ON-SCENE DETERMINATION OF DRIVER CRASH CAUSATION AND AVOIDANCE MANEUVERS IN REAR-END COLLISIONS

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ABSTRACT

Rear-end collisions are one of the most frequent crash types in the U.S. Pre-Collision System (PCS) have been developed to mitigate the frequency and severity of rear-end collisions. The potential effectiveness of these systems, however, depends on the driver's state and their attempted avoidance maneuvers. This study utilized the National Motor Vehicle Crash Causation Survey (NMVCCS), a unique nationally representative dataset focused on crash causation, to quantify contributing factors in rear-end collisions and the avoidance maneuvers attempted by drivers of the striking vehicle. For a case to be included in NMVCSS, the crash site had to be visited by an investigator prior to the scene being cleared.

Rear-end collisions were more likely to involve a driver that was following too closely, inattentive, distracted by a non-driving activity, focusing on external factors, exhibiting inadequate surveillance, and making false assumptions of other drivers' actions compared to other frontal collisions. Compared to other frontal collisions, rear-end collisions were more likely to have occurred on roadways with traffic flow restrictions, speed limits at highway speeds, multiple lanes, and relation to a junction (e.g. intersections, on-ramps, merging zones). In 72% of rear-end collision the driver attempted an avoidance maneuver. Of those drivers attempting an avoidance maneuver, 67% only applied the brakes, 27% applied the brakes with steering, and 6% only steered. Conversing and non-driving activities were found to be significant factors indicating the lack of an avoidance maneuver in rear-end collisions. In all rear-end collisions, Forward Collision Warning and Pre-Crash Brake Assist could be potentially effective in 84% of crashes, while Autonomous Braking could be effective in 90% of crashes.

Keywords: active safety, rear-end, crash causation

INTRODUCTION

Rear-end collisions, where the front of one vehicle impacts another vehicle traveling in the same direction as the first, are one of the most frequent crash types in the U.S. (Najm, Sen et al. 2003). One of the active safety systems being developed and introduced to mitigate rear-end collisions is the Pre-Collision System (PCS). PCS tracks vehicles and objects in front of equipped vehicles using millimeter-wave radar and/or cameras. When a collision threat is determined credible, PCS can warn the driver (Forward Collision Warning, FCW); pre-charge the brakes for increased braking force once the driver applies the brakes (Pre-collision Brake Assist, PBA); and brake autonomously for the driver even if there is no driver input (Pre-collision Braking, PB) (Aoki, Aga et al. 2010; Kusano and Gabler 2010; Kusano and Gabler 2011).

Because PCS interacts with the driver, the potential effectiveness of PCS in the field depends both on the driver's state and attempted avoidance maneuvers. PCS is most effective for drivers who would not take evasive maneuvers soon enough to avoid a collision, such as a driver that is distracted by tuning the radio and does not realize that he/she is approaching a stopped car. The FCW would alert the distracted driver so that he/she could apply the brakes, then PBA would amplify his/her braking effort, and finally PB would autonomously add to the braking force when the collision is unavoidable. In contrast, an impaired driver who would not maneuver sufficiently prior to an impending collision may not benefit from PCS as much.

Categorizing the factors which lead to rear-end collisions and the drivers' pre-crash avoidance maneuvers in these imminent collision situations is of great importance for both evaluating potential PCS effectiveness and in system design. Traditional data sources for evaluating nationally representative samples of collisions in the U.S., such as the National Automotive Sampling System, Crashworthiness Data Systems (NASS/CDS), focus on injury outcome. Other than the limited factors listed on the police accident report, little detailed information pertaining to contributing factors that lead to the collision is available. Without a comprehensive list of contributing factors, it may be difficult to assess the underlying mechanism that lead to the collision and the applicability of active countermeasures. This study uses a unique nationally representative data source, the National Motor Vehicle Crash Causation Survey (NMVCCS), which focuses on crash causation, to assess the driver's pre-crash state and maneuvers in rear-end collisions.

OBJECTIVE

The objective of this research is to quantify the prominent driver, environmental, road, vehicle, and contributing factors that lead to rear-end collisions; to quantify the avoidance maneuvers attempted by drivers in rear-end collisions; and to assess the potential target crash population that PCS could mitigate.

METHODOLOGY

Data Source

Cases were extracted from the National Motor Vehicle Crash Causation Survey (NMVCCS). NMVCCS is a nationally representative sample of 5,470 crashes that occurred in the United States between July 2005 and December 2007 (Bellis and Page 2008). NMVCSS was conducted by the National Highway Traffic Safety Administration (NHTSA). For a crash case to be included in the NMVCCS database, the crash site had to be visited by an investigator prior to the scene being cleared. This allows the unique opportunity for investigators to perform on-scene interviews with drivers, occupants, witnesses, and first responders to determine crash causation factors that lead to the collision. Other crash databases, such as NASS/CDS, focus on injury outcome and retrospectively investigate collisions, possibly weeks after they occur. NMVCCS focuses on crash causation, and attempts to collect information soon after the crash, when details are still fresh in the memories of those involved. Because on-scene investigation was required, cases collected as part of NMVCCS were restricted to those occurring between 6 am and midnight, with a complete police accident report, and emergency medical service (EMS) dispatched to the scene.

Case Selection

Rear-end collisions were selected using a methodology adapted from Eigen and Najm, which classifies pre-crash scenarios based on critical pre-crash events, maneuvers, and accident type (Eigen and Najm 2009). A rear-end collision was classified as a collision between a vehicle and another vehicle traveling in the same direction as the first vehicle. The striking vehicle is traveling behind the struck vehicle. The struck vehicle could be traveling at a lower speed, decelerating, or stopped. Additionally, the first harmful event must have resulted in frontal damage. To compare the rear-end population to the rest of the frontal crash population, a group of all other frontal collisions was selected. The vehicles in the frontal collision group must have sustained frontal damage from the first harmful event and must have had a pre-crash scenario. Drivers who were not actively involved in a crash were excluded from the frontal collision group. In NMVCCS, such drivers can be identified by their lack of a pre-crash scenario. For example, a vehicle that was stopped waiting to turn left at an intersection and was impacted head-on by a vehicle that drifted out of its lane was excluded. In this case, the contributing factors associated with the driver of the struck, or stopped, vehicle were not related to the cause of the collision. The striking vehicle, or the vehicle that drifted out of its lane, would be included in the frontal collision group because the contributing factors associated with this driver are related to the cause of the crash.

Data Analysis

Contributing Factors in Rear-end Collisions

First, the presence of various driver, environmental, road, vehicle, and contributing factors was tabulated for rear-end collisions. For a point of reference, the presence of factors in rear-end collisions was compared to the presence of those same factors in the rest of the frontal collision population in a univariate approach. To determine which factors were more prevalent in the rear-end crash population compared to all other frontal crashes, relative ratios (*RR*) were computed for each factor. In this study, the risk ratio was defined to be the ratio of the percentage of cases with the factor in the rear-end population to the percentage of the population with the factor in the all other frontal collision population:

$$RR = \frac{\text{\% present in Rear-ends}}{\text{\% present in All Other Frontal}} \quad (1)$$

A ratio equal to 1 indicates an equal proportion of the population with a given factor for both rear-end collisions and all other frontal collisions. A ratio greater than 1 indicates that the factor is more present in the rear-end population compared to the all other frontal population. Conversely, a ratio less than 1 indicates that the factor is more prevalent in all other frontal collisions compared to rear-end collisions. All of the cases in this dataset involved a serious collision requiring EMS activation. Therefore, a ratio near 1 does not indicate that a specific factor is not an important factor in the crash population, but rather that the factor presents itself in a similar number of crashes for each group.

Factors were reduced to binary variables, when they were not already binary in nature. For example, the NMVCCS contains the location of the crash relative to a junction. This variable can have several values (e.g. non-junction related, intersection, intersection related, on ramp/exit ramp related, etc). For this analysis, the relationship to a junction was separated into two groups: non-junction related and junction related collisions. This reduction of all chosen variables to binary variables was performed for two reasons. First, because over 40 factors were considered in this analysis, creating binary variables aided in simplifying presentation while preserving major factors. Second, binary variables allowed for the computation of relative risk ratios in order to identify unique factors present in rear-end collisions that are not as prevalent in other frontal collisions.

Avoidance Maneuvers in Rear-end Collisions

Second, the type of avoidance maneuver taken in rear-end crashes was characterized. The presence of braking and steering was tabulated. By the nature of NMVCSS, all of the rear-end collisions in this dataset were crashes where the driver either did not attempt to avoid the collision at all or did not adequately maneuver the vehicle to avoid the collision. For pre-collision systems such as FCW and PBA, the avoidance maneuvers, or lack thereof, affect the potential system effectiveness. Logistic regression was used to identify which factors contributed to a driver failing to attempt an avoidance maneuver. Drivers that take no avoidance maneuver in rear-end collisions stand to benefit the most from FCW and PBA. Results of the regression are presented in terms of adjusted odds ratios. In this analysis, an odds ratio greater than 1 indicates the presence of a factor that increases the odds that the driver would not attempt an avoidance maneuver. An odds ratio less than 1 indicates the presence of a factor that decreased the odds of not attempting an avoidance maneuver. The adjusted odds ratios are determined from logistic regression coefficients, and represent the odds ratios of a factor while adjusting for all other factors.

Potential Target Population for PCS in Rear-end Collisions

Finally, the potential target population of rear-end crashes that PCS could mitigate or prevent was evaluated. PCS can have several components: FCW (forward collision warning), PBA (pre-crash brake assist), and PB (autonomous pre-crash braking). Alcohol impairment, a medical illness that occurred before the crash, or vehicle failure prior to the crash could all cause various components of PCS to be ineffective in mitigating the collision.

Table 1 summarizes the potential effectiveness of PCS components given the presence of pre-crash factors. If the driver is alcohol impaired, it is likely that the warning provided by FCW would have no effect and the effect of PBA could be greatly reduced. However, even in the case of impairment, PB is potentially effective because it can increase the driver's braking effort autonomously, even if there is no driver input. The same is true for driver illness prior to the crash. On the other hand vehicle condition factors, e.g. brake failure, would cause all the PCS components to be ineffective. A potential target population where PCS could be effective was determined from a sub-set of the main dataset that had no missing values for alcohol involvement, illness prior to the crash, and vehicle failure.

Table 1. Potential Effectiveness of PCS Components in the Event of Incapacitating Pre-crash Factors.

Factor	**FCW**	**PBA**	**PB**
Alcohol Involvement	X	~	Y
Illness Prior to Crash	X	~	Y
Vehicle Condition Factors	X	X	X
All other Factors	Y	Y	Y

X	Ineffective
Y	Potentially Effective
~	Marginally Effective

Statistical Analysis

Cases in NMVCCS were selected by NHTSA for investigation as part of a complex, probability-based sampling strategy. To create a nationally representative sample of cases, each case was assigned a weighting factor proportional to the number of similar collisions that occurred during the sample period by the survey designers. All tabulations in this study used the case weighting factors. Statistical significance was determined using the case weighting and sample design variables included in the dataset. Statistical analysis was performed using survey data routines that account for the complex survey design (SAS v9.2, *SURVEY* procedures). Variance was assessed using Taylor Series Linearization methods. Using traditional standard error methods will underestimate variance in data with a complex design.

RESULTS

Selected Case Demographics

Of the approximately 15,300 vehicle files in NMVVCS, 5,084 vehicles were classified as either rear-end collisions (887) or other frontal collisions (4,197). The frequency of each classification and each pre-crash scenario is shown in Table 2. Of selected vehicles, approximately 18% of vehicles were involved in rear-end collisions. A majority of these rear-end collisions were lead vehicle stopped scenarios. For the other frontal population, left turn across path opposite direction (LTAP/OD) crashes were the most frequent scenario followed by road departures and straight crossing paths (SCP) collisions.

Table 2. Frequency of Selected Rear-end and Frontal Collision by Pre-crash Scenario.

Classification	Scenario	Weighted Frequency	% of Category
Rear-end	Lead Vehicle Stopped	254,316	72%
	Lead Vehicle Decelerating	55,326	16%
	Lead Vehicle Moving	42,522	12%
	TOTAL	352,163	100%
All Other Frontal	LTAP/OD	379,774	24%
	Road Departure - no maneuver	265,943	16%
	SCP	260,653	16%
	Vehicle Turning at Junction	260,164	16%
	Lane Departure - no maneuver	96,606	6%
	All Others	352,077	22%
	TOTAL	1,615,217	100%
ALL		1,967,380	

Table 3 summarizes the sex, age group, and alcohol involvement for the selected collisions. The demographics of the two groups appear to be similar, which is important when comparing the characteristics of the two groups to each other.

Table 3. Sex, Age Group, and Alcohol Involvement for Selected Collisions

		Rear-end		All Other Frontal	
Variable	Category	Wgt Freq	%	Wgt Freq	%
Sex	Male	183,214	52%	879,257	54%
	Female	164,590	47%	729,251	45%
	Missing/Unknown	4,359	1%	6,708	1%
	Total	352,163	100%	1,615,217	100%
Age Group	18 and Under	40,728	12%	139,034	9%
	19 to 25	90,081	26%	353,374	22%
	26 to 54	163,137	46%	813,353	50%
	55+	51,195	15%	284,864	18%
	Missing/Unknown	7,021	1%	24,592	1%
	Total	352,163	100%	1,615,217	100%
Alcohol	No Alcohol Involvement	326,966	93%	1,449,011	90%
	Alcohol Involvement	12,580	4%	97,083	6%
	Missing/Unknown	12,617	3%	69,123	4%
	Total	352,163	100%	1,615,217	100%

Contributing Factors in Rear-end Collisions

Table 4 summarizes the presence of driver factors in rear-end collisions and the relative ratios compared to all other frontal collisions. Confidence limits (α=0.05) are also listed (95% CL) for the percentage and ratio estimates, as discussed in the methodology section. In order to be a statistically significant difference between the prevalence of factors between the rear-end and frontal crash populations, the confidence limits for the relative risk ratio must not contain 1. Statistically significant risk ratios are marked with an asterisk in Table 4 and following tables. Young drivers (under age 21) are more likely to be involved in a rear-end collision compared to all other frontal collisions. Also, police reported safety belt use is greater among rear-end drivers than all other frontal drivers. The remaining factors are present in a similar proportion between rear-end and all other frontal collisions.

Table 4. Driver Characteristics in Rear-end Collisions and Relative Ratios to All other Frontal Collisions.

Factor	**% of Rear-end**	**95% CL**		**RR to Frontal**	**95% CL**		
Male	53%	47%	58%	0.96	0.87	1.07	
Young Driver (<21 yrs)	26%	20%	32%	1.34	1.11	1.61	*
Driver Belted	97%	94%	99%	1.06	1.05	1.07	*
Alcohol Involvement	4%	3%	5%	0.59	0.30	1.16	
Drug Involvement	1%	0%	2%	0.48	0.19	1.23	
Unlicensed Driver	4%	2%	7%	0.63	0.34	1.18	
No Illness Before Crash	96%	93%	98%	0.87	0.48	1.59	

**** statistically significant RR***

Table 5 shows the environmental, roadway, and vehicle factors in rear-end collisions and relative ratios to all other frontal collisions. Rear-end collisions are more likely to occur in the daylight than other frontal collisions. Rear-end collisions are more likely to occur when there are traffic flow restrictions (e.g. congestion, construction), at highway speed limits (> 50 mph), on multi-lane roads, and on straight roads compared to other frontal collisions. Almost two-thirds of rear-end collisions are junction related. Rear-end collisions are less likely to result in rollover compared to all other frontal collisions.

Table 5. Environmental, Roadway, and Vehicle Factors in Rear-end Collisions and Relative Ratios to All other Frontal Collisions

Factor	% of Rear-end	95% CL		RR to Frontal	95% CL		
Dark	13%	9%	17%	0.52	0.32	0.84	*
Roadway Surface Wet	13%	7%	19%	0.84	0.57	1.23	
Traffic Flow Restrictions	28%	20%	36%	3.48	2.17	5.56	*
Highway Speed Limit (>50 mph)	31%	19%	43%	1.78	1.41	2.25	*
Multiple Lanes	74%	66%	81%	1.20	1.02	1.42	*
Junction Related	64%	55%	72%	0.94	0.82	1.07	
Roadway Straight	84%	76%	92%	1.14	1.05	1.23	*
Tire Damage prior to Crash	3%	1%	6%	1.06	0.44	2.56	
Vehicle rollover	2%	0%	3%	0.21	0.08	0.52	*
Vehicle Condition Factors	9%	4%	14%	1.35	0.95	1.92	

**** statistically significant RR***

Table 6 shows the contributing factors in rear-end collisions and relative ratios compared to all other frontal collisions. The percentages in Table 6 represent the proportion of rear-end crashes with the factor present. A detailed description of factors is included as an appendix. The factors are grouped in the table by type of factor (i.e. behavior, attention, fatigue, recognition, and experience). Overall, the behavior, attention, and recognition factors are most prevalent compared to all other frontal collisions. An avoidance maneuver was attempted in 72% (65%-80%, 95% CL) of rear-end collisions, which was a higher proportion of crashes compared to other frontal collisions. Following too closely was the factor that was the most overrepresented in rear-end collisions compared to all other frontal collisions (RR of 28.7), followed by misjudgment of other's actions (RR of 9.7). An illegal driving maneuver was the most underrepresented factor in rear-end collisions as compared to other frontal collisions (RR of 0.16), followed by driver performance errors (RR of 0.41). Rear-end collisions had fewer collisions with one or more passengers present compared to all other frontal collisions (RR of 0.79).

Table 6. Contributing Factors in Rear-end Collisions and Relative Ratios for All other Frontal Collisions.

Type	Factor	% of Rear-end	95% CL		RR to Frontal	95% CL		
Behavior	Avoidance Maneuver Attempted	72%	65%	80%	1.37	1.14	1.66	*
	Aggressive Driving Act	4%	2%	6%	0.54	0.42	0.69	*
	Illegal Driving Maneuver	2%	0%	4%	0.16	0.04	0.59	*
	Driver Emotional Factors	16%	9%	22%	0.84	0.49	1.46	
	Following too Closely	18%	12%	23%	28.71	15.61	52.81	*
Attention	Focusing on External Factors	18%	14%	23%	2.44	1.59	3.75	*
	Driver Conversing	15%	12%	17%	1.20	0.81	1.79	
	Driver Inattention	25%	17%	32%	2.66	1.86	3.80	*
	Inadequate Surveilance	52%	43%	62%	1.90	1.62	2.23	*
	Non-driving Activities	22%	18%	26%	2.41	1.85	3.14	*
	Passenger(s) Present	23%	21%	25%	0.79	0.69	0.91	*
Fatigue	Driver Fatigued	13%	9%	17%	1.00	0.93	1.06	
	Less than 6 hours sleep in last 24 hrs	4%	2%	7%	1.04	0.46	2.37	
	More than 9 hours Average Work	12%	10%	14%	1.14	0.95	1.38	
	Trip longer than 30 minutes	29%	22%	36%	1.24	0.92	1.66	
	Driver Performance Errors	6%	4%	9%	0.41	0.24	0.70	*
Recognition	False Assumption of Other Drivers Actions	26%	19%	32%	2.24	1.57	3.19	*
	Misjudgement of others Actions	15%	5%	26%	9.74	3.40	27.88	*
	Other Recognition Factors	8%	6%	10%	1.39	0.77	2.51	
Experience	Experienced with this Vehicle	98%	97%	99%	1.01	0.99	1.02	
	Experienced with this Route	89%	83%	95%	1.02	0.93	1.12	
	Other Experience Factors	11%	5%	17%	1.03	0.57	1.85	

**** statistically significant RR***

Avoidance Maneuvers in Rear-end Collisions

Table 7 shows the pre-crash maneuvers attempted by drivers in rear-end collisions. Of all rear-end drivers, 28% did not apply the brakes or steer (i.e. no avoidance maneuver). Of drivers, 68% applied the brakes, of which 72% did not steer along with braking. Of all drivers, 4% steered but did not brake. In 8% of rear-end cases, the avoidance maneuver was unknown or missing.

Table 7. Avoidance Maneuvers Attempted in Rear-end Collisions.

	No Steering	Steer Left	Steer Right	Total
No Braking	89,198 28%	7,607 2%	6,975 2%	103,780 32%
Braking	156,736 49%	27,011 8%	34,632 11%	218,379 68%
Accelerating	79 0%	- -	- -	79 0%
Other	321 0%	- -	- -	321 0%
Total	246,334 76%	34,618 11%	41,607 13%	322,559
Missing				29,604 8%
All				352,163

An avoidance maneuver was attempted by 71% (95% CL 69%-73%) of young drivers (age less than 21 years) involved in a rear-end collision, compared to 59% (95% CL 57%-61%) of young drivers in other frontal collisions, suggesting young drivers were more likely to attempt an avoidance maneuver in a rear-end collision compared to other frontal collisions. The presence of an avoidance maneuver and maneuver type was further examined by age group, with no significant differences between groups.

Next, logistic regression was performed to determine which contributing factors were most associated with a driver who took no avoidance maneuver. In order to perform logistic regression, all factors included in the model must have a known value. Of the 352,163 weighted rear-end cases (887 cases), 238,015 had complete observations (626 raw cases) and were used for the logistic regression analysis. The adjusted odds ratios for each factor are shown in Table 8. A driver conversing (OR = 2.91) and the presence of non-driving activities (OR = 2.83) were the only two statistically significant factors affecting if a driver in a rear-end collision attempted an avoidance maneuver. All other factors, including driver age, were not significant. Again, all cases considered were collisions requiring EMS activation. Therefore, a non-significant result does not indicate a factor is not important in crash causation, but rather these non-significant factors do not increase the likelihood that a driver takes no avoidance maneuver in a rear-end collision.

Table 8. Adjusted Odds Ratios for No Avoidance Maneuver Attempted in Rear-end Collisions.

Factor	Odds Ratio	95% CL		
Driver performance errors present	3.19	0.81	12.65	
Driver conversing	2.91	1.81	4.69	*
Other non-driving activities present	2.83	1.31	6.11	*
Occuring in the dark	1.95	0.97	3.91	
External factors present	1.64	0.89	3.04	
Junction related	1.51	0.51	4.47	
Speed limit above 55 mph	1.23	0.53	2.86	
Other recognition factors present	1.17	0.43	3.21	
Driver inattention present	1.14	0.50	2.60	
Alcohol Present vs. Not Present	1.13	0.37	3.40	
False asumptions of other's action	1.05	0.61	1.79	
Number of Occupants	1.01	0.84	1.21	
Age (in years)	1.00	0.97	1.03	
Driver surveillance factors	0.89	0.56	1.42	
Male vs. Female	0.89	0.57	1.38	
Trafficway Flow Restrictions Present	0.83	0.41	1.67	
Experienced with vehicle	0.82	0.35	1.88	
Misjudgement of other's distance/speed	0.80	0.50	1.28	
Following too close	0.69	0.42	1.12	
Experienced with route	0.66	0.32	1.40	
Other experience factors present	0.57	0.29	1.12	
Wet surface	0.35	0.08	1.43	

**** statistically significant***

Both the continuous age in years and number of occupants was found to be non-significant in determining if a driver attempted a pre-crash avoidance maneuver. Categorical variables for age and number of occupants also yielded non-significant results. The interaction between driver age and the number of occupants was also examined. All combinations of categorical and continuous interactions yielded non-significant results, suggesting that there is no interaction between age and the number of occupants in determining if a driver takes evasive maneuvers prior to a rear-end collision.

Potential Target Population for PCS in Rear-end Collisions

Of the 5,084 rear-end and frontal collisions in NMVCCS, 3,925 cases (1,457,372) had complete records of alcohol involvement, illness prior to the crash, and vehicle failure and were used to assess the potential target population for PCS in rear-end collisions. In the dataset, there were 261,060 rear-end collisions and 1,196,312 other frontal collisions. Table 9 summarizes the potential effectiveness of PCS in rear-end collisions. The column labeled "+/-" shows confidence limits to the 95% level of the percentage estimates. Of rear-end collisions, FCW is potentially effective in 84% (+/- 8%). PBA is potentially effective in 84% of collisions (+/- 8%)

and marginally effective in 7% of collisions (+/- 4%). PB is potentially effective in 90% of collisions (+/- 7%).

Table 9. Potential Effectiveness of PCS Components in

	Potentially Effective			Marginally Effective			Ineffective		
PCS Component	Weighted Frequency	Percentage	+/-	Weighted Frequency	Percentage	+/-	Weighted Frequency	Percentage	+/-
FCW	218,405	84%	8%				42,655	16%	8%
PBA	218,405	84%	8%	17,468	7%	4%	25,187	10%	7%
PB	234,918	90%	7%				26,142	10%	7%

Table 10 summarizes the potential target population of PCS in rear-end collisions compared to all other frontal collisions. Here, the potential population is identified as those rear-end collisions where PB would be effective. Of all frontal collisions, PCS has a potential to be effective in 16% (+/- 2%) of collisions.

Table 10. Overall Potential Crash Population for PCS in Rear-end Collisions.

	Weighted Frequency	**Percentage**	**+/-**
Rear-end, PCS Potentially Effective	234,918	16%	2%
Rear-end, PCS Ineffective	26,142	2%	2%
All other Frontal and Ineffective Rear-end	1,196,312	82%	2%
Total	1,457,372	100%	

DISCUSSION

Contributing Factors in Rear-end Collisions

This study quantified the driver, environmental, roadway, vehicle, and contributing factors that are associated with rear-end collisions. Rear-end collisions tended to involve younger drivers traveling in daylight on high-volume roads (i.e. multiple lanes, high speed limits) compared to all other frontal collisions in the database. Compared to all other frontal collisions, more drivers attempted an avoidance maneuver (72%) and cited following too closely as a contributing factor. Attention related contributing factors were cited more often for rear-end drivers compared to other frontal collisions (focusing on external factors, inattention, inadequate surveillance, and non-driver activities). Fatigue and experience factors were similar between rear-end and other frontal collision drivers.

Crash causation is theorized to be related to 1) being able to recognize hazards as a result of experience, 2) encountering a rare driving event, 3) complex traffic situations, and/or 4) cognitive capacity of the driver (Elvik 2006). Most rear-end collision scenarios are not rare driving events. In the suburban and urban settings, a vehicle stopped or slowing in front of a vehicle may be one of the most frequent events. This study suggests that recognition (misjudgment of other’s actions) and inattention factors (driver inattention, non-driving activities) play an important role in rear-end collisions compared to other frontal crashes. These activities, which increase cognitive load, can be compounded by complex traffic situations that are more prevalent in rear-end collisions compared to other frontal collisions (traffic flow restrictions, junction related, multiple lanes, highway speed limits). Experience with the vehicle and route are generally reported as high; however, young drivers are over represented in rear-end collisions. These complications that are present in rear-end scenarios suggest that PCS could be a very successful countermeasure, as PCS can warn and assist the driver in collision imminent situations.

The NMVCCS database only contains collisions with a complete police accident report and EMS activation. As such, avoided collisions are not considered in the database. As a result, the factors in rear-end collisions with a relative ratio that is not close to 1 are compared to other frontal collisions. Therefore, as noted previously, cases with a ratio that is close to 1 should not be interpreted as unimportant in crash causation, but instead the non-significant factors are in similar proportions in rear-end collisions compared to all other frontal collisions.

Also not contained in this analysis are collisions where the driver steered and successfully avoided an impending rear-end collision, but then was involved in another collision. In NMVCCS, pre-crash information is restricted to the critical event that preceded the first harmful event. For example, in a collision where a vehicle avoided a stopped vehicle, departed the roadway, and struck a tree, the critical pre-crash event would be a road departure, not avoiding a rear-end collision. The movement prior to the critical crash event does contain a category "avoidance maneuvers to a previous critical event." However, it is not possible to determine what this previous event was (e.g. did the driver avoid a stopped vehicle or a vehicle encroaching into its lane?). Only 2% of the collisions in this study had this pre-crash movement coded. Therefore, the data does not suggest that there is a large secondary crash population from avoiding rear-end collisions.

Comparison to Previous Studies

NMVCCS provides a unique data source for examining crash causation in a nationally representative sample of collisions. Other methods of gauging crash causation in rear-end collisions have yielded similar results to this study. Neale *et al* examined crash causation in a small number of rear-end collisions taken from a naturalistic driving environment (Neale, Dingus et al. 2005). In 93% of rear-end crashes and 68% of near-crashes, driver inattention was present, as gauged by the driver's actions prior to the event as recorded on in-vehicle video. Kostyniuk and Edy interviewed 26 drivers involved in rear-end collisions to determine causation factors (Kostyniuk and Edy 1998). When asked about the direct cause of the collision, drivers cited the misinterpretation of other drivers' actions and inattention as leading factors. McEvoy *et al* interviewed drivers in the hospital involved in a variety of collision types to assess the involvement of distraction in these crashes (McEvoy, Stevenson et al. 2007). A third of all crashes involved distraction, but of rear-end collisions over half (57%) involved distraction, which included inattention, focusing on external factors, and non-driving activities. Baldock et al performed investigations of rear-end collisions in Australia focusing on roadway design (Baldock, Long et al. 2005). They found young, male drivers were more likely to be involved in rear-end collisions and that higher traffic density, the presence of an intersection, and presence of a right turning vehicle increased the likelihood of a crash.

Many of these previous studies relied on self-reported factors from questionnaires administered to the drivers. Because an investigator was on the scene in every collision in the NMVCCS database, contributing factors were determined from multiple sources (interviews with drivers, witnesses, and first responders). As a result, factors were identified with the investigators best judgment using all available information. However, the availability and quality of information varies from case to case, allowing for uncertainty to still exist in on-scene investigations.

Young drivers have been shown to be more at risk to be involved in a collision, which is amplified in the presence of passengers, when compared to adult drivers (Thor and Gabler 2010). In the current study, fewer rear-end collisions had one or more passengers present compared to other frontal collisions. Rear-end collisions were found to be more likely to involve young drivers (age less than 30 years) compared to other frontal collisions. The interaction between age and passenger presence was not examined in this study. Also, the presence of passengers was not found to contribute to drivers failing to attempt an avoidance maneuver. There was found to be no significant interaction between age and number of occupants in attempting an avoidance maneuver. These results suggest young drivers are more likely to be involved in rear-end collisions compared to other frontal collision types, but age and number of occupants does not determine if the driver will attempt an avoidance maneuver. Furthermore, age does not seem to have a large effect on the presence of an avoidance maneuver attempted.

Avoidance Maneuvers in Rear-end Collisions

Almost three quarters of drivers in rear-end collisions attempted an avoidance maneuver, which was higher than other frontal collisions. This finding suggests that drivers often attempt an avoidance maneuver, but either do so too late or with insufficient brake or steering inputs. Of drivers who attempted an avoidance maneuver, 67% only steered, 6% only braked, and 27% braked and steered. For the remaining quarter of drivers that did not attempt an avoidance maneuver, the driver conversing and the presence of non-driving activities were found to be significant factors when adjusting for other factors.

These findings have direct impact for the design of active safety systems, e.g. PCS. The driving population that attempted avoidance maneuvers could benefit from additional braking that PCS could provide. However, those who do not attempt an avoidance maneuver stand to benefit the most from PCS. Conversing and non-driving activities are both factors where FCW could alert drivers and allow them apply the brakes, which otherwise would not have done.

Potential Target Rear-end Population for PCS

In this study, it was found that 84% to 90% of rear-end collisions could be potentially mitigated by PCS. The rear-end collisions that PCS would be ineffective in were identified using conditions that would leave the driver incapable of utilizing the additional warning and braking power of PCS. These conditions would include alcohol involvement, illness prior to the crash, and vehicle failure prior to the crash. The addition of PB and PBA to FCW increases the number of collisions that could be mitigated. Overall, PCS could mitigate 16% of all frontal collisions. This identification of the target population is not an estimate of system effectiveness. The actual effectiveness of PCS in the target population will vary dependent on factors, such as roadway condition and PCS design.

Limitations

The main limitation of this study is that some factors exhibit a high percentage of drivers with a missing or unknown value coded. This is specifically prevalent for the crash causation factors. The proportion of missing or unknown values for each factor considered in this study is included in the appendix. Sleep within the last 24 hours was the factor with the most missing values (32%), followed by trip length (31%), average hours worked (29%), and driver fatigued (28%). Over half of the factors considered had less than 10% of cases with missing values and a quarter had less than 1% missing. The approach was to use available case analysis for identification of which factors are more prominent in rear-end crashes compared to all other frontal crashes (i.e. proportions were compared between all cases with known values of a given factor). For the logistic regression used to identify which factors are associated with no avoidance maneuver attempted, a complete case approach was used (i.e. only cases with all variables known were used).

Both available case and complete case analyses can introduce bias into statistical measures, as they do not account for the mechanisms of missing data (Schafer and Graham 2002). Multiple Imputation (MI) can account for missing data by statistically explaining missing data and providing a plausible complete dataset. However, MI can quickly become unwieldy with a dataset involving many variables, as a model for missingness must be specified for each variable and assumptions must be checked. In the NMVCCS dataset, where over 40 variables are being examined and over 400 total variables in the dataset, it was not feasible to perform MI on each variable.

When examining if a driver attempted an avoidance maneuver, one important factor that was not available in this dataset is the travel speed of the vehicle. Higher travel speed lowers the amount of reaction time available for the driver compared to a slower travel speed. The posted speed limit of the roadway was used in the analysis as a surrogate for travel speed. It was found to be a non-significant factor in determining if the driver attempted an avoidance maneuver in a rear-end collision. However, the speed limit does not necessarily correspond to the vehicle’s actual travel speed; the driver could have been speeding or even traveling at a lesser speed. Accurate estimates of travel speed are not available in most in-depth crash databases e.g. NMVCCS; however, the effect of speed may be an important indicator to the presence of an avoidance maneuver.

CONCLUSIONS

Rear-end collisions are one of the most frequent crash types in the U.S. Pre-Collision System (PCS) have been developed to mitigate the frequency and severity of rear-end collisions. The potential effectiveness of these systems, however, depends on the driver’s state and their attempted avoidance maneuvers. This study quantified the driver, environmental, roadway, vehicle, and contributing factors; quantified driver pre-crash maneuvers; and identified the potentially population for PCS in rear-end collisions on U.S. roads.

Compared to all other frontal collision in the dataset, drivers in rear-end collisions are more likely to be following too closely, misjudge the actions of other drivers, be inattentive, and be involved in non-driving activities. In addition, rear-end crashes are more likely to involve younger drivers on complex roadways (i.e. traffic flow restrictions, highway speed limits, multiple lanes, and junction related) compared to other frontal collisions. Nearly three quarters of drivers involved in rear-end collisions attempted an avoidance maneuver. Of those attempting an avoidance maneuver, 67% only applied the brakes, 27% applied the brakes with steering, and 6% only steered. For the remaining quarter of drivers who did not attempt an avoidance maneuver, conversing and non-driving activities were found to be significant factors indicating the lack of an avoidance maneuver.

These findings have important implications for PCS system design. FCW was potentially effective in 84% of rear-end collisions. PBA could be potentially effective in 84% and marginally effective in 7% of rear-end collisions. PB could be potentially effective in 90% of rear-end collisions. This information can be utilized in predicting the field effectiveness of a proposed PCS, as well as designing intervention strategies of PCS.

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REFERENCES

Aoki, H., M. Aga, et al. (2010). Safety Impact Methodology (SIM) for Effectiveness Estimation of a Pre-Collision System (PCS) by Utilizing Driving Simulator Test and EDR Data Analysis.

Baldock, M. R. J., A. D. Long, et al. (2005). Rear end Crashes. South Australia, Austraila, Centre for Automotive Safety Research.

Bellis, E. and J. Page (2008). National Motor Vehicle Crash Causation Survey SAS Analyical Users Manual. Washington, DC, National Highway Traffic Safety Administration.

Eigen, A. M. and W. G. Najm (2009). Problem Definition for Pre-Crash Sensing Advanced Restraints, U.S. Department of Transportation.

Elvik, R. (2006). "Laws of accident causation." Accid Anal Prev **38**(4): 742-747.

Kostyniuk, L. and D. W. Edy (1998). Exploring rear-end roadway crashes from the driver's perspective, University of Michigan Transportation Research Institute.

Kusano, K. D. and H. C. Gabler (2010). "Potential Occupant Injury Reduction in Pre-Crash System Equipped Vehicles in the Striking Vehicle of Rear-end Crashes." Ann Adv Automot Med **54**: 203-214.

Kusano, K. D. and H. C. Gabler (2011). Potential Effectiveness of Integrated Forward Collision Warning, Pre-Collision Brake Assist, and Automated Pre-Collision Braking Systems in

Real-world, Rear-end Collisions. Proceedings of the 22nd International Enhanced Safety of Vehicles Conference, Washington, D.C., Paper Number 11-0364.
McEvoy, S. P., M. R. Stevenson, et al. (2007). "The prevalence of, and factors associated with, serious crashes involving a distracting activity." Accid Anal Prev **39**(3): 475-482.
Najm, W. G., B. Sen, et al. (2003). Analysis of Light Vehicle Crashes and Pre-Crash Scenarios Based on the 2000 General Estimates System. Washington, D.C., Department of Transportation.
Neale, V. L., T. A. Dingus, et al. (2005). An overview of the 100-car naturalistic study and findings. Proceedings of the 19th International Enhanced Safety of Vehicles Conference, Washington, D. C., Paper Number 05-0400.
Schafer, J. L. and J. W. Graham (2002). "Missing data: our view of the state of the art." Psychol Methods **7**(2): 147-177.
Thor, C. P. and H. C. Gabler (2010). "Assessing the residual teen crash risk factors after graduated drivers license implementation." Ann Adv Automot Med **54**: 295-308.

APPENDIX

Table A1. Detailed Description of Driver and Environmental/Road/Vehicle Factors.

Type	Factor	Description
Driver	Male	Sex of driver is male
	Young Driver	Age less than 30 years old
	Driver Belted	Police reported seat belt use
	Alcohol Involvement	Police reported alcohol involvement
	Drug Involvement	Police reported drug involvement
	Unlicensed Driver	Unlicensed, suspended license, revoked license, other non-valid license
	No Illness Before Crash	Medically verified illness during precrash stage
Environment/ Road/ Vehicle	Dark	Crash occurred in dark (i.e. no sunlight)
	Roadway Surface Wet	Road surface was wet, snow covered, icey, or slush
	Traffic Flow Restrictions	Prexisting trafficway flow restriction hindered general flow of traffic
	Highway Speed	Posted speed limit is greater than 50 mph
	Multiple Lanes	Multiple travel lanes in the direction of travel
	Junction Related	Related to junction (e.g. intersection, on-ramp/exit ramp)
	Roadway Straight	Roadway is not curved
	Passengers Present	One or more occupants in the vehicle
	Tire Damage prior to Crash	Tire is damaged prior to the collision
	Vehicle rollover	Vehicle rolled over as a result of the crash
	Vehicle Condition Factors	Vehicle condition factors present prior to crash (e.g. brake failure)

Table A2. Detailed Description of Contributing Factors.

Type	Factor	Description
Behavior	Avoidance Maneuver Attempted	an avoidance maneuver was attempted
	Aggressive Driving Act	driver performed aggressive driving act
	Illegal Driving Maneuver	driver performed any illegal maneuvers
	Driver Emotional Factors	driver is upset, stressed induced by work, in a hurry, or other emotional factors
	Following too Closely	driver traveled less than recommended gap interval to forward traffic
Attention	External Factors	driver was focusing on anything exterior to vehicle that may have influenced focus away from driving task
	Driver Conversing	driver conversing with passenger, on phone, etc
	Driver Inattention	driver was inattentive due to focusing on concerns
	Inadequate Surveilance	driver had inadequate surveillance actions
	Non-driving Activities	activities inside vehicle, other than conversing, diverted driver's attention
Fatigue	Driver Fatigued	assessment of driver's fatigue based on current and preceeding sleep and work schedule
	Less than 6 hours sleep in last 24 hrs	driver had less than 6 hours of sleep in the last 24 hours
	More than 9 hours Average Work	driver works more than 9 hours per day on average
	Trip longer than 30 minutes	This trip is longer than 30 minutes in length
	Driver Performance Errors	driver performed any driving errors (e.g. overcompensation, poor direction control)
Recognition	False Assumption of Other Drivers Actions	Driver made false assumptions about other driver(s) actions
	Misjudgement of others Actions	Driver decision error in which the driver misjudge gap distance or relative velocity of other vehicle(s)
	Other Recognition Factors	Other recognition factors (e..g. impending problem masked by flow pattern, focusing on extraneous vehicle)
Experience	Experienced with this Vehicle	Driver used this vehicle less than 2-5 times in the last 3 months
	Experienced with this Route	Driver "rarely" or "never" naviages this route
	Other Experience Factors	Other inexperience (e.g. uncomforatable with traffic density or speed)

Table A3. Proportion of Cases with Missing Values for Each Factor.

Factor	Frequency	Missing	%
Less than 6 hours sleep in last 24 hours	1,336,675	630,705	32%
Trip longer than 30 minutes	1,359,211	608,169	31%
More than 9 hours average work	1,405,963	561,416	29%
Driver fatigued	1,411,272	556,108	28%
Experienced with this Route	1,479,807	487,573	25%
Experienced with this Vehicle	1,480,883	486,497	25%
Driver Inattention	1,492,616	474,764	24%
Driver Illness prior to Crash	1,510,732	456,648	23%
Non-driving activities	1,518,703	448,677	23%
Other experience factors	1,527,392	439,988	22%
Driver emotional	1,529,378	438,002	22%
Driver Conversing	1,530,762	436,618	22%
Driver focusing on Exterior Factors	1,544,372	423,008	22%
Other recognition factors	1,612,791	354,589	18%
Inadequate Surveillance	1,637,543	329,837	17%
False asmptions of other driver(s) actions	1,756,755	210,625	11%
Avoidance Maneuver Attempted	1,757,380	210,000	11%
Police reported Drug Use	1,769,679	197,701	10%
Tire damage prior to collision	1,798,461	168,919	9%
Driver performance errors	1,800,533	166,847	8%
Inadequate Evassive maneuvers	1,802,176	165,204	8%
Misjudgement of Other's Actions	1,817,413	149,967	8%
Aggressive Driving Act	1,833,870	133,510	7%
Police Reported Belt Use	1,838,402	128,978	7%
Vehicle condition factors	1,882,577	84,802	4%
Police Reported Alcohol Presence	1,885,640	81,740	4%
Unlicensed/Invalid License	1,892,656	74,724	4%
Following too Closely	1,895,499	71,881	4%
Illegal Driving Maneuver	1,935,241	32,139	2%
Young Driver (< 30)	1,935,767	31,613	2%
Driver Sex	1,956,313	11,067	1%
Rumble Strip Presence	1,966,526	854	0%
Dark Lighting Conditions	1,966,875	505	0%
Rollover	1,966,893	487	0%
Trafficway Flow Restrictions Present	1,967,138	242	0%
Roadway Straight	1,967,380	-	0%
Highway Speeds (speed limit >50 mph)	1,967,380	-	0%
Mutliple travel lanes	1,967,380	-	0%
Junction Related	1,967,380	-	0%
Surface Wet	1,967,380	-	0%
One or more Passengers	1,967,380	-	0%