HUMAN FACTORS AND SAFETY IMPACTS OF DELINEATION COUNTERMEASURES ON TWO-LANE RURAL ROADS

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Paper prepared for presentation

at the
Road Safety Engineering – New Developments and Initiatives Session

of the
2004 Annual Conference of the
Transportation Association of Canada
Québec City, Québec

September 19 – 22, 2004

ABSTRACT

A conventional approach to reducing lane departure crashes is to improve path delineation, in particular on curves. Current treatments on two-lane rural highways include permanent raised pavement markers (PRPMs) and rumble strips. This paper considers the effect of these treatments on driver behaviour and on safety.

Snowplowable PRPMs were shown to be associated with improved safety on high volume, high design standard roads in a recent NCHRP study. Conversely, there was a deterioration in safety (26% more nighttime crashes on low volume roads (5-15000 veh/day) with degrees of curvature >3.5 (about 500m). Based on studies of related devices, it is expected that, with snowplowable PRPMs, drivers will position themselves further from the centreline. This likely underlies the positive safety impacts found on high volume, high design standard roads. However, a second expected effect is that with improved preview of the road ahead, drivers increase speed at night. This adaptive behaviour, in combination with a lane position closer to the shoulder, likely underlies the negative safety impact found on tighter curves.

Centreline rumble strips were associated with improved safety both day and night in a recent Insurance Institute for Highway Safety study. Target crashes were reduced by an average of 25%. No negative safety impacts were seen. Based on studies of related devices, it is expected that with centreline rumble strips, which provide auditory feedback of lane crossing but do not improve path delineation, drivers are likely to reduce lane encroachments but unlikely to increase speed. These effects may explain the overall positive safety impact.

1 Introduction

A conventional approach to reducing lane departure crashes is to improve path delineation, in particular on curves. Current treatments on two-lane rural highways include permanent raised pavement markers (PRPMs) and rumble strips. In this paper, the effect of these two treatments on visibility, lane position and speed are considered and used to provide a basis for predicting and interpreting the safety impacts that have been found in recent studies.

2 PRPMs, Driver Response and Safety

The purpose of PRPMs is to provide improved delineation at night. Studies have shown that drivers on approaches to curves need 3 to 5 seconds of preview distance in order to feel comfortable with the changes in the road path (1). At night, such long preview distances cannot be provided by paint, but are possible using PRPMs, PMDs, and chevrons. It is expected that the improved path visibility produced by PRPMs will affect crash rates by impacting two types of driver behaviour:

- Lane control and positioning
- Speed control

Conventional PRPMs protrude above the road surface. Thus there is a secondary impact on lane control because of the auditory warning of lane crossing. This effect is not found with snowplowable PRPMs. This is important to the interpretation of the results, given that the only driver response studies found were carried out with conventional PRPMs, whereas the safety studies involved snowplowable PRPMs.

2.1 Lane Control and Positioning

Five studies of conventional PRPMs found that they were associated with fewer encroachments into the adjacent lane on horizontal curves (2), (3), (4), (5), and (6). One of these studies (2) examined sites with and without lighting, and found that encroachments were significantly reduced at both sites, but more at the site with lighting, which corroborates findings of other studies showing that encroachments were reduced during the day as well as at night after the placement of PRPMs on curves. Two studies found that drivers moved away from the PRPMs (7) and (5). One study found, at one site, that lane position variability decreased significantly (3).

No studies were found of the impact of snowplowable markers on lane control. Since snowplowable PRPMs do not have the auditory impact of conventional PRPMs any change in lane position at night with snowplowable PRPMs is expected to be the result of improved delineation only. It has been found that drivers re-position themselves further away from conspicuous post-mounted delineators (PMDs) (8). Similarly, other studies have found that drivers move away from wider centrelines (e.g., [9 and 10]). Such studies support the hypothesis that snowplowable PRPMs will have a similar effect.

2.2 Speed Control

When preview of the road ahead is reduced, as it is during nighttime with low beam headlights, lane control becomes more difficult, and driver workload increases, causing drivers to compensate by reducing their speed. Conversely, when preview of the road is improved through delineation, driver workload decreases and drivers may compensate by increasing speeds. Harms investigated speed choice in fog, and found that drivers tend to under-compensate (not reduce speeds enough) in poor visibility conditions (11). In simulator and on-road studies, improved delineation (higher contrast lane striping) was associated with higher speeds (12).

Based on these and other studies of driver speed choice, Rumar and Marsh predict that drivers overcompensate (increase speeds too much) in improved visibility conditions (13). Improved delineation, in the form of PMDs, was associated with nighttime speed increases and increased crash frequency on low design standard roads, but not on high design standard roads (8). A driver who increases speed, especially at night, is responding inappropriately. While PRPMs improve visibility of changes in the road path, they do not improve visibility of other hazards such as pedestrians, bicyclists, animals, or debris. Higher speeds lead to longer stopping distances and greater crash potential. Higher speeds in curves will result in an increase in lateral acceleration and a greater potential for run-off-road crashes.

With respect to speed, most studies of conventional PRPMs examined impacts on curves and findings were mixed. The smaller studies showed increases, decreases or no change, depending on the site (e.g., Mullowney, 1982 – 2 sites, Niessner, 1984 – 3 sites, Agent and Creasey, 1986 – 2 sites). The largest study, of 12 horizontal curves, by Zador et al (1987) found a statistically significant overall increase of about 2.2 km/h in the curves at night after PRPM application. A study by Krammes and Tyer (1991) involved the replacement of post-mounted delineators with PRPMs. There were significant but small increases in speed at two of the five sites, and though there were increases in speed at the other three sites, effects were not significant. This study also examined the effects 11 months after installation of PRPMs compared to immediately after installation found that speeds were lower when measured later, possibly due to lower reflectivity, which would reduce preview distance. In summary, the evidence suggests that PRPMs are associated with small increases in speed at night.

The issue of speed is likely to be more of a problem on curves with small radii. On high-speed roads, such curves force drivers to make large speed reductions. However, studies of driver lateral acceleration in curves show that drivers drive closer to the safety margin on tight curves than on gentle curves (14). This suggests drivers are reluctant to drop speed too much, and trade off comfort for time savings. Any small increase in speeds associated with PRPMs will have a greater negative safety effect when drivers are closer to the safety margin. This greater negative safety effect may be the explanation for the results of the 1993 Kallberg study, which found an increase in crash frequency associated with PMDs on low design standard roads.

Wet weather is another situation in which drivers are likely operating closer to the safety margin by not slowing sufficiently to compensate for increased braking distance. Thus, the negative impacts of any speed increases on tight curves may be exacerbated in wet weather.

2.3 Predicted Driver Response to Snowplowable PRPMs

No studies were found of driver response to snowplowable as compared to conventional PRPMs. Snowplowable PRPMs do not have the auditory feedback of conventional PRPMs but do substantially improve nighttime centreline visibility. As a result snowplowable PRPMs are expected to have the following impacts on driver behaviour on two-lane rural roads:

- Positioning further from the centreline
- Reduced oncoming/left lane encroachments at night
- Increases in shoulder encroachments at night
- Small increases in speeds at night

These changes in driver behaviour would be expected to impact both head-on and run-off-road crashes at night. Below we describe the results of a recent safety analysis carried out by Bahar et al. (15). This is followed by a discussion of each of the safety impacts in light of driver response.

2.4 Safety Impact of Snowplowable PRPMs

The safety impact of snowplowable PRPMs, installed on 2-lane roadways in 4 states in U.S., i.e., Illinois, New Jersey, New York, and Pennsylvania, was examined using Empirical Bayesian (EB) methodology (16). The EB methodology was used to properly account for regression to the mean while normalizing for differences in traffic volume and other factors between the before and after periods.

The EB methodology requires the use of crash, roadway inventory and traffic volume data. These data were collected for treatment, reference and comparison sites for many years. A total of 983 miles (1573 km) of treatment sections were surveyed. In all jurisdictions studied, PRPMs were installed on segments that included a combination of tangent and curved sections; the start and end of each curve and its radius were recorded.

For the states with selective implementation policies (Pennsylvania: based on total crash history; New York: based on total, nighttime and wet crash history), a sample of untreated 2-lane roadways was identified to comprise a reference group from which safety performance functions (SPFs) were calibrated for each year of the analysis period. An SPF provides the expected crash frequencies for a range of traffic volumes on a given type of road facility (here, 2-lane roadways). The SPFs for roadways for different conditions allow the researcher to estimate the frequency and severity of crashes with and without the specific measure.

Where PRPMs were installed non-selectively (i.e. in Illinois and New Jersey), the reference group information used for calibrating SPFs comprised the before period data at all the identified locations with snowplowable PRPMs. During the after period installation continued throughout the state. This meant that data, involving sites without snowplowable PRPMs, available for calibrating the SPFs was continually reduced as installation continued. To calibrate the SPFs for these later years, a comparison group of sites that consisted of as yet untreated locations, or locations on which PRPMs have been installed prior to the beginning of the study period, was identified where possible, to account for time trends between the SPF calibration period and the rest of the analysis period. Due to the widespread implementation of PRPMs in Illinois, it was not possible to select suitable comparison group sites. In such case, SPFs were fitted to the data for the later years of the after period at treatment sites to develop time trend factors for these later years.

The results of the analyses are presented separately for composite and disaggregate effects. The composite safety effects are presented in terms of values expressed as indices of effectiveness (è). The *Index of Effectiveness* (è) equals the ratio of the observed number of crashes during the after period to the expected number of crashes that would have occurred if PRPMs were not implemented.

Table 1 shows the results of the safety evaluation of PRPMs on 2-lane roadways. New York installations show highly significant decreases ($P \leq 0.05$) in total crashes (9.5 %), nighttime crashes (13%) and wet weather crashes (20%) after the selective implementation of PRPMs based on *wet weather nighttime* crash history. Similar benefits were not found in Pennsylvania where PRPMs were implemented at locations selected based on *total* crash history or in Illinois and New Jersey, which implement PRPMs non-selectively. In fact, Illinois actually experienced significant increases in some crash types, such as daytime, dry weather and wet weather crashes.

TABLE 1: Composite Safety Effect of PRPMs on 2-Lane Roadways

Crash Type	Illinois (Non-selective) # Sites = 5347 # Miles = 460.53		New Jersey (Non-selective) # Sites = 779 # Miles = 173.98		New York (Selective) # Sites = 226 # Miles = 81.75		Pennsylvania (Selective) # Sites = 5383 # Miles = 266.94	
	Observed (Expected)	è (s.e.)	Observed (Expected)	è (s.e.)	Observed (Expected)	è (s.e.)	Observed (Expected)	è (s.e.)
Total	1133 (1038)	1.091 (0.035)	3508 (3399)	1.032 (0.027)	1121 (1238)	0.905 (0.034)	1244 (1270)	0.980 (0.030)
Injury	292 (272)	1.071 (0.065)	1219 (1275)	0.955 (0.038)	424 (415)	1.020 (0.057)	231 (227)	1.017 (0.068)
Daytime	592 (502)	1.179 (0.051)	2338 (2232)	1.047 (0.034)	672 (669)	1.003 (0.048)	739 (767)	0.963 (0.038)
Daytime Injury	167 (155)	1.080 (0.086)	861 (882)	0.976 (0.044)	293 (272)	1.074 (0.072)	133 (136)	0.978 (0.086)
Nighttime	541 (540)	1.001 (0.045)	1148 (1158)	0.991 (0.040)	449 (514)	0.873 (0.052)	505 (486)	1.039 (0.048)
Nighttime Injury	156 (141)	1.106 (0.091)	350 (389)	0.899 (0.058)	131 (131)	1.000 (0.097)	98 (91)	1.074 (0.110)
Dry	773 (711)	1.087 (0.041)	2601 (2476)	1.050 (0.032)	764 (729)	1.047 (0.048)	798 (816)	0.978 (0.037)
Wet	284 (246)	1.155 (0.072)	876 (900)	0.972 (0.045)	333 (417)	0.798 (0.050)	440 (420)	1.047 (0.053)
Head-On	28 (33)	0.859 (0.163)	180 (224)	0.804 (0.068)	Sample size too small		120 (87.45)	1.372 (0.127)
Guidance	397 (390)	1.018 (0.053)	180 (224)	0.804 (0.068)	Sample size too small		279 (233.1)	1.197 (0.074)

Two types of disaggregate analyses were undertaken on the results for nighttime crashes, the type that is targeted by PRPMs. The first was a univariate exploratory analysis of the results of each State, aiming to identify and isolate factors that might be associated with the variation in the safety impact of PRPM installations at individual sites. The results of the exploratory analyses were used to guide a more formal analysis that used multivariate modeling to relate the safety impact of PRPM to variables found in the initial analysis to affect this impact.

In the exploratory analysis, two-dimensional plots and spreadsheets were used to sort the data and results for each site by various columns, and to group by ranges of a variable in order to explore the relationship between factors and the measured *Index of Effectiveness* (*q*). This cursory analysis led to the following general observations on the nighttime crash effects:

- On 2-lane roadways, the safety benefit of PRPMs increases as traffic volumes increase
- On 2-lane roadways, the safety benefit effect of PRPMs decreases as the degree of curvature of a curve increases (as radius decreases)
- On 2-lane roadways, the safety benefit of PRPMs appears to be greater on sections with illumination, but this effect is not a strong one
- On 2-lane roadways, the safety benefit of PRPMs decreases as the roadway width and shoulder width decrease, but these effects don't appear to be strong.

Naturally, some of these observations could result from correlations among the various variables that may affect the PRPM safety impact. This could mask the effects or indicate effects that are not real. The more formal analysis that is described next was performed with the intent of minimizing the effects of this limitation.

In this more formal disaggregate analysis, data for all States were combined to develop a model to estimate the value of the *Index of Effectiveness* (q) for an individual site using traffic volumes and other site characteristics (e.g. surface width, shoulder widths, illumination, other delineators etc.) and PRPM design features (e.g. spacing) as explanatory variables.

The data for modeling were combined - all sites sharing a set of characteristics (e.g. all urban, no curvature, AADT < 20 000) were grouped by summing, over all sites, the segment lengths, the count of nighttime crashes in the after period and the expected after period crashes without PRPM. The value of q for a group was then calculated using these summed values.

To facilitate the grouping, ranges for variables such as degree of curvature and AADT had to be assigned an ordinal value. This was accomplished with the use of an iterative process to determine the best ranges considering the number of crashes in one range, the variation in crashes/mile-year within and among ranges, and the observations from the univariate analysis.

Stepwise linear regression was performed by means of the SAS statistical analysis software package, using the estimates of the Index of Effectiveness for individual sites as estimates of the dependent variable. Statistically insignificant variables at the 10% level were eliminated. It should be pointed out that the absence of a variable in the final model does not necessarily mean that the variable would not affect the safety impact of PRPM since a statistically insignificant effect could result from correlation with other variables, a lack of variation in the data or a sample that is too small. In addition, it should be emphasized that the generally small size of the composite safety effects of PRPM was already strongly indicative of the reality that one is unlikely to detect many factors that affect the safety effect of PRPMs.

Table 2 shows the calibrated model for two-lane highways. For example, at AADTs ranging between 15,000 and 20,000 on a roadway with a degree of curvature < 3.5

(radius > 500 m), a decrease in nighttime crashes of 24.3% (= 100 (1 – (1.1573 - 0.4004))) following PRPM installation can be estimated from the model. At lower AADTs and sharper curvature, PRPMs can in fact be associated with an increase in nighttime crashes. For example, for PRPMs installed on roadways with AADT between 5,000 and 15,000, an increase in nighttime crashes of 26% can be estimated from the model. That PRPMs are more effective at night on roadways with more gentle curvature (degree of curvature ≤ 3.5 or radius ≥ 500 m) is contrary to a belief held by many.

TABLE 2: Index of Effectiveness Model for 2-Lane Roadways (Nighttime Crashes)

Model Parameters	Applicable condition	Estimate	Standard Error	p-value
Constant	AADT ≤ 5000 Degree of curve ≤ 3.5	1.1573	0.0260	<.001
AADT 2	AADT > 5000 and ≤ 15000	-0.1700	0.0395	0.003
AADT 3	AADT > 15000 and ≤ 20000	-0.4004	0.0607	<.001
Doccat 1	Degree of curve > 3.5	0.2736	0.0824	0.011

2.5 Driver Behaviour Underlying Safety Impacts of Snowplowable PRPMs

The findings concerning the impact of snowplowable PRPMs on safety are discussed in light of driver response.

2.5.1 Reduced Nighttime Head-on Crashes, with Increasing Benefits as Traffic Volumes Increase

The safety analysis showed:

- Statistically significant decreases in head-on crashes on 2-lane roadways in New Jersey (non-selective implementation)
- Statistically non-significant decreases in head-on crashes, against a statistically significant increase in total crashes in 2-lane roadway Illinois data (non-selective implementation)

The majority of head-on crashes are due to inadvertent excursions into the oncoming lane (only 4% of head-on fatalities are associated with overtaking) (17). Inadvertent excursions are less likely if drivers are positioned further from the centreline. Based on studies discussed earlier, drivers move away from a centreline that is made more visible through the use of PRPMs.

Although available sample sizes did not permit a composite or disaggregate analysis of nighttime head-on crashes, the AMFs determined for 2-lane roadways show statistically significant improvements in the safety performance of PRPMs at night as traffic volumes increase. Since the majority of head-on crashes are due to inadvertent excursions into the oncoming lane, the probability that such excursions result in head-on crashes increases as traffic volumes increase. Thus a measure which reduces inadvertent excursions into the opposing lane will be more effective in higher traffic volumes.

2.5.2 Decreasing Safety Benefits as Degree of Curvature Increases

On sharper curves (i.e., higher degree of curvature), it is possible that the negative safety impact of speed increases and lane positioning closer to the shoulder, is not offset by the positive safety impact of improved visibility, and lane positioning away from the centre, resulting in an increase of nighttime crashes. This proposition is supported by the univariate analysis of 2-lane roadways, as well as the results of the disaggregate analysis, which show that PRPMs will have negative safety effects on roadways with a degree of curvature exceeding 3.5 (radii 500 m or less), for all ranges of traffic volumes examined.

2.5.3 Decreasing Safety Benefits as Vehicle Position Closer to the Edgeline

PRPMs make the centreline more conspicuous and drivers respond by positioning themselves further from it (the same effect occurs with PMDs, but here drivers move towards the centreline). As vehicles move away from the centreline towards the edgeline due the presence of PRPMs, it seems reasonable to expect an increase in the risk of run-off-road crashes on 2-lane roadways with lower design standards (e.g., higher degrees of curvature, narrower pavements widths, etc.). As an example, narrower shoulder widths reduce the recovery area for vehicles that leave the travel lane. The univariate analysis indicated a positive correlation between traffic volumes and pavement widths, meaning that higher traffic volume roadways are normally associated with higher roadway design standards. This may in part explain why the Accident Modification Factors (AMFs) determined in this study show decreasing safety benefits with decreased traffic volumes, which are in turn associated with roads with narrower pavement widths.

2.5.4 Reduced Wet Weather Nighttime Crashes

The results of the safety composite analysis indicated a statistically significant decrease in wet weather nighttime crashes (by 20%) in 2-lane roadways in New York where locations were selected for PRPM installation on the basis of their nighttime wet weather crash history. PRPMs result in a significant improvement in visibility in wet weather at night. No studies have measured changes in speed under wet weather conditions with and without PRPMs, however an increase would be expected. Clearly at the selected sites, the increase in speed, if any, did not offset the safety benefit of improved visibility.

2.5.5 Slight Decrease in Daytime Wet Weather Crashes

The safety composite analysis of the 2-lane roadways in New York indicated a 23% reduction in all wet weather crashes after selective implementation of snowplowable PRPMs. Snowplowable PRPMs may improve daytime visibility under wet weather conditions due to the profile of the PRPM housing above the film of water covering the painted markings. This might contribute to a decrease in daytime wet weather crashes.

3 Centreline Rumble Strips, Driver Response and Safety

3.1 Driver Response

While there are studies of driver response to lateral rumble strips, no studies were found of the impact of longitudinal centreline or shoulder edge rumble strips on driver behaviour. However, longitudinal rumble strips, inside the lane edge, have been used in the Netherlands, to narrow the comfortable lane width, without decreasing the physical lane width, which would impact safety. The purpose of this application was to decrease speeds on 80 km/h highways at village entrance points. Simulator and on-road studies were used to determine impacts on drivers (9) and (10). One of the impacts was that drivers moved towards the centreline, away from the rumble strip. This response was eliminated when a wider more conspicuous centre line was used, and the edgeline conspicuity was reduced. Drivers did slow by small amounts as a result of this treatment.

Centreline rumble strips would be expected to cause drivers to position themselves a little further from the centreline. Based on the effect of conventional PRPMs on lane encroachments, centreline rumble strips would be expected to have a substantial impact on lane position, and therefore on centreline crossing, and on both head-on crashes (vehicle present) and run-off-road crashes (vehicle absent) to the left of the roadway. However, given that centreline rumble strips have little impact on visibility of delineation, no speed changes would be anticipated due to their use.

The more curved the road is, the more quickly an inattentive or impaired driver will leave the road. Thus centreline rumble strips might be expected to have more impact on curved as compared to straight road sections.

3.2 Prediction of Centreline Rumble Strips' Impacts on Safety

The auditory feedback from crossing the centreline, together with the lack of improvement of path delineation due to centreline rumble strips are expected to have the following impacts on driver behaviour:

- Lane position further from the centreline and closer to the shoulder
- Substantially reduced oncoming/left lane encroachments day and night and particularly on curves
- Small increases in shoulder encroachments

- No impact on speed

These changes in driver behaviour would be expected to impact both head-on and run-off-road crashes, with similar effects during the day as at night. Below we describe the results of a recent safety analysis carried out by Persaud et al. (18). This is followed by a discussion of the safety impacts in light of driver response.

3.3 Safety Study of Centreline Rumble Strips (CLRS)

A recent evaluation of the safety impact of CLRS using the empirical Bayes methodology (16) was carried out by Persaud et al. (18) for the Insurance Institute for Highway Safety. Data were drawn from seven states: California, Colorado, Delaware, Maryland, Minnesota, Oregon, and Washington. In total, 98 treatment sites along approximately 210 miles (336 km) of 2-lane rural road were studied. In all jurisdictions studied, centreline rumble strips tended to be installed on extended segments that included a combination of tangent and curved sections. Washington and Colorado segments may have a higher prevalence of curves than the segments in other states.

The composite results from the IIHS study are shown in Table 3. Overall, crashes were reduced 12% (95% confidence interval (95% CI) = 7-18%). Injury crashes were reduced by an estimated 14% (95% CI = 5-23%). Frontal (head-on) and opposing-direction sideswipe crashes — the primary target of centreline rumble strips — were reduced by an estimated 25% (95% CI = 8-42%). Frontal (head-on) and opposing-direction sideswipe crashes involving injuries were reduced by an estimated 25% (95% CI = 6-44%). Table 4 provides the percent reduction in all crashes disaggregated for daytime and nighttime hours. Although the percent reduction was somewhat greater at night than during the day (15% versus 8%), this difference was not significant at the 5% level (p=0.20).

TABLE 3: Composite Results for CLRS

			Crashes recorded in after period		**Empirical Bayes estimate of crashes expected after without centreline rumble strips (standard error)**		**Percent reduction (95% confidence interval)**	
Miles	**Sites**	**Crash type**	**All**	**Injury**	**All**	**Injury**	**All**	**Injury**
210.8	98	All	1,777	647	2,029.6 (48.2)	749.3 (27.7)	12% (7-18%)	14% (5-23%)
		Frontal/ opposing-direction sideswipe	155	87	203.8 (18.0)	115.3 (8.7)	25% (8-42%)	25% (6-44%)

TABLE 4: Percent Reduction in All Crashes for CLRS: Day vs. Night

Miles Sites	Time of day	Crashes recorded in after period	Empirical Bayes estimate of crashes expected after without centreline rumble strips (standard error)	Percent reduction
210.8 98	Day	996	1083.4 (34.6)	8% (p=0.05)
	Night	749	884.7 (20.9)	15% (p<0.001)

A limited disaggregate analysis was conducted to identify factors that might affect the safety impact of CLRS. The factors investigated were AADT (all jurisdictions) crash frequency (all jurisdictions), speed limit (Washington), curvature (Washington), lane width (Washington and California) and speed limit (Washington). This analysis could not establish any circumstances under which CLRS was more effective than others. This does not mean that such circumstances do not exist since it is possible that the data on hand were inadequate for isolating them.

3.4 Driver Behaviour Underlying Safety Impacts of Centreline Rumble Strips

CLRS would be expected to have minor if any impact on visibility, but based on studies of inside edge longitudinal rumble strips, and conventional PRPMs, would be expected to reduce lane encroachments significantly. The reductions in frontal/opposing-direction and sideswipe crashes by 25% is likely due to the reduction in lane encroachments. This should be confirmed in a study of driver response to CLRS. The study should examine both lane position and speed.

Snowplowable PRPMs had negative safety impacts on tight curves. CLRS do not improve visibility at night, therefore no increase in speed would be expected. However, they are expected to result in lane position further from the centreline. This may impact run-off-road crashes to the right on low design standard roads (sharp curves, narrow lanes, narrow or no shoulders). As noted above, a limited disaggregate analysis was carried out which did examine lane width and curvature and no impacts were found. However the sample size was small and this should be confirmed in a further study.

4 Summary

Before changes are made to the road environment for the purposes of improving safety, their impacts on driver behaviour should be assessed. When the roadway changes, drivers are likely to change their driving strategies, and not necessarily in the manner intended by engineers. The experience with conventional PRPMs, as well as other delineation improvements, suggests that the improved visibility associated with snowplowable PRPMs can be expected to lead to increased driver comfort as well as small increases in speed. On tangents and gentle curves, these small increases would have little impact. Indeed, in these situations the safety studies show an overall improvement in safety. On tighter curves, drivers are driving closer to the safety margin, and small increases in speed would have a more negative impact, eliminating the benefit of improved visibility. The increases in crashes found on curves with degree of curvature < 3.5 degrees suggests that the increase in speed may have offset the improved visibility to such a large degree that safety actually deteriorated.

With CLRS there is no change in visibility, so no effect on speed is expected. The auditory warning of lane crossing would be expected to impact safety day and night, and the crash findings bear this out. The limited disaggregate analysis on lane width and curvature did not show different impacts related to these elements. However, further study with a larger sample should be carried out.

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