results of this study, t-tests were conducted, and p-statistics produced, to determine the actual significance of the differences between the mean values presented in the figures. This study used a common significance level of 5% for hypothesis testing, with any p-statistic results greater than 0.05 deemed not statistically significant [18]. Table 3 shows a statistical comparison of the mean collision rates between each CZP category.

There are significant differences between the mean rates of all three CZP categories for "overall", or total, collision rates. Comparisons between CZP Categories 'A' and 'B', and Categories 'A' and 'C' for PDO result in significant differences. The comparison between Categories 'B' and 'C', for PDO collisions was not statistically significant. There was a significant difference between Categories 'A' and 'C' for collisions involving injuries when using a t-test.

Although the mean fatality rates appear quite different, none of the comparisons resulted in statistically significant differences. Greater sample sizes would likely produce more significant results.

Table 3: Statistical analysis: comparison of means between CZP categories

Categories	Significant (95%)			
	PDO	Injury	Fatality	Overall
A B	Yes	No	No	Yes
A C	Yes	Yes	No	Yes
B C	No	No	No	Yes

The results of these analyses indicate that highways in New Brunswick with more CZP have lower single-vehicle run-off-road collision rates in terms of fatalities, injuries, PDO, and overall SVROR collision frequency. This conclusion is further strengthened, as this trend in lower collision rates remains virtually the same when comparing highway sections with different CZP but normalizing for the influence of posted speeds.

It is possible that other factors not considered in this study may have also influenced any or all of the collision rates; however, based on this study, CZP appears to be the highway design criteria most influential in terms of lowering SVROR collision rates.

DISCUSSION

Reductions in collisions rates as determined by this study were compared to the TAC clear zone encroachment probability curve, and are presented in Table 4. To make this comparison, the encroachment rates taken from the TAC curve were determined based on the mean distance for each CZP category (e.g. 3.0m, 8.0m, and 12.0m). The collision rate for CZP category 'A' was given a base rate of "1.0", with 'B' and 'C' being a ratio of 'A'. This provided three collision reduction factors (which are directly related to CZP) allowing for a basic comparison to the rates derived from the TAC curve. Although rates do vary, both show a similar reduction in encroachment/collision rates as roadside distance is increased.

Table 4: Encroachment rates vs. normalized collision rates

Category	A	B	C
Clear zone provided (CZP)	**< 6m**	**6 – 10m**	**10m+**
TAC encroachment probabilities	0.8	0.30	0.14
Normalized study collision rates	1.00	0.60	0.39

Although the studies conducted from the 1960's to present (including this study) all differ to varying degrees in both methodology and results, they all conclude that providing more clear area, or clear zone width, at highway roadsides has been proven to reduce single-vehicle run-off-road collision rates. Zeeger and Council [14] reported that increases in recovery area of 3.0

and 4.6m yielded estimated collision reductions of 25 and 35%, respectively. These estimates are comparable to the results noted above (Table 4) from this study.

The results of this study may prove to be very useful for highway planners to conduct benefit/cost analyses on various roadside design options. For example, using the relationships found in this study: on a 100 km section of highway with an AADT of 2000 and a CZP of 5.5m, collision rates, on average, should be 0.53 fatalities, 7.19 injuries, and 17.39 PDO, per year. Doubling the CZP of this section to 11m should reduce these collision rates to 0.2 fatalities, 3.64 injuries, and 5.83 PDO, on average, per year. These reductions are substantial, illustrating how influential CZP is on the safety of a highway section.

Table 5 presents the results of this study using the collision rate for Category 'A' CZP as a base, with 'B' and 'C' as ratios of 'A'. In this format, the information presented in this table can allow planners to estimate how much collision rates could be reduced by increasing the CZP, and be a valuable tool for benefit-cost analysis.

Table 5: Collision reduction factors using Category 'A' as base

Category	A	B	C
Clear zone provided (CZP)	**< 6m**	**6 – 10m**	**10m+**
Fatal	1.0	0.10	0.39
Injury	1.0	0.70	0.51
PDO	1.0	0.53	0.34
Total	1.0	0.60	0.39

The results of this study quantify actual reductions in single-vehicle run-off-road (SVROR) collision rates in relation to increased CZP. Quantifying the reduction of damages for SVROR collisions of all three severities (injury, fatality, and PDO) can be directly compared to the costs of providing more clear roadside area so that a benefit (reduced damages) vs. costs (right-of-way acquisition, addition construction/grading) comparison may be done. This provides an analytical tool for highway planners and designers to include as an integral part of their design process.

CONCLUSIONS

This study confirms that there is a strong basic relationship between collision rates and width of clear zone provided (CZP). The findings reinforce other clear zone research conducted over the last 40 years; however, quantification of collision rate reduction has been refined.

Collision rates for each severity type were determined for different width categories of Clear Zone Provided (CZP) and statistically significant differences were found between most of them. Even with the limitations of this study, the results show that SVROR collision rates are reduced by approximately 40% when the clear zone provided is extended from a Category 'A' (<6m) to Category 'B' (6 – 10m). Similarly, collision rates are reduced by over 60% when the clear zone provided is extended to Category 'C' (10+m). This represents a dramatic reduction in collision rates that illustrates the need to choose appropriate CZP during highway planning and design.

The rate for injury collisions was found to be 2.0 times that for roads with <6m of CZP versus those with >10m of CZP. Similarly, the rate for PDO collisions was found to be 3.0 times that for roads with <6m versus 10.0+m of CZP. Statistically significant conclusions could not be made regarding differences in fatal collision rates associated with CZP width categories.

Posted speeds were found not to influence the variations in collision rates for road sections of different CZP categories. This suggests that posted speed is not a significant factor in the rates of single-vehicle run-off-road (SVROR) collisions.

RECOMMENDATIONS

Conclusions from the study have led to the following recommendations on how to enhance safety.

1. Further research in this area would benefit by using more and narrower CZP categories to allow for the development of a more continuous relationship. This would, of course, require the use of larger data sets.

2. The results of this study should be used by highway planners and designers to better understand the financial trade-offs of choosing wider clear zones for new or rehabilitation/upgrade projects.

3. It would be very useful to include the effects of rumble strips in any analysis that examines the benefit/cost of clear zone width selection.

4. This study did not take into consideration the influence of actual cross slope grade on the consequences of vehicles running off-road. In the TAC design guide, there are specific requirements for roadside slopes in clear zones. It would be very useful in future studies to include roadside slopes in order to better understand the entire roadside setting in terms of its influence on single-vehicle run-off-road (SVROR) collisions.

This study has reinforced the need for government and other transportation management agencies to adopt roadside safety design policies that ensure that the appropriate roadside environment is provided at all times on all roadways. Minimizing the frequency of SVROR collisions, and immeasurable losses which result from highway collisions, should always be of primary importance.

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