

Reduction of Backing Crashes by Production Rear Vision Camera Systems

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Abstract

Today's automotive Rear Vision Camera (RVC) systems display an image to the driver of an area behind the vehicle generated by a camera located in the rear of the vehicle. This paper examined if, and to what extent, these systems offered on a wide variety of production vehicles are addressing backing crashes (estimated to represent approximately 3%-4% of all annual police-reported crashes in the United States). Police-reported crashes from ten United States state crash databases were examined to determine the frequency of backing crashes and control (baseline) crashes. The logistic regression model developed suggests that production RVC systems examined may be reducing overall police-reported backing crashes by 52%. This is a particularly promising finding because these systems may also be helping to avoid additional backing crashes that have not been reported to the police. This research can be used to inform emerging crash avoidance system-related system consumer metrics (e.g., New Car Assessment Program (NCAP) programs), government regulations surrounding RVC systems, and system performance requirements associated with RVC consumer metrics and regulations.

Keywords: Rear vision camera; Rear video Camera; Backing crashes; Crash avoidance; NCAP

Introduction

The United States Department of Transportation has estimated that the number of backing crashes could be as high as approximately half million per year in the United States, and that these crashes are associated with 50,000 injuries and 390 fatalities per year [1]. Using National Automotive Sampling System General Estimates System (NASS GES) crash data, it has been estimated that backing crashes represent approximately 3-4% of all annual crashes in the United States, and that 94% of backing crashes involve striking another vehicle, 4% involve striking an object, and 2% involve striking a pedestrian or pedalcyclist [2,3]. Since these NASS GES dataset estimates are focused on traffic-related crashes, these estimates do not tend to account for backing crashes that occur on private roads, such as in or around driveways or in parking lots. This paper is focused on determining if, and the extent to which, Rear Vision Camera (RVC) systems offered on many production automobiles are addressing backing crashes.

When a vehicle is in reverse, as shown in Figure 1, RVC systems display an image of the area behind the vehicle to the driver. This image is shown on a display in the front passenger compartment (e.g., a screen in the center of the vehicle or in the rear view mirror). The RVC image is generated by a rear camera that is located in the rear of the vehicle at or near vehicle centerline. The image displayed provides a limited field-of-view (e.g., 130 degrees laterally), and displayed images may be farther or closer than they appear. Despite these limitations, the RVC system may help the driver to avoid a crash or reduce crash damage while backing. This can occur, for example, by helping drivers who use the RVC information to see objects that they would not see or be capable of seeing otherwise (e.g., due to a blind spot to the rear of the vehicle) [4], or by providing "distance-to-object" information.

This research is also intended to inform government regulations (e.g., United States Federal Motor Vehicle Safety Standards), as well as emerging crash avoidance system-related consumer metrics (e.g., the United States Department of Transportation's National Highway Transportation Safety Administration New Car Assessment Program (NCAP)), surrounding RVC systems. The goal of NCAP is to improve

motor vehicle safety by providing market incentives for vehicle manufacturers to voluntarily design vehicles with improved safety performance, and to provide independent safety information to aid consumers in making informed vehicle purchases.

In the United States, starting with the 2011 model year, crash avoidance features have been added to the NCAP program, which has historically focused on vehicles' occupant protection performance. NHTSA currently informs the public of the availability of Lane Departure Warning, Forward Collision Warning, Electronic Stability Control, and (most recently) RVC systems on light vehicles that meet defined minimum system performance requirements. This information is provided at the www.safercar.gov website in a checklist format. Hence, for example, in the United States the current analysis of the field effectiveness of production RVC systems could be used to inform if the RVC feature should be included as a feature to the current NCAP and/or inform FMVSS rule-making surrounding RVC systems.

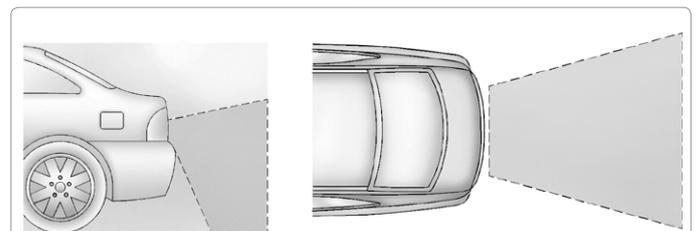


Figure 1: View displayed by the Rear Vision Camera (RVC).

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This later rule-making is in response to the Cameron Gulbransen Kids Transportation Act of 2007; and motivated by the involvement of young children (under the age of 5 years) in backover pedestrian crash fatalities [5].

Previous work on the potential benefits of rear-vision cameras have focused on object detection and experimental work on test tracks. Kidd & Brethwaite measured the blind zones of a variety of large and small vehicles as the area behind the vehicle in which a target of various sizes cannot be seen [6]. Targets were sized to three heights based on the average height of a young child of 12-15 months, 30-36 months, and 60-72 months. They showed that rear blind zones for all vehicles are reduced by an average of 90 percent by rear-vision cameras.

Research on test tracks, conducted under experimentally-controlled “surprise” (unexpected) rear obstacle conditions [7,8] also provides promising evidence that RVC systems may substantially reduce backing crashes. For example, Mazzae *et al.* reported that drivers of RVC-equipped minivans had a 28% reduction in backing crashes, compared to those without RVC, under the staged rear-obstacle condition in their study [7].

Though this experimental work is promising, the potential real-world benefits of production RVC systems have yet to be examined using existing crash databases. The focus of this paper is a comparison of the field performance of vehicles equipped with RVC to those that are not. The aim is to evaluate whether there is evidence that backing crashes are being reduced by RVC systems.

Method

To explore the effect of production General Motors RVC systems on backing crash rates, we matched police-reported crashes from state crash databases with a database listing equipment installed on 1.3 million GM vehicles from model years 2008 through 2010. Vehicle Identification Number (VIN) was used to link vehicles in the state crash databases with vehicles in the equipment database.

The equipment database indicated for each vehicle whether Rear Vision Camera (RVC) and Rear Park Assist (RPA) were installed. The RPA feature was examined because there is substantial overlap in installation of RVC and RPA features, both having the potential to reduce backing crashes. Furthermore, since parking crashes make up an important subset of backing crashes, we were interested in separating, to the extent possible, the effects of RPA and RVC on backing crashes. For vehicles examined in this effort, the RPA feature operates at speeds less than 5 mph (8 km/h), and assists the driver with parking and avoiding known objects while in reverse by providing “distance to object detected” information via visual and auditory alerts. The RPA sensors on the rear bumper are used to detect the distance to an object up to 8 feet (2.5 m) behind the vehicle, and at least 10 inches (25.4 cm) off the ground.

Ten state crash databases were identified that provided 17 character VIN information that could be matched to the VINs in the equipment database. These states included Florida, Idaho, Maryland, Michigan, North Carolina, Nebraska, New Mexico, Tennessee, Washington, and Wisconsin. Crash data from these states were available from calendar years 2005 through 2009, though only 2007 through 2009 included vehicles with RVC. Of the vehicles in the equipment list, 6,185 vehicles matched vehicles involved in crashes. Of these, 637 vehicles were equipped with the RVC and RPA features, 2,111 were equipped with RPA only, and 3,437 were not equipped with either the RVC or

RPA feature. Thus, all RVC-equipped vehicles in the dataset were also equipped with RPA.

In order to estimate the effectiveness of the RVC system, we need to compare “system-relevant” crashes to a baseline (control) crash type across vehicles equipped with each of the three system configurations (RVC/RPA, RPA only, none). Two specific “system-relevant” crash types were identified: “backing” and “backing during parking”. Of the matched crashes in the database, 216 “system-relevant” crashes were observed and used in all the analyses. Of these, 198 (or 92%) were “backing during parking.” The two types of crashes are subsequently collectively referred to as “backing crashes”, and hence include both backing and backing during parking crashes.

The control crash type was selected to be rear-end-struck crashes, which is defined as a rear-end crash type with rear damage to the vehicle. A vehicle in this crash type is generally considered to be not at fault, though fault was not specified in these databases per se. Rear-end-struck crashes are often used as controls in this type of analysis [9] since this control crash type has the desirable quality of being primarily influenced by driving exposure, rather than driver riskiness.

In addition to the control crash type, driver age, driver gender, and road condition were included in the analysis to control for driver-based differences in relative involvement in different types of crashes. We also limited analysis to make/models with some equipped and unequipped vehicles in the crash database and included make/model in the analysis. Since ownership of certain vehicle make/models may predict involvement in certain crash types, a difference in driver demographics for drivers of RVC-equipped vehicles versus drivers of vehicle not equipped with RVC could potentially masquerade as a RVC effect or can mask a safety effect associated with the RVC system. Make/models used in this analysis include: Cadillac CTS, Cadillac SRX, Chevrolet Tahoe, GMC Acadia, GMC Yukon, and GMC Yukon XL.

Logistic regression was used to model the probability that a given crash in the dataset is a system-relevant crash rather than a control crash, as a function of covariates (driver age, driver gender, make/model, and road condition) and the system configuration (None, RPA Only, RPA and RVC). Make/model was kept in the model regardless of its significance, but other covariates were removed in backwards stepwise fashion. SAS 9.3 PROC LOGISTIC was used for analysis

Results

Table 1 shows the overall number of system-relevant crashes (backing crash) and control crashes (rear-end struck) for vehicles equipped and not equipped with the RPA and RVC features. As indicated in Table 1, for vehicles equipped with both RVC and RPA, 9.9% of identified crashes (i.e., the sum of system-relevant and control crash types) were backing (system-relevant) crashes; for RPA-only vehicles, 15.9% of crashes were backing crashes; and for unequipped vehicles, 14.9% of crashes were backing crashes. Corresponding data for the ratio of “System-Relevant” to “Control” crashes is also provided in Table 1. Overall, the data in Table 1 provides initial evidence that fewer backing crashes are occurring for vehicles equipped with the RVC system, and that the RPA system is having no impact on such crashes.

Table 2 shows the same information as Table 1, but data are limited to the make/models for which there is some variation in RVC or RPA equipment across crashes. In addition, cases must have non-missing covariates (e.g., driver age and gender). Table 2 shows the equipment and crash counts for each of the six make/models that are the focus of

Crash Type	No Rear-Vision Camera (RVC) or Rear Park Assist (RPA)	Rear Park Assist (RPA) Only	Rear-Vision Camera (RVC) and Rear Park Assist (RPA)
"System-Relevant" Backing Crashes (Subset of "Backing During Parking" crashes)	116 (101)	83 (81)	17 (16)
"Control" Rear-End Struck Crashes	663	440	155
Percent of identified crashes (i.e., the sum of "system-relevant" and "control crashes") that were "System Relevant"	14.9%	15.9%	9.9%
Ratio of "System-Relevant" to "Control" Crashes	0.17	0.19	0.11

Table 1: System-relevant and control crash type frequencies for all vehicles in the dataset as a function of Rear Vision Camera (RVC) and Rear Park Assist (RPA) features.

Vehicle Make/Model	Crash Type	No Rear-Vision Camera (RVC) or Rear Park Assist (RPA)	Rear Park Assist (RPA) Only	Rear-Vision Camera (RVC) and Rear Park Assist (RPA)
Cadillac CTS	Backing	20	11	0
	Rear-End Struck	162	86	0
Cadillac SRX	Backing	12	0	0
	Rear-End Struck	84	2	2
Chevrolet Tahoe	Backing	2	5	3
	Rear-End Struck	10	11	24
GMC Acadia	Backing	25	42	6
	Rear-End Struck	118	229	62
GMC Yukon	Backing	0	1	1
	Rear-End Struck	0	7	18
GMC Yukon XL	Backing	0	0	3
	Rear-End Struck	2	0	14
Total	Backing	59	59	13
	Rear-End Struck	376	335	120

Table 2: System-relevant (backing) and rear-end-struck (control) crash type frequencies by make/model for the analysis subset of vehicles as a function of Rear Vision Camera (RVC) and Rear Park Assist (RPA) features.

further analysis. Of the backing crashes in Table 2 (which are those used in subsequent analysis), one struck a pedestrian, two struck a fixed object, 16 (12%) struck a parked car, 80 (61%) struck another vehicle (not parked), and 32 (24%) were unknown. Hence, for backing crashes not included in the "unknown" category, results indicate that approximately 97% of backing crashes involve striking another vehicle, 2% involve striking an object, and 1% involves striking a pedestrian or pedalcyclist.

The logistic regression model included the following covariates: driver age (broken into three categories to avoid assuming a specific form of the relationship), driver gender, make/model (Buick Lacrosse, Cadillac SRX, Chevrolet Tahoe, GMC Acadia, GMC Yukon, and GMC Yukon XL), and RVC/RPA presence (None, RPA Only, RVC and RPA). Driver age groups were 15-30 (young), 31-50 (middle), and 51+ (older) years old. Vehicle make/model and equipment were forced in the model, but other covariates were removed in backwards stepwise fashion if non-significant. None of the driver or road covariates was significant, so all were removed and the regression model was limited to vehicle make/model and equipment type.

Results indicated that the presence of the RVC is associated with a marginally statistically significant (Wald $X^2(1)=3.61$, $p=0.057$) decrease in system-relevant backing crashes compared to vehicles not equipped with either RPA or RVC. With respect to the magnitude of this marginally significant effect, the adjusted Odds Ratio (for RVC/RPA-equipped versus not equipped) is 0.479 (CI: 0.224, 1.023). (A discussion of a more practical interpretation of these results is discussed further below.)

Results also indicated that vehicles equipped with RPA only are not different from those vehicles not equipped with either RPA or RVC ($X^2(1)=0.011$, $p=0.915$). The only other significant effect was the coefficient for the Cadillac CTS. In this analysis, the GMC Acadia

was selected as the reference vehicle because it had the largest number of cases and was therefore the most stable. Make/model effects are compared only to the Acadia, which happened to have a mid-level rate of rear-end crashes. The Cadillac CTS was marginally statistically different from the GMC Acadia (Wald $X^2(1)=3.73$, $p=0.053$), but no other make/models were different from the Acadia. However, a complete analysis of make/model would require all possible comparisons, since the selection of the Acadia as the reference vehicle is arbitrary. The full model and significance tests are shown in Table 3.

Table 4 provides a way of looking at the practical outcome associated with the estimated odds ratios for RPA- and RVC- equipped vehicles, based on the logistic regression model. The table shows, based on this model, the expected number of backing crashes that will occur per 100 rear-end-struck crashes, averaged across the vehicles in the analysis, along with 95-percent confidence intervals on that value. Since equipment is not expected to influence the number of rear-end-struck crashes for each make/model, we can compare the number of backing crashes with RVC-equipped vehicles to those with no RVC equipment. The percent reduction in overall backing crashes is 52% for all vehicle types.

Summary and Conclusions

The RVC system displays an image to the driver of an area behind the vehicle generated by a camera located in the rear of the vehicle. This paper was focused on determining the extent to which Rear Vision Camera (RVC) systems offered on many production automobiles are addressing backing crashes. Backing crashes reported to the police are estimated to represent approximately 3% of all annual crashes in the United States [2,3].

Results indicated that the current GM production RVC systems, largely representative of RVC implementations throughout the industry, should reduce overall police-reported backing crashes by

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Prob. > Chi-Square
Intercept		1	-1.5997	0.1965	66.2561	<.0001
Equipment (Reference is "No Rear-Vision Camera (RVC) or Rear Park Assist (RPA)")	Rear Park Assist (RPA) Only	1	-0.0236	0.2218	0.0113	0.9153
	Rear Park Assist (RPA) and Rear Vision Camera (RVC)	1	-0.7360	0.3873	3.6116	0.0574
Vehicle Model (Reference is "GMC Acadia")	Cadillac CTS	1	-0.4675	0.2420	3.7322	0.0534
	Cadillac SRX	1	-0.3695	0.3627	1.0379	0.3083
	Chevy Tahoe	1	0.4224	0.3902	1.1721	0.2790
	GMC Yukon	1	-0.4486	0.7696	0.3399	0.5599
	GMC Yukon XL	1	0.5662	0.7017	0.6510	0.4197

Table 3: Logistic Regression Model Statistics.

Equipment	Expected Backing Crashes per 100 Rear-End Struck Crashes
No Rear-Vision Camera (RVC) or Rear Park Assist (RPA)	17.75 (10.12, 29.53)
Rear Park Assist (RPA) Only	17.34 (9.87, 28.87)
Rear-Vision Camera (RVC) and Rear Park Assist (RPA)	8.56 (3.69, 18.55)

Table 4: Expected number of backing crashes per 100 rear-end-struck crashes for each make/model/equipment combination. Corresponding 95th percentile confidence interval is given in parentheses.

52%, on average. This is a particularly promising finding because these systems may also be helping to avoid additional backing crashes that have not been reported to the police. The large magnitude of this observed backing crash reduction effect is consistent with previous test track research [7,8]. For vehicles equipped with the Rear Park Assist (RPA) feature that were not equipped with the RVC feature, no effect was observed on backing crashes. However, it should be noted these results do not directly address the potential for the RPA feature to reduce non-police reported crashes. Consistent with previously reported backing crash breakdowns [1,5], results indicates that the vast majority (97%) of backing crashes analyzed here involved striking another vehicle, whereas backing crashes involving either striking an object (2%) or striking a pedestrian or pedalcyclist (1%) were scarce.

It should be noted that vehicles equipped with RVC systems in the current study were also equipped with the RPA feature. Hence, although an explanation of these RVC benefits involving a synergistic effect of the coupling of the RVC and RPA features cannot be directly addressed by the current study, previous test track research comparing "RVC only" versus "RPA and RVC" effectiveness under "surprise obstacle" conditions provides strong support that the observed reduction in backing crashes can be fully attributed to the RVC feature [7,8].

Another limitation was the relatively small sample of matched crashes for vehicles equipped with RVC/RPA. Although the effect is large, it was still marginally significant because penetration of these systems into the fleet is still relatively limited. Future work will benefit from greater numbers of RVC-equipped vehicles in the fleet.

Although pedestrian backing crashes (backover), especially those involving children has been a focus of research [6] and NHTSA interest in RVC systems, this study does not address backover specifically. The number of these events each year is very small and the requirement to match to a VIN content database limits the sample even further. In the future, with greater penetration of RVC systems and perhaps a larger collection of VINs, it may be possible to look specifically at pedestrian crashes in the future as well. That said, a large reduction in backing crashes into objects suggests that reductions in all crashes involving backing are likely.

This research was also intended to inform emerging crash avoidance system-related system consumer metrics (e.g., the United States

Department of Transportation's National Highway Transportation Safety Administration New Car Assessment Program (NCAP)), as well as regulations surrounding crash avoidance systems (including RVC) and associated performance requirements (e.g., field-of-view coverage, image size, and how quickly the image is displayed to the driver). These results suggest that it is appropriate that NHTSA inform the public of the availability of RVC systems on light vehicles at the www.safercar.gov website that meet defined minimum system performance levels consistent with the levels of current production vehicles.

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