Crash Avoidance Potential of Five Vehicle Technologies

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ABSTRACT

Objectives: The objective of this report was to discuss the maximum potential of five crash avoidance technologies: blind spot detection/warning, forward collision warning/mitigation, emergency brake assist, lane departure warning/prevention, and adaptive headlights.

Methods: Crash records were extracted from the 2002-06 files of the National Automotive Sampling System General Estimates System (NASS GES) and the Fatality Analysis Reporting System (FARS). Crash descriptors such as location of damage on vehicle, road characteristics, time of day, and precrash maneuvers were reviewed to determine whether the information or action provided by each technology could potentially have prevented the crash.

Results: Of the five technologies, the one with the greatest potential is the forward collision warning/mitigation system, which potentially could prevent 2.3 million crashes in the United States each year. Lane departure warning/prevention systems appear relevant to 483,000 crashes per year. Blind spot detection/warning, emergency brake assist, and adaptive headlights could prevent 457,000, 417,000, and 143,000 crashes per year, respectively. Lane departure warning/prevention systems were relevant to the most fatal crashes: up to 10,000 fatal crashes per year.

Conclusions: There is great potential effectiveness for vehicle-based crash avoidance systems. However, it is yet to be determined how drivers will interact with them. The actual effectiveness of these crash avoidance systems will not be known until sufficient real-world experience has been gained.

Keywords: Crash risk; Active safety; GES; FARS.

INTRODUCTION

A number of reports have been published predicting how many crashes might be prevented by various crash avoidance technologies. Many of these predictions were based on laboratory, simulator, or test track experiments. For example, adaptive headlights, which rotate as the front wheels are turned, were reported to increase visibility of pedestrians on dark curves by 14 percent (Sivak et al., 1994).

The National Highway Traffic Safety Administration (NHTSA) published a report in 1996 estimating the effectiveness of systems that warn drivers of potential rear-end, lane change, and road departure crashes (NHTSA, 1996). Such systems were not available at the time, but the authors predicted that future systems meeting the assumed specifications would prevent 791,000 rear-end, 90,000 lane change, and 297,000 road departure crashes in the United States each year.

Another NHTSA report predicted that warning systems could prevent 336,000 road departure crashes per year (Pomerleau et al., 1999). A study published in 2005 concluded that warning systems could prevent nearly 14,000 lane change and road departure crashes per year in the European Union (Abele et al., 2005). A real-world field test of a prototype road departure warning system produced mixed results (Wilson et al., 2007). Each of 78 drivers used the system for 4 weeks, driving on various types of roads. The system worked consistently well on roads with clear lane markings, but only 36 percent of the time on nonfreeways. Taking this into account, the authors estimated the system could reduce road departure crashes in the United States by 5,000 to 41,000 per year.

A prototype forward collision warning system was field tested by 66 drivers for 4 weeks each (Najm et al., 2006). Based on the number of near-crash scenarios identified, the system was projected to reduce rear-end collision rates by 10 percent. Sugimoto and Sauer (2005) estimated that a system with automatic braking in addition to a warning could prevent 38 percent of rear-end collisions, while Coelingh et al. (2007) predicted a 50 percent reduction.

Emergency brake assist systems detect potential panic braking, then prepare the brakes for more efficient and powerful activation. An analysis of Mercedes-Benz cars in Germany reported an 8 percent decline in rear-end collision rates after emergency brake assist became a standard feature (Breuer et al., 2007).

The purpose of the present report is not to give precise predictions of crash reductions, but rather to discuss the maximum potential of five selected technologies: blind spot detection/warning for collisions due to intentional lane changing, forward collision warning/mitigation, emergency brake assist, lane departure warning/prevention, and adaptive headlights. Crashes that possibly could have been prevented by a crash avoidance system are counted as relevant for that technology. This is meant to address not only the technology currently available but also the improved systems that may be available in the future.

These crash counts are estimates of the maximum potential effect of these collision avoidance technologies. Their actual effect when present in large numbers of passenger vehicles will depend on how people respond to the information and actions of the systems. Not all drivers will react to the immediate situation with proper behavior. The ultimate effect of the technology also depends on whether this new information alters the driving task sufficiently to change driver behavior more globally. For example, if certain information systems lead to increased driver cell phone use or travel speeds, then some or all safety benefits could be negated.

METHOD

Data were extracted from two NHTSA databases. The National Automotive Sampling System General Estimates System (NASS GES) contains information from annual probability samples of police-reported crashes in the United States. Approximately 57,000 crashes are sampled each year. When each case is weighted by the inverse of its selection probability, the yearly sample is representative of about 6 million crashes nationwide (NHTSA, 2008). The Fatality Analysis Reporting System (FARS) is an annual census of crashes that result in the death of a vehicle occupant or other involved party within 30 days of the crash.

All passenger vehicle records in the 2002-06 NASS GES and FARS files (vehicle body types 1-49) were merged with the corresponding crash records. Records in GES were weighted by their case weights to produce national estimates. Crashes in GES with maximum injury severity coded as incapacitating or nonincapacitating were classified as those with nonfatal injuries. Imputed data were used whenever available in the GES files.

The first step was to assign each crash to one of nine general categories: changing lanes, angle, front-to-rear, single-driver, head-on, other front-to-front, sideswipe same direction, sideswipe opposite direction, and other. Classification was hierarchical, so any crash with characteristics of more than one category was assigned to the earliest category in the list. In other words, changing lanes took precedence over all other categories.

In both files NHTSA defines crash types using a variable called manner of collision. The manner of collision (MANCOL_I) codes in GES are 0=not a collision with a motor vehicle in transport (i.e., single-driver), 1=rear-end, 2=head-on, 3=rear-to-rear, 4=angle, 5=sideswipe same direction, and 6=sideswipe opposite direction. In addition, there is a variable called accident type (ACC_TYPE) that gives specifics of how each vehicle was configured in the crash. Codes range from 0 to 98 and allow for a finer breakdown of manner of collision. So, for example, records with manner of collision coded as head-on were classified as head-on only if accident type had values 50-53. Otherwise they were classified as other front-to-front collisions.

The manner of collision (MAN_COLL) codes in FARS are 0=not a collision with a motor vehicle in transport (i.e., single-driver), 1=front-to-rear (includes rear-end), 2=front-to-front (includes head-on), 3=front-to-side same direction, 4=front-to-side opposite direction, 5=front-to-side right angle (includes broadside), 6=front-to-side angle (direction not specified), 7=sideswipe same direction, 8=sideswipe opposite direction, 9=rear-to-side, 10=rear-to-rear, and 11=other.

A lane-changing crash was defined as one involving a passenger vehicle driver who was intentionally changing lanes, merging, or turning. This was based on the variable called precrash vehicle movement. The variable MANEUV_I in GES has codes 1=going straight, 2=decelerating in traffic lane, 3=accelerating in traffic lane, 4=starting in traffic lane, 5=stopped in traffic lane, 6=passing or overtaking another vehicle, 7=disabled or parked in travel lane, 8=leaving a parked position, 9=entering a parked position, 10=turning right, 11=turning left, 12=making U-turn, 13=backing up, 14=negotiating a curve, 15=changing lanes, 16=merging, 17=corrective action to a previous critical event, and 97=other. The variable VEH_MAN in FARS has codes 1=going straight, 2=slowing or stopping in traffic lane, 3=starting in traffic lane, 4=stopped in traffic lane, 5=passing or overtaking another vehicle, 6=leaving a parked position, 7=parked, 8=entering a parked position, 9=controlled avoidance maneuver, 10,11,12=turning right, 13=turning left, 14=making U-turn, 15=backing up, 16=changing lanes or merging, 17=negotiating a curve, and 98=other.

After crashes were classified according to the nine general categories, they were further separated into nonrelevant and potentially relevant crash types for each of the five crash avoidance technologies. For example, a crash caused by a driver who intentionally changes lanes probably would not be prevented by a lane departure warning system, but may be prevented by a blind spot warning system.

Crashes that involved preimpact braking were identified using the variable called corrective action (P_CRASH3) in GES and avoidance maneuver (AVOID) in FARS. Crashes that occurred while negotiating a curve were identified using the variable called precrash vehicle movement (MANEUV_I in GES, VEH_MAN in FARS). Crashes that involved speeding were identified using the variables called speed related and violations charged (SPEEDREL, VLTN_I) in GES and driver related factors and violations charged (DR_CF1-4, VIOLCHG1-3) in FARS.

RESULTS

There were 269,291 crash records in the 2002-06 NASS GES files that involved at least one passenger vehicle. When the sampling weights are applied, these represent approximately 29,955,000 crashes nationwide. According to the 2002-06 FARS files, there were 172,953 fatal crashes that involved at least one passenger vehicle. On average, then, during the five study years there were approximately 5,991,000 crashes per year involving passenger vehicles, and 34,591 of these were fatal. Average annual counts for each of the nine general crash types are summarized in Table 1.

Table 1. Average annual crashes involving passenger vehicles during 2002-06

Crash type	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Lane changing/merging/turning	1,727,000	214,000	4,711
Angle (without lane changing)	612,000	95,000	3,416
Front-to-rear (without lane changing)	1,714,000	126,000	1,772
Single-driver (without lane changing)	1,614,000	269,000	18,590
Front-to-front, head-on (without lane changing)	41,000	14,000	2,839
Front-to-front, other (without lane changing)	10,000	3,000	607
Sideswipe, same direction (without lane changing)	174,000	11,000	521
Sideswipe, opposite direction (without lane changing)	96,000	16,000	2,014
Other (e.g., rear-to-rear, end-swipe, unknown)	3,000	<1,000	120
	5,991,000	750,000	34,591

Blind Spot Detection/Warning Systems

Certain lane-changing crashes could be prevented if drivers are warned of vehicles in their blind spots. Of the 1.7 million lane-changing crashes each year, only certain types of angle, front-to-rear, and sideswipe same direction crashes seem relevant to blind spot warning/detection systems. These crash types account for 26 percent of the lane-changing crashes, or approximately 457,000 crashes per year (Table 2). Such crashes are characterized by a vehicle approaching from behind, so relatively few involve moderate-to-serious injuries (24,000) or deaths (428).

Table 2. Annual lane-changing crashes relevant to blind spot warning systems

Crash type	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Lane changing, single-driver	167,000	35,000	963
Lane changing, more than two vehicles	67,000	18,000	534
Lane changing, front-to-front	3,000	1,000	416
Lane changing, angle, different travel directions	977,000	134,000	1,559
Lane changing, front-to-rear, striking	55,000	3,000	80
Lane changing, sideswipe opposite direction	2,000	<1,000	732
(Total nonrelevant)	(1,271,000)	(191,000)	(4,284)
Lane changing, angle, same travel direction	193,000	13,000	6
Lane changing, angle, unknown travel direction	5,000	<1,000	12
Lane changing, front-to-rear, struck	57,000	5,000	88
Lane changing, sideswipe same direction	202,000	6,000	298
Lane changing, other	<1,000	<1,000	24
(Total relevant)	**(457,000)**	**(24,000)**	**(428)**
	1,727,000	214,000	4,711

Forward Collision Warning/Mitigation Systems

Systems that sound alerts and/or initiate braking when a vehicle is too close to another vehicle or object in front are relevant for some angle, front-to-rear, and single-driver crashes. Potentially relevant crashes were restricted to those in which the front of a passenger vehicle struck a vehicle, pedestrian, or other object in its path. Crashes were classified by considering the following variables: relation to roadway (REL_RWY in GES, REL_ROAD in FARS), first harmful event (EVENT1_I in GES, HARM_EV in FARS), number of vehicles (VEH_INVL in GES, VE_FORMS in FARS), driver-related factors (DR_CF1-4 in FARS), critical event (P_CRASH2 in GES), and avoidance maneuver (DRMAN_AV in GES, AVOID in FARS).

Collisions occurring off the roadway were classified as nonrelevant for two reasons: (1) detection of objects may be unreliable given the environment and erratic path of a vehicle, and (2) braking may be less effective than would be possible on the road surface. Collisions preceded by the successful avoidance of an object in the vehicle's path also were classified as nonrelevant. The erratic path of a vehicle in the midst of an avoidance maneuver seems likely to hinder the detection of obstacles. Also, these types of avoidance maneuvers may be prompted by forward collision warnings. Collisions involving more than two vehicles were classified as nonrelevant because of an inability to clearly define the sequence of events.

If a driver already has recognized the threat of collision and has initiated braking, then the warning/mitigation system may be unnecessary. For this reason crashes with evidence of the striking vehicle braking were classified as only possibly relevant. Tables 3A-3C include estimates of relevant crash counts both with and without evidence of braking. Thus each table provides a range of estimates for crashes relevant to forward collision warning/mitigation systems.

Potentially relevant crash types account for 76-81 percent of the angle crashes in Table 1, or approximately 463,000-498,000 crashes per year (Table 3A).

Table 3A. Annual angle crashes relevant to forward collision warning systems

Crash type	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Angle, off roadway	3,000	<1,000	33
Angle, more than two vehicles	30,000	9,000	348
Angle, vehicle/road defect	2,000	<1,000	8
Angle, avoidance maneuver	<1,000	<1,000	380
Angle, struck by non-passenger vehicle	79,000	6,000	441
(Total nonrelevant)	(114,000)	(15,000)	(1,210)
Angle, other, with braking (relevant?)	**36,000**	**7,000**	**235**
Angle, other, without braking (relevant)	**463,000**	**72,000**	**1,970**
(Total relevant)	**(498,000)**	**(79,000)**	**(2,206)**
	612,000	95,000	3,416

Potentially relevant crash types account for 69-81 percent of the front-to-rear crashes in Table 1, or approximately 1,176,000-1,382,000 crashes per year (Table 3B).

Table 3B. Annual front-rear crashes relevant to forward collision warning systems

Crash type	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Front-to-rear, off roadway	6,000	<1,000	118
Front-to-rear, more than two vehicles	271,000	37,000	537
Front-to-rear, vehicle/road defect	4,000	<1,000	4
Front-to-rear, avoidance maneuver	8,000	1,000	108
Front-to-rear, struck by non-passenger vehicle	44,000	5,000	182
(Total nonrelevant)	(333,000)	(43,000)	(949)
Front-to-rear, other, with braking (relevant?)	**206,000**	**16,000**	**76**
Front-to-rear, other, without braking (relevant)	**1,176,000**	**67,000**	**746**
(Total relevant)	**(1,382,000)**	**(83,000)**	**(822)**
	1,714,000	126,000	1,772

Potentially relevant crash types account for 23-24 percent of the single-driver crashes in Table 1, or approximately 373,000-388,000 crashes per year (Table 3C). These are primarily collisions with pedestrians, bicyclists, parked vehicles, and animals.

Table 3C. Annual single-driver crashes relevant to forward collision warning systems

Crash type	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Single-driver, off roadway	1,164,000	210,000	13,431
Single-driver, on road, vehicle/road defect	6,000	1,000	35
Single-driver, on road, non-collision	56,000	10,000	986
(Total nonrelevant)	(1,226,000)	(221,000)	(14,452)
Single-driver, other, with braking (relevant?)	**15,000**	**5,000**	**544**
Single-driver, other, without braking (relevant)	**373,000**	**43,000**	**3,594**
(Total relevant)	**(388,000)**	**(48,000)**	**(4,138)**
	1,614,000	269,000	18,590

Combining Tables 3A-3C, there are approximately 2,012,000-2,268,000 crashes annually that are relevant to forward collision warning/mitigation systems. Of these, 182,000-210,000 involve only nonfatal injuries and 6,310-7,166 involve fatal injuries.

Emergency Brake Assist Systems

Emergency brake assist systems are activated only if a driver already has applied the brakes. Relevant crashes for this technology were restricted to those in which the driver of a frontally impacted passenger vehicle applied the brakes. These crash types account for 7 percent of the crashes in Table 1, or approximately 417,000 crashes per year (Table 4).

Table 4. Average annual crashes relevant to emergency brake assist systems

Crash type with evidence of braking	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Lane changing/merging/turning	85,000	18,000	542
Angle (without lane changing)	37,000	7,000	380
Front-to-rear (without lane changing)	222,000	18,000	143
Single-driver (without lane changing)	58,000	13,000	1,251
Front-to-front, head-on (without lane changing)	7,000	2,000	405
Front-to-front, other (without lane changing)	1,000	<1,000	67
Sideswipe, same direction (without lane changing)	3,000	<1,000	42
Sideswipe, opposite direction (without lane changing)	3,000	1,000	242
Other (e.g., rear-to-rear, end-swipe, unknown)	<1,000	<1,000	6
	417,000	**61,000**	**3,079**

Lane Departure Warning/Prevention Systems

Systems that alert a driver who has inadvertently strayed across the lane markings probably are not relevant to intentional lane-changing, angle, or front-to-rear crashes. They are, however, relevant to the other crash types in Table 1 if the driver inadvertently drifted out of the lane. Maneuvers that successfully avoided an obstacle in the vehicle's path were not classified as intentional lane changes, but they were not inadvertent either. Crashes involving such maneuvers were deemed nonrelevant.

The lane departure warning may be too late to do any good if a driver is speeding. For this reason, crashes with evidence of speeding were classified as only possibly relevant. Tables 5A-5D include estimates of relevant crash counts both with and without evidence of speeding. Thus each table provides a range of estimates for crashes relevant to lane departure warning/prevention systems.

Single-driver crashes on the roadway typically were pedestrian, bicyclist, or animal strikes. Avoidance maneuvers may have been attempted, but they were unsuccessful. As with successful avoidance maneuvers, such crashes were classified as nonrelevant. The vehicle did not inadvertently stray from the travel lane. Single-driver crashes were coded as loss of control if the driver lost control of the vehicle due to environmental conditions, overcorrecting, or reckless driving. These also were considered nonrelevant.

Potentially relevant crash types account for 13-16 percent of the single-driver crashes in Table 1, or approximately 211,000-260,000 crashes per year (Table 5A). Driver fatigue, inattentiveness, or drifting out of lane was specifically mentioned in the reports for 82 percent of the potentially relevant crashes, 92 percent of the injury crashes, and 64 percent of the fatal crashes.

Table 5A. Annual single-driver crashes relevant to lane departure warning systems

Crash type	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Single-driver, on roadway	450,000	59,000	5,159
Single-driver, run off road, vehicle/road defect	82,000	13,000	170
Single-driver, run off, avoidance maneuver	674,000	106,000	3,004
Single-driver, run off, loss of control	148,000	32,000	3,054
(Total nonrelevant)	(1,354,000)	(210,000)	(11,387)
Single-driver, other, speeding (relevant?)	**49,000**	**16,000**	**3,216**
Single-driver, other, without speeding (relevant)	**211,000**	**43,000**	**3,987**
(Total relevant)	**(260,000)**	**(59,000)**	**(7,203)**
	1,614,000	269,000	18,590

Potentially relevant crash types account for 66-88 percent of the head-on crashes in Table 1, or approximately 27,000-36,000 crashes per year (Table 5B). Driver fatigue, inattentiveness, or drifting out of lane was specifically mentioned in the reports for 96 percent of the potentially relevant crashes, 97 percent of the injury crashes, and 82 percent of the fatal crashes.

Table 5B. Annual head-on crashes relevant to lane departure warning systems

Crash type	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Head-on, more than two vehicles	<1,000	<1,000	296
Head-on, vehicle/road defect	1,000	<1,000	12
Head-on, avoidance maneuver	<1,000	<1,000	625
Head-on, non-passenger vehicle out of lane	4,000	1,000	118
(Total nonrelevant)	(5,000)	(2,000)	(1,050)
Head-on, other, speeding (relevant?)	**9,000**	**3,000**	**282**
Head-on, other, without speeding (relevant)	**27,000**	**9,000**	**1,507**
(Total relevant)	**(36,000)**	**(12,000)**	**(1,789)**
	41,000	14,000	2,839

Potentially relevant crash types account for 55-67 percent of the sideswipe same direction crashes in Table 1, or approximately 96,000-116,000 crashes per year (Table 5C). Driver fatigue, inattentiveness, or drifting out of lane was specifically mentioned in the reports for 66 percent of the potentially relevant crashes, 61 percent of the injury crashes, and 36 percent of the fatal crashes.

Table 5C. Annual sideswipe same-direction crashes relevant to lane departure warning systems

Crash type	**All crashes**	**Nonfatal injury crashes (A or B)**	**Fatal crashes**
Sideswipe same, more than two vehicles	8,000	1,000	119
Sideswipe same, vehicle/road defect	5,000	1,000	5
Sideswipe same, avoidance maneuver	1,000	<1,000	94
Sideswipe same, non-passenger vehicle out of lane	45,000	3,000	16
(Total nonrelevant)	(59,000)	(5,000)	(234)
Sideswipe same, other, speeding (relevant?)	**19,000**	**2,000**	**81**
Sideswipe same, other, without speeding (relevant)	**96,000**	**4,000**	**207**
(Total relevant)	**(116,000)**	**(6,000)**	**(288)**
	174,000	11,000	521

Potentially relevant crash types account for 57-74 percent of the sideswipe opposite direction crashes in Table 1, or approximately 55,000-71,000 crashes per year (Table 5D). Driver fatigue, inattentiveness, or drifting out of lane was specifically mentioned in the reports for 92 percent of the potentially relevant crashes, 97 percent of the injury crashes, and 54 percent of the fatal crashes.

Table 5D. Annual sideswipe opposite-direction crashes relevant to lane departure warning systems

Crash type	**All crashes**	**Nonfatal injury crashes (A or B)**	**Fatal crashes**
Sideswipe opposite, more than two vehicles	3,000	1,000	382
Sideswipe opposite, vehicle/road defect	3,000	1,000	16
Sideswipe opposite, avoidance maneuver	7,000	1,000	495
Sideswipe opposite, non-passenger vehicle out of lane	11,000	3,000	56
(Total nonrelevant)	(24,000)	(6,000)	(949)
Sideswipe opposite, other, speeding (relevant?)	**16,000**	**3,000**	**261**
Sideswipe opposite, other, without speeding (relevant)	**55,000**	**7,000**	**804**
(Total relevant)	**(71,000)**	**(10,000)**	**(1,065)**
	96,000	16,000	2,014

Combining Tables 5A-5D, there are approximately 389,000-483,000 crashes annually that are relevant to lane departure warning/prevention systems. Of these, 63,000-87,000 involve only nonfatal injuries and 6,505-10,345 involve fatal injuries.

Under the tighter restriction that driver fatigue, inattentiveness, or drifting out of lane must be specifically mentioned, the lower limits on potentially relevant crashes drop to 308,000 overall, 58,000 with nonfatal injuries, and 4,361 with fatal injuries.

Adaptive Headlight Systems

Adaptive headlights are meant to improve visibility on curved roads. Relevant crashes were defined as all front-to-rear, single-driver, and sideswipe same direction crashes while negotiating curves in darkness (or twilight). These crash types account for 4 percent of the front-to-rear, single-driver, and sideswipe same direction crashes in Table 1, or approximately 143,000 crashes per year (Table 6).

Table 6. Average annual crashes relevant to adaptive headlight systems

Crash type while negotiating dark curves	All crashes	Nonfatal injury crashes (A or B)	Fatal crashes
Lane changing/merging/turning	4,000	<1,000	18
Angle (without lane changing)	1,000	<1,000	42
Front-to-front, head-on (without lane changing)	3,000	1,000	179
Front-to-front, other (without lane changing)	<1,000	<1,000	22
Sideswipe, opposite direction (without lane changing)	7,000	1,000	111
Other (e.g., rear-to-rear, end-swipe, unknown)	<1,000	<1,000	3
(Total nonrelevant)	(16,000)	(3,000)	(376)
Front-to-rear (without lane changing)	5,000	1,000	15
Single-driver (without lane changing)	135,000	30,000	2,527
Sideswipe same direction (without lane changing)	3,000	<1,000	11
(Total relevant)	**(143,000)**	**(31,000)**	**(2,553)**
	159,000	34,000	2,929

Combined effect

There is some degree of overlap in the relevant crashes of Tables 2-6. For example, the front-to-rear crashes with braking in Table 3B also were included as relevant in Table 4. As a final step, crashes were identified that were potentially relevant to any of the five technologies. A combination of all five technologies could prevent/mitigate (without double counting) up to 3,435,000 crashes each year, including 370,000 nonfatal injury crashes and 20,777 fatal crashes.

DISCUSSION

Approximately 57 percent of the 6 million police-reported crashes each year are potentially relevant to at least one of these five crash avoidance technologies: blind spot detection/warning, forward collision warning/mitigation, emergency brake assist, lane departure warning/prevention, and adaptive headlights. Of these five technologies, the one with the greatest potential is the forward collision warning/mitigation system. This could potentially prevent/mitigate up to 2.3 million police-reported crashes each year (38 percent), including 1.4 million front-to-rear crashes. It has been estimated that half of all front-to-rear crashes are not reported to police, so the potential for forward collision warning/ mitigation systems may be up to 3.7 million crashes prevented each year (Najm et al., 2006). It also has great potential for preventing serious crashes. A forward collision warning/mitigation system could prevent up to 210,000 nonfatal injury crashes and 7,166 fatal crashes each year.

Another technology that could be very effective is the lane departure warning/prevention system. This could potentially prevent/mitigate up to 483,000 crashes per year (8 percent), including 87,000 nonfatal injury crashes and 10,345 fatal crashes. The warning system alone is similar to an environment-based technology already available on many roadways — raised or grooved rumble strips along lane boundaries. Vibrations and noise from rumble strips reportedly prevent 25-30 percent of potential run-off-road, head-on, and sideswipe opposite direction collisions (Corkle et al., 2001; Outcalt, 2001; Persaud et al., 2004).

These crash avoidance features currently are available on just a handful of vehicle models, but they are becoming more common. They also are becoming more sophisticated. After flashing an indicator light and/or sounding an alarm to warn the driver of an imminent collision, some forward collision warning systems will tighten the safety belts and begin automatic braking. Emergency brake assist systems originally responded only to movement of the accelerator and brake pedals, but some now use the forward collision radar sensors to decide when and how to prepare the brakes. Some lane departure and blind spot warning systems actively resist the movement of a vehicle out of its travel lane. These improvements will not add to the list of potentially relevant crashes, but they could increase the percentage of such crashes that actually will be prevented.

Gottselig et al. (2008) predicted somewhat lower effectiveness for the technologies currently available. Because many current systems do not function at low speeds, they restricted the potential of each technology to crashes occurring at or above some minimum speed. Based on crash reconstruction data from Germany, they predicted that forward collision warning systems with autonomous braking could potentially prevent 10 percent of crashes involving passenger cars. They predicted that lane departure warning systems could potentially prevent 4-15 percent of crashes and that blind spot detection systems could prevent 1-3 percent of crashes.

The counts listed in Tables 2-6 are the crashes that potentially could be avoided if these technologies worked perfectly. There are bound to be difficulties. Environmental conditions may affect the reliability of sensors and cameras. Drivers may misunderstand or react inappropriately to the alerts. False alarms may cause drivers to mistrust the system and either ignore it or turn it off (Campbell et al., 2007). On the other hand, drivers with too much faith in the system may be less observant or drive more aggressively. For example, research on reflector posts, raised pavement markers, and other roadway markings on curves has reported that drivers sometimes increase their speed when visibility is improved (Kallberg, 1993: Zador et al., 1987). This could offset the potential benefits of adaptive headlights.

Driver interaction with these systems is the subject of ongoing field studies, track tests, and simulator studies. Researchers are trying to find the best way to warn drivers of dangerous situations and assist in correcting errors. However, drivers in an experimental setup, even when using their own vehicles on a public road, do not always behave realistically. The true test of the effectiveness of these crash avoidance systems will have to wait until sufficient numbers of them are on the road gaining real-world experience.

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APPENDIX

Following are the SAS program statements used to classify relevant crashes. Variable names are those used in the NHTSA SAS data files. However, for two-vehicle crashes the data for both vehicles were combined into one crash record. The second vehicle was given variable names with a '_p' extension. For example, the body type for vehicle 1 is body_typ while that for vehicle 2 is body_typ_p. Note that variable names and the interpretation of their values are different for GES and FARS. See the NHTSA user manuals for details: NASS GES Analytical User's Manual 1988-2006, FARS Analytic Reference Guide 1975 to 2006 (both available at http://www-nrd.nhtsa.dot.gov/CATS/index.aspx).

1. General Crash Types

GES

Merge vehicle records of all crash-involved passenger vehicles (BDYTYP_H 1-49) with their crash records for calendar years 2002-06.

Define crash types:

```
Crash_type 1='Changing lanes' 3='Angle' 4='Front-rear' 5='Single-driver'
           6='Head-on' 7='Other Front-front' 8='Sideswipe same' 9='Sideswipe opposite'
           10='Other' 11='Unknown';
```

Assign a crash type to each vehicle record:

```
if mancol_i=0 then crash_type=5;
else if mancol_i=4 & (68 le acc_type le 91) then crash_type=3;
else if mancol_i=1 | (20 le acc_type le 33) then crash_type=4;
else if mancol_i=2 & (50 le acc_type le 53) then crash_type=6;
else if mancol_i=2 then crash_type=7;
else if mancol_i=4 & (44 le acc_type le 49) then crash_type=8;
else if mancol_i=4 & (64 le acc_type le 67) then crash_type=9;
else if mancol_i=5 then crash_type=8;
else if mancol_i=6 then crash_type=9;
else crash_type=10;
```

Examine vehicle records to look for evidence of speeding, intentional lane changing, sideswipes, or angle collisions. Then reclassify crash records:

```
if first.casenum then do;
  flag_an=0; flag_lc=0; flag_ss=0; flag_so=0; flag_sp=0;
end;
if (1 le bdytyp_h le 49) then do;
  if speedrel=1 | (2 le vltn_i le 4) then flag_sp+1;
  if maneuv_i in (10,11,12,15,16,17) | acc_type in (46,47,70,71,72,73) then flag_lc+1;
  else if mancol_i=4 & (44 le acc_type le 49) then flag_ss+1;
  else if mancol_i=4 & (64 le acc_type le 67) then flag_so+1;
  else if mancol_i=4 then flag_an+1;
end;
if last.casenum then do;
  if flag_lc then crash_type=1;
  else if flag_an then crash_type=3;
  else if flag_ss then crash_type=8;
  else if flag_so then crash_type=9;
  output;
end;
```

FARS

Merge vehicle records of all crash-involved passenger vehicles (BODY_TYP 1-49) with their crash records for calendar years 2002-06.

Define crash types:

```
Crash_type 1='Changing lanes' 3='Angle' 4='Front-rear' 5='Single-driver'
           6='Head-on' 7='Other Front-front' 8='Sideswipe same' 9='Sideswipe opposite'
           10='Other' 11='Unknown';
```

Assign a crash type to each vehicle record:

```
if ve_forms=1 | man_coll=0 then crash_type=5;
else if man_coll in (5,6) then crash_type=3;
else if man_coll=1 then crash_type=4;
else if man_coll=2 & traf_flo in (1,5) then crash_type=6;
else if man_coll=2 then crash_type=7;
else if man_coll in (3,7) then crash_type=8;
else if man_coll in (4,8) then crash_type=9;
else if man_coll=99 then crash_type=11;
else crash_type=10;
```

Examine vehicle records to look for evidence of speeding or intentional lane changing. Then reclassify crash records:

```
if first.st_case then do;
  flag_lc=0; flag_sp=0;
end;
if (1 le body_typ le 49) then do;
  if dr_cf1 in (44,46) | dr_cf2 in (44,46) | dr_cf3 in (44,46) | dr_cf4 in (44,46)
    | (21 le violchg1 le 29) | (21 le violchg2 le 29) | (21 le violchg3 le 29)
    then flag_sp+1;
  if veh_man in (9,10,11,12,13,14,16) then flag_lc+1;
end;
if last.st_case then do;
  if flag_lc then crash_type=1;
  output;
end;
```

2. Relevant Crashes

GES

Flag preimpact braking:

```
if impact_h in (11,12,1) & p_crash3 in (2,3,4,5,8,9) & (1 le bdytyp_h le 49)
  then brakeflag=1;
if impact_h_p in (11,12,1) & p_crash3_p in (2,3,4,5,8,9) & (1 le bdytyp_h_p le 49)
  then brakeflag=1;
```

Flag crashes on dark curves:

```
if lgtcon_i in (2,3,4,5) then do;
  if (1 le bdytyp_h le 49) & maneuv_i=14 then cat8=1;
  if (1 le bdytyp_h_p le 49) & maneuv_i_p=14 then cat8=1;
end;
```

Break out lane-changing crashes:

```
Cat1 1='Single-driver' 2='More than 2 vehicles' 3='Angle same' 4='Angle opposite'
     5='Angle unknown' 6='Front-LC rear' 7='Front-rear other' 8='Front-front'
     9='Sideswipe same' 10='Sideswipe opposite' 11='Other' 12='Unknown';

if crash_type=1 then do;                  /* further breakdown of lane-changing crashes */
  if veh_invl lt 2  | (0 le acc_type le 16) | mancol_i=0 then cat1=1;
  else if veh_invl gt 2 then cat1=2;
  else if mancol_i=4 | (68 le acc_type le 91) then do;
    cat1=5;
    if acc_type in (70,71,72,73) then cat1=3;
    else if (20 le acc_type le 49) then cat1=3;
    else if (50 le acc_type le 91) then cat1=4;
    else if p_crash2 in (51,52,53,60,61) | p_crash2_p in (51,52,53,60,61) then cat1=3;
    else if (54 le p_crash2 le 74) | (54 le p_crash2_p le 74) then cat1=4;
    else if maneuv_i=12 | maneuv_i_p=12 then cat1=4;
  end;
  else if mancol_i=1 | (20 le acc_type le 33) then do;
    cat1=7;
    if maneuv_i in (10,11,12,15,16,17) | acc_type in (46,47,70,71,72,73) then do;
      if impact_h in (4,13,14) then cat1=6;
    end;
    else if maneuv_i_p in (10,11,12,15,16,17) | acc_type_p in (46,47,70,71,72,73) then do;
      if impact_h_p in (4,13,14) then cat1=6;
    end;
  end;
  else if mancol_i=2 then cat1=8;
  else if mancol_i=4 | (44 le acc_type le 49) then cat1=9;
  else if mancol_i=4 | (64 le acc_type le 67) then cat1=10;
  else if mancol_i=5 then cat1=9;
  else if mancol_i=6 then cat1=10;
  else if mancol_i=3 then cat1=11;
end;
```

Break out angle crashes:

```
Cat21 1='Off roadway' 3='More than 2 vehicles' 4='Vehicle/road problem'
      5='Avoidance' 6='Non-Collision' 7='Non-PV' 8='Relevant';

if crash_type=3 then do;                          /* further breakdown of angle crashes */
  if rel_rwy ne 1 then cat21=1;
  else if veh_invl gt 2 then cat21=3;
  else if (1 le p_crash2 le 5) | (1 le p_crash2_p le 5) then cat21=4;
  else if (80 le p_crash2 le 92) | (80 le p_crash2_p le 92) then cat21=5;
  else if (1 le drman_av le 3) | (1 le drman_av_p le 3) then cat21=5;
  else if drman_av=5 | drman_av_p=5 then cat21=5;
  else if (1 le bdytyp_h le 49) & impact_h in (1,11,12) then cat21=8;
  else if (1 le bdytyp_h_p le 49) & impact_h_p in (1,11,12) then cat21=8;
  else cat21=7;
end;
```

Break out front-rear crashes:

```
Cat2 1='Off roadway' 3='More than 2 vehicles' 4='Vehicle/road problem'
     5='Avoidance' 6='Non-Collision' 7='Non-PV' 8='Relevant';

if crash_type=4 then do;                     /* further breakdown of front-rear crashes */
  if rel_rwy ne 1 then cat2=1;
  else if veh_invl gt 2 then cat2=3;
  else if (1 le p_crash2 le 5) | (1 le p_crash2_p le 5) then cat2=4;
  else if (80 le p_crash2 le 92) | (80 le p_crash2_p le 92) then cat2=5;
  else if (1 le drman_av le 3) | (1 le drman_av_p le 3) then cat2=5;
  else if drman_av=5 | drman_av_p=5 then cat2=5;
  else if (1 le bdytyp_h le 49) & impact_h in (1,11,12) then cat2=8;
  else if (1 le bdytyp_h_p le 49) & impact_h_p in (1,11,12) then cat2=8;
  else cat2=7;
end;
```

Break out single-driver crashes:

```
Cat22 1='Off roadway' 3='More than 2 vehicles' 4='Vehicle/road problem'
      5='Avoidance' 6='Non-Collision' 7='Non-PV' 8='Relevant';

if crash_type=5 then do;                  /* further breakdown of single-driver crashes */
  if rel_rwy ne 1 then cat22=1;
  else if (1 le p_crash2 le 5) | (1 le p_crash2_p le 5) then cat22=4;
  else if (1 le event1_i le 10) then cat22=6;
  else cat22=8;
  if surcon_i=1 then cat32=1;
  else cat32=2;

Cat4 1='On-road' 2='ROR Vehicle/road problem' 3='ROR Object in path'
     4='ROR Loss of control' 5='ROR Out of lane' 6='ROR Other/Unknown';

  if rel_rwy=1 then cat4=1;
  else if (1 le p_crash2 le 5) then cat4=2;
  else if (50 le p_crash2 le 92) then cat4=3;
  else if (1 le drman_av le 97) then cat4=3;
  else if acc_type in (3,8,13) then cat4=3;
  else if p_crash2 in (6,8,9) then cat4=4;
  else if p_crash2 in (10,11,12,13) then cat4=5;
  else cat4=6;
end;
```

Break out head-on crashes:

```
Cat5 1='More than 2 vehicles' 2='Vehicle/road problem' 3='Object in path'
     4='Non-PV' 5='Out of lane' 6='Other/Unknown';

if crash_type=6 then do;                        /* further breakdown of head-on crashes */
  if veh_invl gt 2 then cat5=1;
  else if (1 le p_crash2 le 5) | (1 le p_crash2_p le 5) then cat5=2;
  else if (80 le p_crash2 le 92) then cat5=3;
  else if (1 le drman_av le 3) | (1 le drman_av_p le 3) then cat5=3;
  else if drman_av=5 | drman_av_p=5 then cat5=3;
  else if p_crash2 in (10,11,12,13,54,62,63) | p_crash2_p in (10,11,12,13,54,62,63)
    then cat5=5;
  else cat5=6;
  if cat5=5 then do;             /* check that out of lane vehicle is passenger vehicle */
    if p_crash2 in (10,11,12,13,54,62,63) & (49 lt bdytyp_h lt 100) then cat5=4;
    if p_crash2_p in (10,11,12,13,54,62,63) & (49 lt bdytyp_h_p lt 100) then cat5=4;
  end;
end;
```

Break out sideswipe same-direction crashes:

```
Cat6 1='More than 2 vehicles' 2='Vehicle/road problem' 3='Object in path'
     4='Non-PV' 5='Out of lane' 6='Other/Unknown';

if crash_type=8 then do;       /* further breakdown of sideswipe same-direction crashes */
  if veh_invl gt 2 then cat6=1;
  else if (1 le p_crash2 le 5) | (1 le p_crash2_p le 5) then cat6=2;
  else if (80 le p_crash2 le 92) then cat6=3;
  else if (1 le drman_av le 3) | (1 le drman_av_p le 3) then cat6=3;
  else if drman_av=5 | drman_av_p=5 then cat6=3;
  else if p_crash2 in (10,11,12,13,60,61) | p_crash2_p in (10,11,12,13,60,61) then cat6=5;
  else cat6=6;
if cat6=5 then do;               /* check that out of lane vehicle is passenger vehicle */
    if p_crash2 in (10,11,12,13,60,61) & (49 lt bdytyp_h lt 100) then cat6=4;
    if p_crash2_p in (10,11,12,13,60,61) & (49 lt bdytyp_h_p lt 100) then cat6=4;
  end;
end;
```

Break out sideswipe opposite-direction crashes:

```
Cat7 1='More than 2 vehicles' 2='Vehicle/road problem' 3='Object in path'
     4='Non-PV' 5='Out of lane' 6='Other/Unknown';

if crash_type=9 then do;         /* further breakdown of sideswipe opposite-dir crashes */
  if veh_invl gt 2 then cat7=1;
  else if (1 le p_crash2 le 5) | (1 le p_crash2_p le 5) then cat7=2;
  else if (80 le p_crash2 le 92) then cat7=3;
  else if (1 le drman_av le 3) | (1 le drman_av_p le 3) then cat7=3;
  else if drman_av=5 | drman_av_p=5 then cat7=3;
  else if (50 le p_crash2 le 59) | (50 le p_crash2_p le 59) then cat7=3;
  else if p_crash2 in (10,11,12,13,54,62,63) | p_crash2_p in (10,11,12,13,54,62,63) then cat7=5;
  else cat7=6;
if cat7=5 then do;         /* check that out of lane vehicle is passenger vehicle */
    if p_crash2 in (10,11,12,13,54,62,63) & (49 lt bdytyp_h lt 100) then cat7=4;
    if p_crash2_p in (10,11,12,13,54,62,63) & (49 lt bdytyp_h_p lt 100) then cat7=4;
  end;
end;
```

FARS

Flag preimpact braking:

```
if impact1 in (11,12,1) & avoid in (1,2,3,5) & (1 le body_typ le 49) then
  brakeflag=1;
if impact1_p in (11,12,1) & avoid_p in (1,2,3,5) & (1 le body_typ_p le 49) then
  brakeflag=1;
```

Flag crashes on dark curves:

```
if lgt_cond in (2,3,4,5) then do;
  if (1 le body_typ le 49) & veh_man=17 then cat8=1;
  if (1 le body_typ_p le 49) & veh_man_p=17 then cat8=1;
end;
```

Break out lane-changing crashes:

```
Cat1 1='Single-driver' 2='More than 2 vehicles' 3='Angle same' 4='Angle opposite'
     5='Angle unknown' 6='Front-LC rear' 7='Front-rear other' 8='Front-front'
     9='Sideswipe same' 10='Sideswipe opposite' 11='Other' 12='Unknown';

if crash_type=1 then do;                  /* further breakdown of lane-changing crashes */
  if ve_forms=1 | man_coll=0 then cat1=1;
  else if ve_forms gt 2 then cat1=2;
  else if man_coll=6 then do;
    cat1=5;
    if dr_cf1 in (26,27,28,33,34,35,47) | dr_cf2 in (26,27,28,33,34,35,47)
      | dr_cf3 in (26,27,28,33,34,35,47) | dr_cf4 in (26,27,28,33,34,35,47)
      | dr_cf1_p in (26,27,28,33,34,35,47) | dr_cf2_p in (26,27,28,33,34,35,47)
      | dr_cf3_p in (26,27,28,33,34,35,47) | dr_cf4_p in (26,27,28,33,34,35,47) then
        cat1=3;
    else if dr_cf1 in (38,39,48,50,51) | dr_cf2 in (38,39,48,50,51)
      | dr_cf3 in (38,39,48,50,51) | dr_cf4 in (38,39,48,50,51)
      | dr_cf1_p in (38,39,48,50,51) | dr_cf2_p in (38,39,48,50,51)
      | dr_cf3_p in (38,39,48,50,51) | dr_cf4_p in (38,39,48,50,51) then cat1=4;
  end;
  else if man_coll=5 then cat1=4;
  else if man_coll=1 then do;
    cat1=7;
    if veh_man in (9,10,11,12,13,14,16) & impact1 in (4,5,6) then cat1=6;
    else if veh_man_p in (9,10,11,12,13,14,16) & impact1_p in (4,5,6) then cat1=6;
  end;
  else if man_coll=2 then cat1=8;
  else if man_coll in (3,7) then cat1=9;
  else if man_coll in (4,8) then cat1=10;
  else if man_coll in (9,10,11) then cat1=11;
  else cat1=12;
end;
```

Break out angle crashes:

```
Cat21 1='Off roadway' 3='More than 2 vehicles' 4='Vehicle/road problem'
      5='Avoidance' 6='Non-Collision' 7='Non-PV' 8='Relevant';

if crash_type=3 then do;                          /* further breakdown of angle crashes */
  if rel_road ne 1 then cat21=1;
  else if ve_forms gt 2 then cat21=3;
  else if dr_cf1 in (79,80,82) | dr_cf2 in (79,80,82)
      | dr_cf3 in (79,80,82) | dr_cf4 in (79,80,82) then cat21=4;
  else if dr_cf1_p in (79,80,82) | dr_cf2_p in (79,80,82)
      | dr_cf3_p in (79,80,82) | dr_cf4_p in (79,80,82) then cat21=4;
  else if dr_cf1 in (81,83,86) | dr_cf2 in (81,83,86)
      | dr_cf3 in (81,83,86) | dr_cf4 in (81,83,86) then cat21=5;
  else if dr_cf1_p in (81,83,86) | dr_cf2_p in (81,83,86)
      | dr_cf3_p in (81,83,86) | dr_cf4_p in (81,83,86) then cat21=5;
  else if avoid in (4,5) | avoid_p in (4,5) then cat21=5;
  else if (1 le body_typ le 49) & impact1 in (1,11,12) then cat21=8;
  else if (1 le body_typ_p le 49) & impact1_p in (1,11,12) then cat21=8;
  else cat21=7;
end;
```

Break out front-rear crashes:

```
Cat2 1='Off roadway' 3='More than 2 vehicles' 4='Vehicle/road problem'
     5='Avoidance' 6='Non-Collision' 7='Non-PV' 8='Relevant';

if crash_type=4 then do;                     /* further breakdown of front-rear crashes */
  if rel_road ne 1 then cat2=1;
  else if ve_forms gt 2 then cat2=3;
  else if dr_cf1 in (79,80,82) | dr_cf2 in (79,80,82)
      | dr_cf3 in (79,80,82) | dr_cf4 in (79,80,82) then cat2=4;
  else if dr_cf1_p in (79,80,82) | dr_cf2_p in (79,80,82)
      | dr_cf3_p in (79,80,82) | dr_cf4_p in (79,80,82) then cat2=4;
  else if dr_cf1 in (81,83,86) | dr_cf2 in (81,83,86)
      | dr_cf3 in (81,83,86) | dr_cf4 in (81,83,86) then cat2=5;
  else if dr_cf1_p in (81,83,86) | dr_cf2_p in (81,83,86)
      | dr_cf3_p in (81,83,86) | dr_cf4_p in (81,83,86) then cat2=5;
  else if avoid in (4,5) | avoid_p in (4,5) then cat2=5;
  else if (1 le body_typ le 49) & impact1 in (1,11,12) then cat2=8;
  else if (1 le body_typ_p le 49) & impact1_p in (1,11,12) then cat2=8;
  else cat2=7;
end;
```

Break out single-driver crashes:

```
Cat22 1='Off roadway' 3='More than 2 vehicles' 4='Vehicle/road problem'
      5='Avoidance' 6='Non-Collision' 7='Non-PV' 8='Relevant';

if crash_type=5 then do;                  /* further breakdown of single-driver crashes */
  if rel_road ne 1 then cat22=1;
  else if dr_cf1 in (79,80,82) | dr_cf2 in (79,80,82)
      | dr_cf3 in (79,80,82) | dr_cf4 in (79,80,82) then cat22=4;
  else if dr_cf1_p in (79,80,82) | dr_cf2_p in (79,80,82)
      | dr_cf3_p in (79,80,82) | dr_cf4_p in (79,80,82) then cat22=4;
  else if harm_ev in (1,2,3,4,5,6,7,16,44,47,51,60) then cat22=6;
  else cat22=8;

Cat4 1='On-road' 2='ROR Vehicle/road problem' 3='ROR Object in path'
     4='ROR Loss of control' 5='ROR Out of lane' 6='ROR Other/Unknown';

  if rel_road=1 then cat4=1;
  else if dr_cf1 in (79,80,82) | dr_cf2 in (79,80,82)
      | dr_cf3 in (79,80,82) | dr_cf4 in (79,80,82) then cat4=2;
  else if dr_cf1 in (81,83,84,85,86) | dr_cf2 in (81,83,84,85,86)
      | dr_cf3 in (81,83,84,85,86) | dr_cf4 in (81,83,84,85,86) then cat4=3;
  else if avoid in (4,5) then cat4=3;
  else if harm_ev in (8,9,11) then cat4=3;
  else if dr_cf1 in (1,6,28) | dr_cf2 in (1,6,28) | dr_cf3 in (1,6,28)
      | dr_cf4 in (1,6,28) then cat4=5;
  else if dr_cf1 in (8,17,36,58,77,78,87,88) | dr_cf2 in (8,17,36,58,77,78,87,88)
     | dr_cf3 in (8,17,36,58,77,78,87,88) | dr_cf4 in (8,17,36,58,77,78,87,88)
     then cat4=4;
  else cat4=6;
end;
```

Break out head-on crashes:

```
Cat5 1='More than 2 vehicles' 2='Vehicle/road problem' 3='Object in path'
     4='Non-PV' 5='Out of lane' 6='Other/Unknown';

if crash_type=6 then do;                        /* further breakdown of head-on crashes */
  if ve_forms gt 2 then cat5=1;
  else if dr_cf1 in (79,80,82) | dr_cf2 in (79,80,82)
      | dr_cf3 in (79,80,82) | dr_cf4 in (79,80,82) then cat5=2;
  else if dr_cf1_p in (79,80,82) | dr_cf2_p in (79,80,82)
      | dr_cf3_p in (79,80,82) | dr_cf4_p in (79,80,82) then cat5=2;
  else if dr_cf1 in (81,83,86) | dr_cf2 in (81,83,86)
      | dr_cf3 in (81,83,86) | dr_cf4 in (81,83,86) then cat5=3;
  else if dr_cf1_p in (81,83,86) | dr_cf2_p in (81,83,86)
      | dr_cf3_p in (81,83,86) | dr_cf4_p in (81,83,86) then cat5=3;
  else if avoid in (4,5) | avoid_p in (4,5) then cat5=3;
  else if dr_cf1 in (1,6,28) | dr_cf2 in (1,6,28) | dr_cf3 in (1,6,28)
      | dr_cf4 in (1,6,28) then cat5=5;
  else if dr_cf1_p in (1,6,28) | dr_cf2_p in (1,6,28) | dr_cf3_p in (1,6,28)
      | dr_cf4_p in (1,6,28) then cat5=5;
  else cat5=6;

if cat5=5 then do;               /* check that out of lane vehicle is passenger vehicle */
    if dr_cf1 in (1,6,28) | dr_cf2 in (1,6,28) | dr_cf3 in (1,6,28)
      | dr_cf4 in (1,6,28) then do;
      if (body_typ gt 49) then cat5=4;
    end;
    if dr_cf1_p in (1,6,28) | dr_cf2_p in (1,6,28) | dr_cf3_p in (1,6,28)
      | dr_cf4_p in (1,6,28) then do;
      if (body_typ_p gt 49) then cat5=4;
    end;
  end;
end;
```

Break out sideswipe same-direction crashes:

```
Cat6 1='More than 2 vehicles' 2='Vehicle/road problem' 3='Object in path'
     4='Non-PV' 5='Out of lane' 6='Other/Unknown';

if crash_type=8 then do;        /* further breakdown of sideswipe same-direction crashes */
  if ve_forms gt 2 then cat6=1;
  else if dr_cf1 in (79,80,82) | dr_cf2 in (79,80,82)
      | dr_cf3 in (79,80,82) | dr_cf4 in (79,80,82) then cat6=2;
  else if dr_cf1_p in (79,80,82) | dr_cf2_p in (79,80,82)
      | dr_cf3_p in (79,80,82) | dr_cf4_p in (79,80,82) then cat6=2;
  else if dr_cf1 in (81,83,86) | dr_cf2 in (81,83,86)
      | dr_cf3 in (81,83,86) | dr_cf4 in (81,83,86) then cat6=3;
  else if dr_cf1_p in (81,83,86) | dr_cf2_p in (81,83,86)
      | dr_cf3_p in (81,83,86) | dr_cf4_p in (81,83,86) then cat6=3;
  else if avoid in (4,5) | avoid_p in (4,5) then cat6=3;
  else if dr_cf1 in (1,6,28) | dr_cf2 in (1,6,28) | dr_cf3 in (1,6,28)
      | dr_cf4 in (1,6,28) then cat6=5;
  else if dr_cf1_p in (1,6,28) | dr_cf2_p in (1,6,28) | dr_cf3_p in (1,6,28)
      | dr_cf4_p in (1,6,28) then cat6=5;
  else cat6=6;

if cat6=5 then do;               /* check that out of lane vehicle is passenger vehicle */
    if dr_cf1 in (1,6,28) | dr_cf2 in (1,6,28) | dr_cf3 in (1,6,28)
      | dr_cf4 in (1,6,28) then do;
      if (body_typ gt 49) then cat6=4;
    end;
    if dr_cf1_p in (1,6,28) | dr_cf2_p in (1,6,28) | dr_cf3_p in (1,6,28)
      | dr_cf4_p in (1,6,28) then do;
      if (body_typ_p gt 49) then cat6=4;
    end;
  end;
end;
```

Break out sideswipe opposite-direction crashes:

```
Cat7 1='More than 2 vehicles' 2='Vehicle/road problem' 3='Object in path'
     4='Non-PV' 5='Out of lane' 6='Other/Unknown';

if crash_type=9 then do;         /* further breakdown of sideswipe opposite-dir crashes */
  if ve_forms gt 2 then cat7=1;
  else if dr_cf1 in (79,80,82) | dr_cf2 in (79,80,82)
      | dr_cf3 in (79,80,82) | dr_cf4 in (79,80,82) then cat7=2;
  else if dr_cf1_p in (79,80,82) | dr_cf2_p in (79,80,82)
      | dr_cf3_p in (79,80,82) | dr_cf4_p in (79,80,82) then cat7=2;
  else if dr_cf1 in (81,83,86) | dr_cf2 in (81,83,86)
      | dr_cf3 in (81,83,86) | dr_cf4 in (81,83,86) then cat7=3;
  else if dr_cf1_p in (81,83,86) | dr_cf2_p in (81,83,86)
      | dr_cf3_p in (81,83,86) | dr_cf4_p in (81,83,86) then cat7=3;
  else if avoid in (4,5) | avoid_p in (4,5) then cat7=3;
  else if dr_cf1 in (1,6,28) | dr_cf2 in (1,6,28) | dr_cf3 in (1,6,28)
      | dr_cf4 in (1,6,28) then cat7=5;
  else if dr_cf1_p in (1,6,28) | dr_cf2_p in (1,6,28) | dr_cf3_p in (1,6,28)
      | dr_cf4_p in (1,6,28) then cat7=5;
  else cat7=6;

if cat7=5 then do;               /* check that out of lane vehicle is passenger vehicle */
    if dr_cf1 in (1,6,28) | dr_cf2 in (1,6,28) | dr_cf3 in (1,6,28)
      | dr_cf4 in (1,6,28) then do;
      if (body_typ gt 49) then cat7=4;
    end;
    if dr_cf1_p in (1,6,28) | dr_cf2_p in (1,6,28) | dr_cf3_p in (1,6,28)
      | dr_cf4_p in (1,6,28) then do;
      if (body_typ_p gt 49) then cat7=4;
    end;
  end;
end;
```