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16. Abstract

This report documents an approach used to establish crash populations (or target crash populations) for five groups of collision avoidance technologies in passenger vehicles: (1) forward collision prevention, (2) lane keeping, (3) blind zone detection, (4) forward pedestrian impact, and (5) backing collision avoidance. These technologies, categorized as SAE Level 0–1 driving automation systems have been increasingly offered by vehicle manufacturers under a variety of marketing terminologies. Passenger vehicles defined here include cars, cross-overs, SUVs, light trucks and vans with gross vehicle weight ratings (GVWR) 10,000 lbs and under.

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GLOSSARY

AAAM	Association for the Advancement of Automotive Medicine
AEB	automatic emergency braking
AIS	Abbreviated Injury Scale
BSD	blind spot detection
BSI	blind spot intervention
CDS	Crashworthiness Data System
CIB	crash imminent braking
CPI	Consumer Price Index
CRSS	Crash Report Sampling System
DBS	dynamic brake support
ECI	Employment Cost Index
FCW	forward collision warning
EMS	emergency medical services
FARS	Fatality Analysis Reporting System
GES	General Estimates System
GVWR	gross vehicle weight rating
IIHS	Insurance Institute for Highway Safety
LCA	lane centering assist
LCC	lane centering control
LCM	change/merge warning
LDW	lane departure warning
LKA	lane keeping assist
LTV	light truck and van
LV	lead vehicle
MAIS	Maximum Abbreviated Injury Scale
MOU	Memorandum of Understanding
NASS	National Accident Sampling System
NCAP	New Car Assessment Program
NCSA	National Center for Statistics and Analysis
OD	opposite direction
PAEB	pedestrian automatic emergency braking
PDOVs	property-damage-only vehicles
PVs	passenger vehicles
QALYs	quality adjusted life years

RAB	rear automatic braking
RCTA	rear cross traffic alert
RD	roadway departure
RvAB	reverse automatic braking
SAE	Society of Automotive Engineers
SAS	Statistical Analysis System
SOE	sequence of events
Volpe	Volpe National Transportation Systems Center
VSL	value of statistical life

1 EXECUTIVE SUMMARY

This report documents an approach used to establish crash populations (or target crash populations) for five groups of collision avoidance technologies in passenger vehicles: (1) forward collision prevention, (2) lane keeping, (3) blind zone detection, (4) forward pedestrian impact, and (5) backing collision avoidance. These technologies, categorized as SAE[1] Level 0–1 driving automation systems,[2] have been increasingly offered by vehicle manufacturers under a variety of marketing terminologies. Passenger vehicles defined here include cars, cross-overs, SUVs, and light trucks and vans with gross vehicle weight ratings 10,000 lbs and under.

(1) Forward collision prevention technologies generally include three safety systems: forward collision warning, crash imminent braking, and dynamic brake support. Together, CIB and DBS systems also are commonly referred to as “automatic emergency braking.”

(2) Lane keeping technologies include lane departure warning, lane keeping assist, and lane centering assist.[3]

(3) Blind zone detection technologies broadly include blind spot detection, blind spot intervention, and lane change/merge warning.

(4) Forward pedestrian impact avoidance technologies primarily include pedestrian automatic emergency braking.

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[1] Society of Automotive Engineers, known as SAE International since 2006; its standards retain the SAE name.

[2] SAE J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles:
Level 0: No Automation. The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.
Level 1: Driver Assistance. The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
Level 2: Partial Automation. The driving mode-specific execution by one or more driver assistance systems of both steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.
Level 3: Conditional Automation. The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.
Level 4: High Automation. The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.
Level 5: Full Automation. The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.

[3] Has also been referred to as lane centering control.

(5) Backing crash avoidance technologies are branded as various systems such as rear automatic braking, reverse automatic braking, and rear cross traffic alert.[4]

Of these technologies, NHTSA's New Car Assessment Program has recommended FCW, AIB, DBS, and LDW that meet NHTSA's performance specifications.[5] Table 1-1 tabulates the safety systems by the five technology groups.

Table 1-1
Safety Systems of Interest by Technology Groups

	Collision Avoidance Technology Groups	Safety Systems
1	Forward Collision Prevention	FCW, CIB, DBS
2	Lane Keeping	LDW, LKA, LCA
3	Blind Zone Detection	BSD, BSI, LCM
4	Forward Pedestrian Impact	PAEB
5	Backing	RAB, RvAB, RCTA

The target crash population includes police-reported crashes, fatalities, non-fatal injuries, and property-damage-only vehicles. PDOVs are vehicles damaged in non-injury-producing crashes (i.e., crashes in which vehicles only incur property damage and no occupants incur injury). In addition, we also provided societal costs of crashes in the report. The societal costs were measured by comprehensive value, which includes the costs from medical care, rehabilitation, emergency medical services,[6] insurance administration, workplace productivity, legal and court, congestion,[7] property damage, lost productivity, and the nontangible value of physical pain and loss of quality of life (i.e., quality adjusted life years). All societal costs are presented in 2017 dollars. Non-fatal injuries are presented using the MAIS 0-5 scale.[8]

1.1 Data

Real-World Crash Data. The primary real-world data sources included 2011 to 2015 Fatality Analysis Reporting System and National Automotive Sampling System General Estimates

[4] Might also be bundled with blind spot detection systems.

[5] The rearview video system is not included because NHTSA requires this life-saving technology on all new vehicles from May 2018. www.nhtsa.gov/ratings

[6] Including medical, police, and fire services.

[7] Including travel delay, added fuel usage, and adverse environmental affects cost.

[8] The Abbreviated Injury Scale is a classification system for assessing impact injury severity developed and published by the Association for the Advancement of Automotive Medicine and is used for coding single injuries, assessing multiple injuries, or for assessing cumulative effects of more than one injury. AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable). MAIS represents the maximum injury severity of an occupant at an AIS level, i.e., the highest single AIS for a person with one or more injuries. MAIS 0 means no injury.

System. Both GES and FARS record policed-reported crashes on U.S. roadways. The combination of fatal crashes from FARS and non-fatal crashes from GES formed the basis for each target population.

Economic Data. The comprehensive unit costs that NHTSA published in 2015 (Blincoe, Miller, Zaloshnja, & Lawrence, 2015) were used for estimating societal costs from vehicle crashes. Comprehensive unit costs are on a per-person basis for fatalities and MAIS 0-5 injuries and per PDOV basis for property-damage-only crashes.

1.2 Approach

The approach follows the pre-crash typology concept that was developed by the Volpe National Transportation Systems Center. The concept is to categorize crashes into mutually exclusive and dynamically distinct scenarios based on vehicle movements and critical events occurring immediately prior to the crash (Swanson, Foderaro, Yanagisawa, Najm, & Azeredo, in press; Najm, Sen, Smith, & Campbell, 2003; Najm, Smith, & Yanagisawa, 2007; Najm et al., 2013). Based on this concept, a total of 84 mutually exclusive crash scenarios were established, each with the associated fatalities, MAIS 0-5 injuries, PDOVs, and societal cost estimates. Then, the crash scenarios were mapped with safety systems of interest to form the corresponding target population. Fatalities, injuries, PDOVs, and societal costs are collectively referred to as crash statistics, hereafter.

The target crashes were limited to crashes involving at least one PV (i.e., PV crashes). Considering that the safety systems of interest were designed to be activated by the dynamic movement of the technology-equipped vehicle, the target crashes were further limited to PV crashes where a PV initiated the first sequence of events or the critical event/movement. The corresponding crash statistics were the combined results of fatal crashes from FARS and non-fatal crashes from GES. In other words, fatalities were from FARS, whereas MAIS 0-5 injuries were from those in fatal crashes in FARS and those in non-fatal injury crashes in GES. PDOVs were from property-damage-only crashes in GES.

The target populations established for a particular group of technologies represent the crash populations that this group of avoidance safety systems are intended to eliminate or reduce. Therefore, these target populations were not refined to consider the variations in their component implementations (e.g., sensor quality, sensor types) or in system operational design characteristics (e.g., activation speeds, alarm types). Thus, these populations also can be considered as “normalized target populations” for assessing effectiveness across the safety systems within a group of technologies.

1.3 Results

1.3.1 Crash Population – National Level

Table 1-2 lists background crash statistics for all crashes, all PV crashes, and all target crashes at the national level. As explained before, PV crashes are crashes involved at least one PV. Target crashes are crashes where a PV initiated the first SOE or critical event/movement. Note that these databases represent police-reported crashes only. A substantial number of crashes primarily at lower severity levels were not included in the police records (Blincoe, Miller, Zaloshnja, & Lawrence, 2015).

All Crashes. From 2011 to 2015, on average, 5.80 million crashes occurred in the United States annually. These crashes resulted in 33,477 fatalities, 2.81 million MAIS 1-5 injuries, and 7.28 million PDOVs. The annual average societal cost from these crashes is estimated to be $763 billion.

All PV Crashes. There were 5.64 million PV crashes annually, about 97 percent of all crashes. These PV crashes were associated with 29,170 fatalities (87% of all fatalities), 2.73 million MAIS 1-5 injuries (97% of all injuries), and 7.17 million PDOVs (98% of all PDOVs). In all, these PV crashes resulted in a $704 billion societal loss annually (92% of all societal loss).

All Target Crashes. There was an average of 5.45 million target crashes annually, about 94 percent of all crashes. A total of 26,558 fatalities (79% of all fatalities) and 2.63 million MAIS 1-5 injuries (94% of all MAIS 1-5 injuries). In addition, 6.68 million PDOVs (92% of all PDOVs) were resulting from these crashes. These crashes caused a $661 billion societal loss annually (87% of all societal loss).

Table 1-2
Average Annual Crash Statistics From 2011 to 2015

	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
All Crashes	5.80 M	33,477	2.81 M	7.28 M	$762.74 B
All PV Crashes	5.64 M	29,170	2.73 M	7.17 M	$703.90 B
All Target Crashes	5.45 M	26,558	2.63 M	6.89 M	$660.82 B

PDOVs: property-damage-only vehicles; M: Million, B: Billion
Source: 2011 to 2015 FARS and GES

1.3.2 Target Population by Technologies

Table 1-3 summarizes the crash statistics of annual target populations grouped by the previously discussed technologies over the 5-year period from 2011 to 2015. The percentage shown in the table represents the frequency of a specific incidence to the incidence of national level.

Group 1, Forward Collision - FCW/CIB/DBS. Annually, each safety system in this group would affect an average of 1.70 million policed-reported front-to-rear (or rear-end) crashes. These crashes represented 29.4 percent of all policed-reported crashes that occurred in the United States. Consequently, these safety systems would affect 1,275 fatalities (3.8% of all fatalities), 883,386 MAIS 1-5 injuries (31.5% of all MAIS 1-5 injuries) and 2.6 million PDOVs (36.3% of all PDOVs). In terms of economic values, these safety systems would eliminate a portion of the estimated $132.4 billion (17.4% of all societal costs) societal costs associated with front-to-rear crashes.

Group 2, Lane Keeping - LDW/LKA/LCA. Each system in this technology group would affect 1.13 million (19.4% of all crashes) lane departure (type) crashes annually. These crashes resulted in 14,844 fatalities (44.3%), 0.48 million MAIS 1-5 injuries (17.1%), and 0.86 million PDOVs (11.9%) annually. Further, these crashes were estimated to cost society $232.2 billion (30.4%) annually.

Group 3, Blind Zone Detection - BSW/BSI/LCM. Each system would affect 0.50 million (8.7%) blind zone/lane change merger related crashes annually. These crashes resulted in 542 fatalities (1.6%) and 0.19 million MAIS 1-5 injuries (6.7%). In addition, there were 0.86 million PDOVs (11.8%) associated with the crashes. In total, these cashes would cost society $31.7 billion (4.2%) annually.

Group 4, Pedestrian Forward Impact - PAEB. Pedestrian automatic emergency braking can affect 0.11 million (1.9%) pedestrian/cyclist crashes annually. These crashes resulted in 4,106 pedestrian/cyclist fatalities (12.3%) and 0.10 million MAIS 1-5 injuries (3.7%). The crashes resulted in an annual average of $61.3 billion (8.0%) to society.

Group 5, Backing - RAB/RvAB/RCTA. Each of the safety systems in this group can affect 0.15 million backing crashes (2.6% of all crashes) annually. These crashes resulted in 74 fatalities (0.2%) and 0.04 million MAIS 1-5 injuries (1.3%). The cashes were estimated to cost society $5.6 billion (0.7%) annually.

Table 1-3
Summary of Target Crashes by Technology Group

	Safety Systems	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
1	FCW/DBS/CIB	1,703,541 29.4%	1,275 3.8%	883,386 31.5%	2,641,884 36.3%	$132.45 B 17.4%
2	LDW /LKA/LCA	1,126,397 19.4%	14,844 44.3%	479,939 17.1%	863,213 11.9%	$232.17 B 30.4%
3	BSW/BSI/LCM	503,070 8.7%	542 1.6%	188,304 6.7%	860,726 11.8%	$31.72 B 4.2%
4	PAEB	111,641 1.9%	4,106 12.3%	104,066 3.7%	6,985 0.1%	$61.29 B 8.0%
5	RAB/RvAB/RCTA	148,533 2.6%	74 0.2%	35,268 1.3%	231,317 3.2%	$5.63 B 0.7%
	Combined	3,593,182 62.0%	20,841 62.2%	1,690,963 60.3%	4,604,125 63.3%	$463.26 B 60.7%

PDOVs: property-damage-only vehicles; B: Billion
Source: 2011 to 2015 FARS and GES

2 INTRODUCTION

The analysis establishes a target crash population for each of five collision avoidance technologies in PVs: (1) forward collision prevention, (2) lane keeping, (3) blind zone detection, (4) forward pedestrian impact, and (5) backing collision avoidance. These technologies, categorized as SAE Level 0–1 driving automation systems,[9] have been increasingly offered by vehicle manufacturers under a variety of marketing terminologies. Forward collision prevention technologies, generally, but not comprehensively, include three safety systems: forward collision warning, crash imminent braking and dynamic brake support . CIB and DBS systems also are commonly branded under "emergency brake assist" or "automatic braking system." Lane keeping technologies include lane departure warning, lane keep assist and lane centering assist.[10] Blind zone detection technologies include blind spot detection, blind spot intervention, and lane change/merge warning. Forward pedestrian impact avoidance technologies primarily include PAEB. Backing crash avoidance technologies include rear automatic braking, reverse automatic braking, and rear cross traffic alert[11] in this analysis. Of these crash avoidance technologies, NHTSA's New Car Assessment Program has recommended FCW, AEB, DBS, and LDW that meet NHTSA's performance specifications.[12] PVs defined here include cars, cross overs, SUVs, and light trucks and vans with GVWRs 10,000 lbs and under. Table 2-1 summarizes the safety systems by the five technology groups.

Table 2-1
Safety Systems of Interest by Technology Groups

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5	Backing	RAB, RvAB, RCTA

Each target population represents a crash population that a particular group of crash avoidance technologies is designed to eliminate or reduce. These target populations can also be considered as "normalized target populations" for assessing effectiveness for each safety system within a group of technologies. For example, FCW, CIB, and DBS have all been designed for assisting drivers to prevent front-to-rear (i.e., rear-end) crashes. These three systems share

[9] SAE J3016, see footnote 1.

[10] Has also been referred as lane centering control.

[11] RTCA might also be bundled with blind spot detection technologies.

[12] www.nhtsa.gov/ratings. The rearview video system is not included because NHTSA requires this life-saving technology on all new vehicles from May 2018.

the same target population in this analysis even though they are technologically different systems. Likewise, all systems within a technology group share identical target population.

2.1 Technologies of Interest

This section briefly describes the safety systems for each group of technologies.

2.1.1 Group 1, Forward Collision Prevention[13]

Forward Collision Warning. FCW uses radar, camera and/or lidar-based sensors to monitor the distance between the subject vehicle and a vehicle or an object ahead in its forward path. If a frontal collision with a slower moving or stationary vehicle is imminent, an FCW alert is presented to the driver of the subject vehicle with an audible, haptic (touch), and/or visual cue warning. The timing of the FCW alert is intended to provide the driver with enough time to response quickly, thereby preventing a crash.

Crash Imminent Braking. CIB systems are intended to actively assist drivers by mitigating the impact of rear-end collisions. These safety systems have forward-looking vehicle detection capability provided by sensing technologies such as radar, lidar, video cameras, etc. CIB systems mitigate crash severity by automatically applying the vehicle's brakes shortly before the expected impact (i.e., without requiring the driver to apply force to the brake pedal).

Dynamic Brake Support. DBS is a technology that actively increases the amount of braking during rear-end crash avoidance maneuvers. If the driver has applied force to the brake pedal, DBS uses forward-looking sensor data from radar, lidar, video cameras, etc., to assess the potential for a rear-end crash. Should DBS ascertain a crash is likely (i.e., the sensor data indicate the driver has not applied enough braking to avoid the crash), DBS automatically intervenes. Although how DBS is implemented differs among vehicle manufacturers, the objective is largely the same: to supplement the driver's commanded brake input by increasing the output of the foundation brake system. In some situations, the increased braking provided by DBS may allow drivers to avoid crashes. In other cases, DBS interventions mitigate crash severity.

Both CIB and DBS are also branded together under the term "automatic emergency braking.". Based on the evidence that AEB effectively reduced crashes and injuries, NHTSA and the Insurance Institute for Highway Safety issued a challenge to the industry in September 2015 to encourage automakers to voluntarily make AEB a standard feature. On September 11, 2015, NHTSA and IIHS announced that 10 major automakers[14] had committed to making AEB a

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[13] For NCAP description of the technologies, see www.nhtsa.gov/equipment/driver-assistance-technologies#forward-collision-prevention-30631

[14] Audi, BMW, Ford, General Motors, Mazda, Mercedes-Benz, Tesla, Toyota, Volkswagen, and Volvo.

standard feature on all new vehicles.[15] On March 17, 2016, in a Memorandum of Understanding with NHTSA and IIHS, the number of manufacturers increased to 20.[16] These 20 manufacturers had agreed to commit to making AEB standard equipment on all new light-duty cars and trucks with GVWRs of 8,500 lbs or less no later than September 1, 2022, and on virtually all trucks with GVWRs from 8,501 to 10,000 lbs no later than September 1, 2025.[17] In December 2016, NHTSA recommended AEB systems (i.e., CIB and DBS) that meet NCAP performance criteria[18] to consumers on the main NHTSA web site.[19]

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[15] www.iihs.org/iihs/news/desktopnews/u-s-dot-and-iihs-announce-historic-commitment-from-10-automakers-to-include-automatic-emergency-braking-on-all-new-vehicles

[16] Audi, BMW, FCA US LLC, Ford, General Motors, Honda, Hyundai, Jaguar Land Rover, Kia, Maserati, Mazda, Mercedes-Benz, Mitsubishi Motors, Nissan, Porsche, Subaru, Tesla Motors Inc., Toyota, Volkswagen, and Volvo Car USA.

[17] www.iihs.org/iihs/news/desktopnews/u-s-dot-and-iihs-announce-historic-commitment-of-20-automakers-to-make-automatic-emergency-braking-standard-on-new-vehicles

[18] NCAP performance criteria for AEB (i.e., CIB and DBS) deviates from the criteria OEMs agreed to in the 2016 MOU.

[19] www.nhtsa.gov/equipment/driver-assistance-technologies#aeb

2.1.2 Group 2, Lane Keeping[20]

Lane Departure Warning. LDW systems rely on camera-based sensors to calculate the path of vehicles. If the system determines a lane departure is imminent, and the driver has not activated the turn signal or made a control input indicating the lane departure is intentional (e.g., acceleration above a certain threshold), an LDW alert is presented.

Lane Keeping Assist. Whereas an LDW system passively warns the driver that a lane departure is imminent, an LKA system automatically provides active interventions designed to automatically bring the vehicle back into the lane it is currently traveling using automated steering and/or differential braking. LKA interventions are suppressed when the turn signal is activated or the makes a control input indicating the lane departure is intentional.

Lane Centering Assist. LCA systems are designed to help provide heading corrections to keep a driver's vehicle in the center of its travel lane. Like LDW and LKA, LCA systems use camera-based sensors to assess the position of the vehicle in its lane. This information is compared to a predicted path, and steering-based inputs are automatically used to make the heading corrections required to maintain the desired lane position. Like LKA, LCA interventions are suppressed when the turn signal is activated or when a driver makes an intentional lane change without using the turn signal (provided the driver provides sufficient torque to the steering wheel).

2.1.3 Group 3, Blind Zone Detection

The analysis considered two safety systems in this group:

Blind Spot Detection. BSD is a warning-based technology designed to help the driver recognize that another vehicle is approaching or being operated in the blind zone of the vehicle in an adjacent lane. Should the driver initiate a lane change towards this other vehicle, BSD presents an alert before a collision is expected to occur. Depending on the implementation, BSD activation may or may not require the driver to activate a turn signal during lane change. BSD systems typically use radar and/or ultrasonic-based sensors. Note that BSD systems are rear-to-side-facing, and do nothing to help visual obstruction imposed by A-pillars.[21]

Blind Spot Intervention. BSI is an intervention designed to actively help the driver avoid a collision with another vehicle approaching or in the blind spot in an adjacent lane. BSI activation

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[20] For NCAP's description of this group of technologies, see www.nhtsa.gov/equipment/driver-assistance-technologies#lane-side-assist-30676

[21] For NCAP's description of this technology, see www.nhtsa.gov/equipment/driver-assistance-technologies#lane-side-assist-30676. Also see https://www.regulations.gov/document?D=NHTSA-2018-0027-0003

may or may not require the driver to activate a turn signal during lane change. It is anticipated some BSI systems may only operate if the vehicle's BSD is also enabled.[22]

Lane Change Merge. LCM includes lane change merge aids, lane change/merge assist, and lane change merge warning systems. These systems are designed to assist drivers who are intentionally changing lanes by detecting vehicles located in the driver's blind spot.

2.1.4 Group 4, Forward Pedestrian Impact Avoidance

In this group, the analysis considered one safety system, pedestrian automatic emergency braking.[23] PAEB uses radar, camera, and/or lidar to detect a pedestrian and assesses the risk of the pedestrian being struck by the vehicle. When the situation becomes critical, PAEB alerts the driver and applies brakes automatically to mitigate or even avoid the crash. Due to the automatic brake functionality, PAEB can be considered a type of AEB technology.

2.1.5 Group 5, Backing Collision Avoidance

The analysis considered rear automatic braking, reverse automatic braking, and systems that combine rear cross traffic alert and rear emergency braking.[24] These systems are comprised of radar-, camera-, or sonar- based technologies and provide audible alerts first when an object is detected in a specified area behind the vehicle and approaching laterally on a path perpendicular to the path of the RAB-equipped backing vehicle outside the width of the rear end of a car. When a collision is imminent, the system will reduce engine power. If the driver fails to apply brakes, the system will apply the vehicle's service brakes and instructs the driver to apply brakes to keep the vehicle from rolling away. Some systems will activate the parking brake if the driver does not depress the brake pedal. The system disengages when the driver presses the brake pedal or accelerator pedal.

2.2 Technologies Adoption Rates

Although this analysis focuses on target crash populations applicable to the noted crash avoidance technologies, we also present historic adoption rates since they are critical to determine target populations adjusted with the adoption rates for benefit estimates including either the overall benefit (i.e., from 0 to 100% adoption) or incremental benefit (i.e., from a certain level of adoption rate to 100%).[25] Table 2-2 lists the adoption rates for these systems

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[22] www.regulations.gov/document?D=NHTSA-2018-0027-0003

[23] For NCAP's description of these technologies, see www.nhtsa.gov/equipment/driver-assistance-technologies#forward-collision-prevention-30631

[24] For NCAP's description of the technology, see www.nhtsa.gov/equipment/driver-assistance-technologies#backing-parking-30656

[25] As we understand, real-world crashes are the residual outcome that excluded the collective impact of all technologies that were adopted during the crash period. To derive the appropriate benefits, the initial target

from 2013 to 2018. These adoption rates are based on the crash avoidance warning systems reported in the regular data submissions associated with NCAP. As shown, these safety systems have increasingly been offered by manufacturers of light vehicles. Specifically, adoption rates for CIB and DBS are almost doubled for each model year from the 2016 to 2018 model years. The CIB adoption rate increased from 6.6 percent in 2016 to 42.0 percent in 2018 while DBS increased from 7.6 percent to 35 percent. The rapid increase in the installation rate for these two safety systems could be attributed to several factors: (a) the maturity of AEB, (b) the 2016 MOU that was agreed by 20 manufacturers with NHTSA and IIHS, and (c) NCAP added AEB to the list of recommended technologies in December 2016. On December 21, 2017, the first NHTSA and IIHS update on manufacturer progress on AEB showed that 4 automakers reported that AEB is standard on more than half of their 2017 model year vehicles. Another 5 automakers reported that more than 30 percent of their 2017 vehicles were equipped with AEB.[26] LDW, LKS, BSD, and PAEB adoption rates also increased significantly for 2017 and 2018 model year vehicles. Since RAB is an emerging technology, its adoption rate is extremely low.

Table 2-2
Reported Percentage of Adoption Rates

Year	FCW	CIB	DBS	LDW	LKS	BSD	PAEB	RAB
2013	0.2%	1.6%	1.6%	0.2%	0.0%	3.2%	0.2%	
2014	8.1%	3.6%	3.5%	5.6%	0.1%	9.0%	0.1%	
2015	11.8%	6.3%	3.8%	10.4%	1.0%	14.6%	1.0%	0.0%
2016	13.1%	6.6%	7.6%	10.2%	4.1%	17.0%	13.4%	0.0%
2017	24.3%	21.1%	15.8%	27.3%	16.2%	34.1%	14.9%	0.0%
2018	38.3%	42.0%	35.0%	30.1%	23.8%	30.7%	25.6%	0.1%

* Reported in response to NHTSA's Annual Technology Adaptation Survey and includes optional equipment
Note: The LCA adoption rate was not reported since it is extremely rare.

population might need to be adjusted to account for the fact that some of these crashes already had involved vehicles with the technologies of interest. In the absence of technology identifiable information in real-world crash databases such as FARS and GES, historical adoption rates can be used to approximate the adoption rate for target population adjustment.

[26] NHTSA-IIHS Announcement on AEB, www.nhtsa.gov/press-releases/nhtsa-iihs-announcement-aeb

2.3 Organization of the Remaining Analysis

The following outlines the remaining structure of this document. Chapter 3 details the approach of establishing the target population for the safety systems of interest. Chapter 4 presents the background crash statistics and target crash results. Chapter 4 is followed by References and several Appendices, which show detailed crash scenario definitions and supplemental information. Appendix A provides the comprehensive unit costs for economic value calculations. Appendix B lists the definition for each crash scenario. Appendix C describes the conversion from the police-reported KABCO[27] scale to MAIS scale. Appendix D shows the mapping of crash scenarios to safety systems. Appendix E provides crash statistics for each crash scenario.

[27] K: killed, A: incapacitating injury, B: non-incapacitating injury, C: possible injury, and O: no injury, U: Unknown, if Injured

3 ANALYSIS APPROACH

The analysis follows the pre-crash typology concept developed by Volpe to categorize real-word crashes into mutually exclusive and dynamically distinct crash scenarios. The categorization of crash scenarios is based on vehicle movements and critical events occurring immediately prior to the crash (Swanson, Foderaro, Yanagisawa, Najm, & Azeredo, in press; Najm, Sen, Smith, & Campbell, 2003; Najm, Smith, & Yanagisawa, 2007; Najm et al., 2013). Overall, this analysis established 84 mutually exclusive crash scenarios and provided crash statistics (i.e., the number of crashes and the associated fatalities, non-fatal injuries, PDOVs, and societal cost estimates) for each of these scenarios. Then, crash scenarios were mapped with safety systems of interest to derive the target population for these technologies.

Of the crash statistics, non-fatal injuries were represented by MAIS injury scale.[28] PDOVs represent vehicles that were damaged in non-injury producing crashes (i.e., property-damage-only crashes). Societal costs are monetized values of the fatalities, non-fatal Injuries, non-injured persons in injury crashes, and PDOVs. In the analysis, the monetized values were measured by comprehensive values which include the costs from medical care, emergency services, insurance administration, workplace, legal and court services, congestion, property damage, lost productivity, and the nontangible value of physical pain and the loss of quality of life (measuring by QALYs) (Blincoe, Miller, Zaloshnja, & Lawrence, 2015). All societal costs are presented in 2017 dollars.

The analysis is focused on those technologies in PVs. Therefore, the target crashes were crashes involving at least one PV (i.e., PV crashes). Given that the safety systems of interest are designed to be activated by a certain movement from the technology-equipped vehicle or by the interaction between this vehicle with other vehicles/road users, target crashes were further limited to PV crashes where a PV initiated the first sequence of event or the critical event. The following sections detail the process used to establish crash scenarios and target population starting with a data section. The data section is then sequentially followed by these sections: data variables that were used to define crash scenarios, crash scenario definitions, KABCO-to-MAIS conversion, societal cost calculation, and, finally, mapping of crash scenarios with safety systems. The Crash Result chapter presents all crash statistics for each scenario and the target population for the safety systems of interest.

[28] The Abbreviated Injury Scale is a classification system for assessing impact injury severity developed and published by the Association for the Advancement of Automotive Medicine and is used for coding single injuries, assessing multiple injuries or for assessing cumulative effects of more than one injury. AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable). MAIS represents the maximum injury severity of an occupant at an AIS level, i.e., the highest single AIS for a person with one or more injuries.

3.1 Data

This analysis primarily used two types of data: policed-reported, real-world crash data and economic data. Real-world crashes were the base for deriving crash population while economic data, as the name implies, were the basis for calculating the societal costs.

3.1.1 Real-World Crash data

The analysis used 2011-2015 FARS and GES to establish the crash scenarios and target populations. NHTSA's National Center for Statistics and Analysis establishes and maintains these databases in SAS software format.[29] FARS is a census of fatal crashes that occurred on U.S. public roadways (NHTSA, 2016c) while GES is a nationally representative sample of police-reported crashes (NHTSA, 2016b) containing crashes from the least severe "property-damage-only" crashes to fatal crashes. Historically, GES has consistently underestimated fatalities.[30] Therefore, the combination of fatal crashes in FARS and non-fatal crashes in GES formed the basis of crashes for analysis. In other words, fatalities, by design, were from FARS. Non-fatal MAIS 0-5 injuries included those in fatal crashes from FARS and those in non-fatal crashes from GES. PDOVs were from GES.

Note the 2015 data is not the most currently available real-world crash data. GES was transitioned into the newly modernized Crash Report Sampling System in 2016 (NHTSA, 2016a; Zhang, Subramanian, Chen, & Noh, 2018; NHTSA, 2018). The 2016 CRSS was released on March 30, 2018. Due to the lack of time to examine CRSS, we decided not to extend crash data to include 2016 CRSS. FARS data from the same years is used for consistency.

3.1.2 Economic Data

Comprehensive costs were used to measure the societal costs of crashes. NHTSA periodically revises crash cost estimates. The most current update was published in a 2015 report (Blincoe, Miller, Zaloshnja, & Lawrence, 2015) and all costs were in 2010 dollars. The comprehensive unit costs in that report were the basis for societal cost estimates. In the report, comprehensive costs include the costs from medical care, rehabilitation costs, emergency services, insurance administration, workplace costs, legal and court costs, congestion, property damage, lost productivity, and the nontangible value of physical pain and lost quality of life (i.e., QALYs). Emergency service costs included those from medical, police, and fire services. Congestion costs included travel delay, added fuel usage, and adverse environmental impact cost.[31] These unit costs were expressed on a per-person basis for fatalities and all MAIS levels, and per PDOV. These unit costs were in 2010 economic values. In this analysis, these costs were revised to

[29] Statistical Analysis System developed by the SAS institute.

[30] Based on year-to-year direct comparison between GES and FARS up to 2015

[31] Environment impacts included the estimated reduction of greenhouse gas and pollutant emissions due to vehicle delay hours and added fuel consumption that resulted from congestion caused by crashes.

2017 values using the initial costs in 2010 dollars. Table 3-1, below, summarizes the comprehensive unit costs in 2017 dollars. (Appendix A lists the unit cost for all cost components and describes the process used to revise them from 2010 to 2017 values.)

Table 3-1
Comprehensive Unit Costs, 2017 Economic Value

PDOV	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	FATAL
$6,899	$4,972	$48,682	$458,986	$1,091,514	$2,675,603	$6,110,870	$9,926,772

3.2 Data Variables for Categorizing Crash Scenarios

SAS data variables describing vehicle characteristics were used to classify crash scenarios. These variables include a sequence of events (SAS variable in FARS: SOE, SAS variable in GES: SOE), a number of vehicle forms submitted (VE_FORMS), crash type (ACC_TYPE, ACC_TYPE), pre-event movement (P_CRASH1, PCRASH1_IM), pre-crash critical event (P_CRASH2), attempted avoidance maneuver (P_CRASH3), pre-impact stability (PCRASH4), and vehicle body type (BODY_TYPE, BDYTYP_I).[32] Table 3-2 lists the primary SAS variables in FARS and GES that were used to define each crash scenario. In addition, variables such as crash year, crash case number, vehicle numbers that were routinely functioned as "Key" for merging different files under the FARS and GES database umbrella are not listed here.

Table 3-2
Variables Used for Categorizing Crash Scenarios

ID	Description	FARS	GES
1	Sequence of Crash Event	SOE	SOE
2	Event Number	EVENTNUM	EVENTNUM
3	Number of Vehicle Forms Submitted	VE_FORMS	VE_FORMS
4	Accident Type	ACC_TYPE	ACC_TYPE
5	Pre-Event Movement	P_CRASH1	PCRASH1_IM
6	Critical Event – Precrash	P_CRASH2	P_CRASH2
7	Attempted Avoidance Maneuver	P_CRASH3	P_CRASH3
8	Pre-Impact Stability	PCRASH4	PCRASH4
9	Vehicle Body Type	BODY_TYPE	BDYTYP_I

Note that NHTSA started to harmonize FARS and GES in terms of data file structures, data variables, and attributes in 2010. This effort allows a standardized crash scenario definition to be established between FARS and GES using a similar set of variables. However, GES imputed certain police-reported variables to increase their utility. These imputed variables ending with either "_IM" or "_I". Variables ending with "_IM" were derived through a sequential regression

[32] Other variables such as vehicle speed, the object contacted, rollover status, driver distraction status, driver alcohol use, traffic control device, etc., can be used to refine the target populations when a clear system design (e.g., operational speed range) or limitations (e.g., activated by issuing turning signals) is available.

approach[33] where the covariates are selected automatically using stepwise regression (Shelton, 1993).[34] Variables ending with "_I" (e.g., BDYTYP_I) were derived through a univariate distribution approach where unknowns were directly distributed to known attributes proportionally to their sizes. Therefore, by choice, imputed variables in GES were used whenever available to define non-fatal crash scenarios.

3.3 Crash Scenario Definitions

Crashes are classified first by SOE into these top-level categories: first event rollover, jackknife, pedestrian, cyclist, animal, parked vehicle, other non-fixed object, other fixed object, ran-off-road, equipment failure, and remaining crashes. ACC_TYPE, P_CRASH1, P_CRASH2, and P_CRASH4 were used to refine these top-level crashes. In total, the analysis classified crashes into 84 mutually exclusive crash scenarios. Appendix B lists the 84 crash scenarios and their corresponding definitions. Each crash scenario came with an assigned number and description. Crash number serves as a convenient pointer. There is no specific rationale behind the numbering scheme.

3.4 KABCO to MAIS Conversion

FARS and GES only record policed-reported KABCO scale. To use the agency developed MAIS-based crash unit costs, KABCO injuries were translated into MAIS through a KABCO-MAIS translator. The establishment of the translator and the translation process have been well documented in many NHTSA's regulatory impact analyses.[35] Appendix C of this document repeats the description of this translation process.

3.5 Calculation of Societal Costs

Societal costs, as explained before, is the monetized value for each scenario and was measured by comprehensive values. With the compilation of fatalities, injures, and PDOVs for each scenario, societal costs can be derived by summing the multiplications of an individual comprehensive unit cost and its corresponding incidents over incident severity levels. The process can be expressed mathematically by the following formula:

[33] Beginning in 2010.

[34] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/807985

[35] Readers can access Regulations.gov for these analyses. An example is Preliminary Regulatory Impact Analysis for FMVSS No. 150, Vehicle-to-Vehicle Communication Technology for Light Vehicles.

$$SC = \sum_{i=0}^{7} U_i * N_i$$

Where, SC = Societal costs

U_i = Comprehensive unit cost for severity level i with 0: PDOV, 1: MAIS 0, … and 7: fatality.

N_i = incidents at severity i.

3.6 Mapping Crash Scenarios With Technologies of Interest

The matching of an individual scenario with the appropriate safety system(s) was based on our knowledge of these safety systems. This means that a target scenario was assigned to a safety system if the scenario could potentially be addressed by that system. Therefore, the variations in component implementations (e.g., sensor quality or sensor versus camera) or the operational design characteristics (e.g., activation speeds, alert algorithms, or strategies) were not considered in deriving the resulting target crashes. With this practice, all safety systems within a technology group would share identical crash scenarios and thus, target populations. For example, FCW, CIB, and DBS systems all were designed to address front-to-rear crashes as shown below, albeit with various degrees of applicability and effectiveness. Appendix D shows the mapping between crash scenarios and the safety systems of interest.

Example, Crash Scenarios that would be affected by FCW, CIB, or DBS:

2000 Rear-End, LV Stopped
2001 Rear-End, LV Slower
2002 Rear-End, LV Decelerated
2003 Rear-End, Other In-lane Vehicle With Higher Speed
2009 Rear-End, Other/Unspecified
2300 Rear-End Possible, Other In-lane Vehicle Stopped
2301 Rear-End Possible, Other In-lane Vehicle Slower
2302 Rear-End Possible, Other In-lane Vehicle Decelerated

Likewise, LDW, LKA, and LCA systems all would affect crashes where a PV veered off the road or crossed centerline. Preventing vehicles from veering off the road or keeping vehicles inside of the travel lane can reduce the occurrence of would-be rollovers. Therefore, crash scenarios for LDW/LKA/LCA included not only the typical roadway departure scenarios, but also first-event rollovers. Appendix D shows the mapping between crash scenarios and the safety systems of interest.

4 CRASH RESULTS

This chapter summarizes crash statistics (i.e., crashes, fatalities, MAIS 1-5 injuries, PDOVs, and societal costs) at two different levels. The first section presents the national level statistics for all U.S. crashes, all PV crashes, and all target crashes (i.e., PV crashes where a PV initiated the first SOE). These statistics serve as general background information. The second section provides crash statistics for target crashes by safety systems. Appendix D summarizes crash statistics for all established scenarios, including those technologies we did not analyze in this report.

4.1 Annual Crash Statistics

Table 4-1 presents crash statistics from 2011 to 2015. The annual statistics are the combined results of fatal crashes from FARS and non-fatal crashes from GES. As shown, crashes continued to increase from 5.34 million in 2011 to 6.30 million in 2015. This represents an 18 percent increase over the five-year period. Fatalities also showed a general uptick trend increasing from 32,479 in 2011 to 35,485 in 2015, with a 9.3 percent increase over 2011. MAIS 1-5 injuries showed a 13.3 percent increase over 2011, from 2.63 million in 2011 to 2.98 million in 2015. On average, there were 5.8 million policed-reported crashes annually. About 33,477 fatalities and 2.8 million MAIS 1-5 injuries were associated with these crashes. Furthermore, about 7.28 million vehicles sustained damage in property-damage-only crashes (i.e., PDOVs). The average annual societal costs for these crashes is about $763 billion in 2017 economic value.

Of the average annual crashes, 5.64 million (97% of total) were PV crashes, defined as crashes involving at least one PV. The PV crashes resulted in 29,170 fatalities (87% of all fatalities) and 2.73 million MAIS 1-5 injuries (97% of all injuries), and 7.17 million PDOVs (98% of all PDOVs). These PV crashes resulted in a $704 billion annual societal loss (92% of all societal loss).

Target PV crashes, defined as crashes where a PV initiated the first SOE or critical maneuver, comprised 94 percent of all crashes. As shown in Table 4-1, there were 5.45 million target PV crashes annually. An average of 26,558 fatalities (79% of all fatalities), 2.63 million MAIS 1-5 injuries (94% of all MAIS 1-5 injuries), and 6.89 million PDOVs (95% of all PDOVs) were associated with the target crashes. The average annual societal costs for these crashes is about $661 billion (87% of all societal loss). Table 4-2 summarizes the annual average crash statistics for all crashes, all PV crashes, and all target PV crashes for these five years.

Table 4-1
Crash Statistics at National Level

All Crashes

Year	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
2011	5,337,718	32,479	2,632,289	6,611,587	$727,859,699,236
2012	5,615,024	33,782	2,795,024	6,901,600	$768,526,603,292
2013	5,686,598	32,893	2,766,163	7,100,558	$749,448,763,388
2014	6,064,153	32,744	2,855,716	7,738,602	$759,933,075,001
2015	6,295,920	35,485	2,982,109	8,049,205	$807,941,866,648
Average	5,799,883	33,477	2,806,260	7,280,310	$762,742,001,513

All Passenger Vehicle Crashes

Year	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
2011	5,210,135	28,165	2,568,880	6,529,724	$670,496,405,532
2012	5,465,551	29,361	2,720,884	6,808,672	$708,151,653,102
2013	5,534,742	28,578	2,692,520	7,002,447	$690,736,970,033
2014	5,876,524	28,615	2,777,742	7,594,217	$702,023,663,692
2015	6,131,106	31,129	2,906,205	7,936,651	$748,080,360,101
Average	5,643,612	29,170	2,733,246	7,174,342	$703,897,810,492

All Target Passenger Vehicle Crashes

Year	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
2011	5,053,861	25,785	2,487,725	6,307,264	$632,965,826,004
2012	5,289,925	26,782	2,626,827	6,563,713	$666,296,335,933
2013	5,343,398	25,925	2,591,343	6,733,242	$646,877,473,810
2014	5,653,226	25,997	2,668,126	7,260,150	$657,037,084,621
2015	5,902,504	28,301	2,791,880	7,606,861	$700,918,984,108
Average	5,448,583	26,558	2,633,180	6,894,246	$660,819,140,895

PDOV: property-damage-only vehicles; PV: passenger vehicles

Table 4-2
Summary of Average Annual Crash Statistics From 2011 to 2015

	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
Total Crashes	5,799,883	33,477	2,806,260	7,280,310	$762,742,001,513
All PV Crashes	5,643,612	29,170	2,733,246	7,174,342	$703,897,810,492
All Target PV Crashes	5,448,583	26,558	2,633,180	6,894,246	$660,819,140,895

PDOVs: property-damage-only vehicles

4.2 Target Passenger Vehicle Crashes by Technologies

The following five tables present the target crash statistics; each corresponds to one of the five technology groups. All tables are in the same format, each with two portions. The top portion provides crash statistics by crash scenarios with aggregated MAIS 1-5 injuries. The bottom portion lists individual MAIS injuries including MAIS 0 (no injury).

As mentioned earlier, the analysis categorized crashes into 84 mutually exclusive crash scenarios. Each of the following five tables lists all possible crash scenarios that can be affected by the representative technologies. Each scenario begins with a number (such as 2000) followed by a description. There is no specific rationale behind the numbering scheme. The number is used internally in the SAS programing for operational control (i.e., merging and linking among various elements in the SAS database). Any crash scenario with "1V" imbedded in the description represents crashes where only one vehicle was involved whereas "2+V" represents crashes involving at least two vehicles.

4.2.1 Group 1, Forward Collision Prevention - FCW, CIB, and DBS

Table 4-3 provides the target population statistics for the forward collision avoidance technology group which includes FCW, CIB, and DBS. There are eight rear-end crash scenarios that potentially can be affected by FCW, CIB, or DBS. Collectively, on average, 1.70 million rear-end crashes occurred on the U.S. roadways annually. These crashes, which account for about 29.4 percent of all crashes that occurred in the United States, are the target crashes for FCW, CIB, and DBS. These crashes resulted in 1,275 fatalities, 883,386 MAIS 1-5 injuries, and 2.64 million PDOVs. In total, these crashes would cost society approximately $132.45 billion.[36]

[36] Although all three systems have the identical target population, the extent of the savings (or benefits) for each system would depend on the effectiveness of each system against these crashes. Effectiveness, as expected, would vary with system design, operational threshold, component implementation, and driver response for warning-only systems.

Table 4-3
Target Population Statistics, FCW/CIB/DBS

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
2000 Rear-End, Lead Vehicle (LV) Stopped	1,099,868	474	561,842	1,719,177	$80,023,139,895
2001 Rear-End, LV Slower	174,217	527	97,402	252,341	$18,930,190,490
2002 Rear-End, LV Decelerated	374,624	155	196,731	587,031	$28,386,370,919
2003 Rear-End, Other In-lane Vehicle Higher Speed	598	3	273	829	$71,434,395
2009 Rear-End, Other/Unspecified	50,105	70	24,951	77,034	$4,268,912,681
2300 Rear-End Possible, Other In-lane Vehicle Stopped	1,842	37	839	2,510	$493,941,988
2301 Rear-End Possible, Other In-lane Vehicle Slower	813	6	486	1,063	$120,226,679
2302 Rear-End Possible, Other In-lane Vehicle Decelerated	1,475	3	860	1,900	$150,957,924
Combined Total	1,703,541	1,275	883,386	2,641,884	$132,445,174,970
Percent of Total Crashes	29.4%	3.8%	31.5%	36.3%	17.4%

MAIS 0 - 5 Injuries for FCW/CIB/DBS

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
2000 Rear-End, Lead Vehicle (LV) Stopped	613,904	511,272	39,677	8,757	1,547	590
2001 Rear-End, LV Slower	104,695	87,599	7,479	1,846	349	130
2002 Rear-End, LV Decelerated	212,082	178,453	14,231	3,239	570	239
2003 Rear-End, Other In-lane Vehicle Higher Speed	272	242	23	6	1	0
2009 Rear-End, Other/Unspecified	26,095	22,502	1,859	465	89	36
2300 Rear-End Possible, Other In-lane Vehicle Stopped	664	744	72	19	3	1
2301 Rear-End Possible, Other In-lane Vehicle Slower	443	439	37	8	1	1
2302 Rear-End Possible, Other In-lane Vehicle Decelerated	1,216	775	65	16	3	1
Combined Total	959,372	802,025	63,443	14,356	2,563	999

Note: total might not equal the sum due to rounding
LV: lead vehicle

4.2.2 Group 2, Lane Keeping - LDW, LKA, and LCA

Table 4-4 provides the target population statistics for the lane keeping technology group consisting of LDW, LKA, and LCA. Crash scenarios for this group of technologies comprised a wide variety of vehicle pre-crash movements, such as first event rollovers, roadway departure, crossed centerline/median, etc. In all, there are a total of 1.12 million roadway departure type crashes (19.4% of all crashes) that potentially can be affected by LDW, LKA, and LCA. About 14,844 fatalities, 479,939 MAIS 1-5 injuries, and 863,213 PDOVs were associated with these crashes. These crash scenarios would cost society approximately $232.17 billion.

Table 4-4
Target Population for LDW/LKA/LCA

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
100 1V Rollover 1st Event	4,411	63	3,155	2,104	$1,220,716,587
150 2+V Rollover 1st Event	243	3	337	197	$79,378,538
1000 1V, Roadway Departure (RD)	966,709	9,751	359,238	679,402	$159,984,589,044
1050 2+V, Roadway Departure	43,957	1,021	32,069	55,856	$15,574,093,029
1100 1V Cross Centerline/Median	8,560	75	2,910	6,214	$1,262,853,834
1150 2+V Cross Centerline/Median	3,427	106	2,678	4,239	$1,481,800,683
3000 ST Opposite Dir(OD), Head-On	32,751	2,761	37,848	23,992	$35,044,078,412
3009 ST OD Forward Impact, Other	115	11	69	135	$121,800,681
3100 ST OD, Angle Sideswipe	62,214	1,042	38,655	86,054	$16,815,824,875
3200 Head-On Possible, Other Vehicle Encroaching OD	4,008	11	2,979	5,019	$588,480,319
Combined Total	1,126,397	14,844	479,939	863,213	$232,173,616,002
Percent of Total Crashes	19.4%	44.3%	17.1%	11.9%	30.4%

MAIS 0 - 5 Injuries for LDW/LKA/LCA

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
100 1V Rollover 1st Event	998	2,627	360	129	29	10
150 2+V Rollover 1st Event	288	292	33	9	2	1
1000 1V, Roadway Departure (RD)	112,581	307,554	35,914	12,113	2,645	1,012
1050 2+V, Roadway Departure	29,686	27,765	3,010	992	218	84
1100 1V Cross Centerline/Median	953	2,492	290	98	21	9
1150 2+V Cross Centerline/Median	1,883	2,325	253	78	17	6
3000 ST Opposite Dir(OD), Head-On	25,006	31,301	4,316	1,683	392	157
3009 ST OD Forward Impact, Other	72	56	8	4	1	0
3100 ST OD, Angle Sideswipe	31,174	33,708	3,479	1,126	245	98
3200 Head-On Possible, Other Vehicle Encroaching OD	2,297	2,603	270	83	17	7
Combined Total	204,939	410,723	47,932	16,314	3,585	1,383

Note: total might not equal the sum due to rounding

4.2.3 Group 3, Blind Spot Detection – BSD, BSI, and LCM

Table 4-5 provides the crash scenarios and target population statistics for the blind spot detection technology group consisting of BSD. BSI, and LCM. In all, there are a total of 503,070 lane change merge crashes (8.7% of all crashes) that can potentially be affected by these two systems. There were 542 fatalities, 188,304 MAIS 1-5 injuries, and 860,726 PDOVs associated with these crashes. These crashes would cost society about $31.76 billion.

Table 4-5
Target Population for BSD/BSI/LCM

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
8000 LCM in Rear End	48,749	128	26,040	71,977	$5,002,627,200
8001 LCM in ST SD Forward Impact	212	4	62	371	$48,646,405
8002 LCM in ST SD AS	371,504	332	129,595	651,962	$21,340,330,980
8003 LCM CT VT SD	58,389	40	20,685	99,476	$3,251,117,218
8004 LCM Other	24,216	38	11,924	36,940	$2,079,117,478
Combined Total	503,070	542	188,304	860,726	$31,721,839,282
Percent of Total Crashes	8.7%	1.6%	6.7%	11.8%	4.2%

MAIS 0 - 5 Injuries for BSD/BSI/LCM

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
8000 LCM in RE	26,823	23,400	1,997	507	97	39
8001 LCM in ST SD FI	51	57	4	1	0	0
8002 LCM in ST SD AS	96,858	119,573	7,820	1,735	317	150
8003 LCM CT VT SD	15,215	19,058	1,275	279	50	22
8004 LCM Other	10,683	10,754	890	221	41	18
Combined Total	149,630	172,841	11,987	2,742	505	229

Note: total might not equal the sum due to rounding

4.2.4 Group 4, Forward Pedestrian Impact Avoidance - PAEB

Table 4-6 provides the target population statistics for forward pedestrian impact avoidance technology, PAEB. The target population comprised 1.9 percent of all crashes, but 12.3 percent of all fatalities, and 8.0 percent of societal costs. On average, PAEB can potentially affect a total of 111,641 crashes, 4,106 fatalities, 104,066 MAIS 1-5 injuries, and 6,985 PDOVs annually. These PAEB crashes would cost society about $61.29 billion.

Table 4-6
Target Population for PAEB

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
300 1V2Ped RD, Forward Impact	60,322	3,264	57,480	1,836	$44,441,262,896
309 1V2Ped, Other	306	26	264	0	$312,395,297
350 2+V2Ped	511	259	452	0	$2,678,234,739
400 1V2Cyc RD, Forward Impact	50,094	531	45,529	4,910	$13,525,105,674
409 1V2Cyc, Other/Unspecified	175	4	172	0	$71,705,766
450 2+V2Cyc	234	23	169	239	$264,677,663
Combined Total	111,641	4,106	104,066	6,985	$61,293,382,036
Percent of Total Crashes	1.9%	12.3%	3.7%	0.1%	8.0%

MAIS 0 - 5 Injuries for PAEB

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
300 1V2Ped RD, Forward Impact	73,768	47,077	6,781	2,726	639	257
309 1V2Ped, Other	179	214	33	13	3	1
350 2+V2Ped	1,311	362	55	26	6	3
400 1V2Cyc RD, Forward Impact	56,741	38,233	5,018	1,755	389	135
409 1V2Cyc, Other/Unspecified	178	140	21	8	2	1
450 2+V2Cyc	302	144	16	6	2	1
Combined Total	132,479	86,170	11,924	4,536	1,041	396

Note: total might not equal the sum due to rounding

4.2.5 Group 5, Backing Collision Avoidance – RAB, RvAB, and RCTA

Table 4-7 provides the target population statistics for RAB/RvAB/RCTA. Annually, each of the three safety systems in this group can potentially reduce the 148,533 backing related crashes associated with 74 fatalities, 35,268 MAIS 1-5 injuries, and 231,317 PDOVs. In monetized value, RAB crashes would cost society $5.63 billion.

Table 4-7
Target Population for RAB/RvAB/RCTA Technologies

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
302 1V2Ped, Backup	2,811	44	2,590	88	$834,166,610
402 1V2Cyc, Backup	439	3	407	48	$91,516,694
602 1V2ParkedV, Backup	41,957	2	5,293	40,389	$742,379,633
802 1V2Fixed Object, Backup	1,824	2	217	1,732	$57,909,313
6000 Backing Up to Vehicle/Object	101,503	23	26,761	189,059	$3,899,263,166
Combined Total	148,533	74	35,268	231,317	$5,625,235,416
Percent of Total Crashes	2.6%	0.2%	1.3%	3.2%	0.7%

Note: total might not equal the sum due to rounding

MAIS 0 - 5 Injuries for RAB/RvAB/RCTA

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
302 1V2Ped, Backup	3,403	2,242	253	75	16	5
402 1V2Cyc, Backup	484	352	40	12	2	1
602 1V2ParkedV, Backup	1,294	5,009	234	39	6	5
802 1V2Fixed Obj, Backup	18	199	13	4	1	0
6000 Backing Up to Vehicle/Object	11,794	25,205	1,268	227	38	24
Combined Total	16,993	33,005	1,809	356	63	35

Note: total might not equal the sum due to rounding

4.2.6 Summary

From 2011 to 2015, on average, 5.80 million crashes occurred in the United States annually. These crashes resulted in 33,477 fatalities and 2.81 MAIS 1-5 million injuries. In addition, about 7.28 million vehicles sustained damage in property-damage-only crashes. The total societal loss in monetized terms from these crashes is estimated to be $763.26 billion in 2017 dollars.

Collectively, the five groups of safety systems can affect, annually:

- 3.59 million crashes (62.0% of all crashes),
- 20,841 fatalities (62.2%),
- 1.69 MAIS 1-5 injuries (60.3%),
- 4.60 million PDOVs (60.3%), and
- $463.26 billion (60.7%).

Separately, Group 1: FCW, CIB, or DBS, each can affect, annually:

- 1.70 million front-to-rear crashes,
- 1,275 fatalities,
- 883,386 MAIS 1-5 injuries,
- 2.64 million PDOVs, and
- $132.45 billion.

Group 2: LDW, LKA, and LCA, each can affect, annually:

- 1.12 million roadway departure crashes,
- 14,844 fatalities,
- 479,939 MAIS 1-5 injuries,
- 863,213 PDOVs, and
- $232.17 billion.

Group 3: BSD, BSI, and LCM, each can affect, annually:

- 503,070 lane change merge crashes,
- 542 fatalities,
- 188,304 MAIS 1-5 injuries,
- 860,726 PDOVs, and
- $31.726 billion.

Group 4: PAEB can potentially affect, annually

- a total of 111,641 crashes,
- 4,106 fatalities, 104,066 MAIS 1-5 injuries,
- 6,985 PDOVs, and
- $61.29 billion.

Lastly, Group 5: RAB, RvAB, and RCTA can potentially affect, annually:

- 148,533 backing related crashes74 fatalities,
- 35,268 MAIS 1-5 injuries,
- 231,317 PDOVs, and
- $5.63 billion.

Table 4-8 summarizes the average annual crash statistics for target crashes by technologies for all crashes.

Table 4-8
Average Annual* Target Crashes by Technologies of Interest

Technologies Number (% of Total)	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs (2017 $)
FCW/DBS/CIB	1,703,541	1,275	883,386	2,641,884	$132,445,174,970
	29.4%	3.8%	31.5%	36.3%	17.4%
LDW /LKA/LCA	1,126,397	14,844	479,939	863,213	$232,173,616,002
	19.4%	44.3%	17.1%	11.9%	30.4%
BSW/BSI/LCM	503,070	542	188,304	860,726	$31,721,839,282
	8.7%	1.6%	6.7%	11.8%	4.2%
PAEB	111,641	4,106	104,066	6,985	$61,293,382,036
	1.9%	12.3%	3.7%	0.1%	8.0%
RAB/RvAB/RCTA	148,533	74	35,268	231,317	$5,625,235,416
	2.6%	0.2%	1.3%	3.2%	0.7%
Combined All	3,593,182	20,841	1,690,963	4,604,125	$463,259,247,706
	62.0%	62.2%	60.3%	63.3%	60.7%
Total Crashes	5,799,883	33,477	2,806,260	7,280,310	$763,101,230,853

*from 2011 to 2015
Source: 2011-2015 GES and FARS

We note that the target population established here did not consider system design variations or the adoption rates of individual systems. Design variations would affect the effectiveness of individual systems. When estimating the benefit for individual systems, the guiding principle is to align the target population with the sample that was used to derive its effectiveness. To accomplish this, some adjustments to either the target population or the effectiveness would be necessary. In addition, as discussed in the Technology Adoption Rate section, the safety systems of interest have been increasingly offered by manufacturers, but each at a different pace. This reflects that these subject technologies will gradually penetrate the on-road vehicle fleet over a long period of time. Therefore, analysts who use newer crash databases for retrieving target populations should consider the effect of adoption rates on the size of the target population for benefit estimates. For all these reasons, we believe the refinement of target populations would be best considered when estimating the benefits of these systems.

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Appendix A. COMPREHENSIVE UNIT COSTS

The comprehensive value of societal impacts from fatalities and injuries includes a variety of cost components. Table A-1 summarizes the cost components and corresponding unit costs in 2017 dollars. As shown, the cost components included medical, EMS, market productivity, household productivity, insurance administration, workplace costs, legal costs, congestion, travel delay, and the nontangible value of physical pain and loss of quality of life (i.e., quality adjusted life years, QALYs). The unit costs were revised from those published in the agency's 2015 report (Blincoe, Miller, Zaloshnja, & Lawrence, 2015). Blincoe's group reported unit costs in 2010 dollars. To convert them to 2017 economics, the analysis derived adjustment factors from two types of economic indices for adjustment factors: two series of non-seasonally-adjusted Consumer Price Indices and the Employment Cost Index.[37] CPI that were used for deriving adjustment factors include CUUR0000SA0 (All Items, Urban Consumers, U.S. All City Average) and CUUR0000SAM2 (Medical Care Services, Urban Consumers, U.S. All City Average). The ECI used is the series CIU1010000000000I (Total Compensation, Civilian workers, All Industries and Occupations). Each adjustment factor is the ratio of the index value in 2017 to that in 2010. Table A-2 lists the adjustment factors and the indexes they used. Table A-3 lists the base unit costs in 2010 dollars.

Note that instead of using a direct adjustment, the value of QALY for fatality was derived based on the formula shown the last row of Table A-2 adjusting the value of statistical life to reflect after tax wages and household productivity. This is an accounting mechanism that prevents double counting of these factors, which are hypothetically considered to be inherently included in VSL estimates. The current established DOT VSL is $9.6 million (in 2015 dollars) which was based on the most current (2016) guidance on VSL (Moran & Monje, 2016) from the Office of the Secretary, Department of Transportation. After establishing the value of QALYs for fatality, the QALYs for each MAIS injury level is prorated based on the ratio of its QALY value to that for fatality, which was established in Blincoe's report, i.e., the QALY value in 2010 dollars (the last row of Table A-3). For example, the value of QALYs for MAIS 5 is $6.11 million which is 59.30 percent of the QALY value for fatality.

[37] Published by the Bureau of Economic Analysis in the Bureau of Labor Statistics as of April 30, 2018

Table A-1
Comprehensive Unit Costs (2017 $)

Components	PDO	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	FATAL
Medical	$0	$0	$3,448	$14,110	$59,900	$167,943	$473,424	$13,943
EMS	$66	$43	$123	$248	$468	$942	$961	$1,014
Market Prod	$0	$0	$3,151	$22,379	$74,375	$162,783	$390,274	$1,078,851
Household Prod	$69	$52	$996	$8,215	$26,227	$43,397	$110,290	$335,136
Ins. Adm.	$215	$161	$3,707	$5,237	$17,277	$31,728	$81,518	$31,834
Workplace	$72	$53	$394	$3,056	$6,677	$7,353	$12,821	$13,621
Legal	$0	$0	$1,329	$3,767	$13,940	$29,975	$92,966	$119,693
Congestion	$2,432	$1,637	$1,648	$1,676	$1,722	$1,747	$1,768	$6,612
Property Damage	$4,045	$3,026	$8,946	$9,565	$18,014	$18,353	$16,963	$12,602
QALYs	$0	$0	$24,940	$390,733	$872,914	$2,211,382	$4,929,885	$8,313,466
Total	$6,899	$4,972	$48,682	$458,986	$1,091,514	$2,675,603	$6,110,870	$9,926,772

Table A-2
Adjustment Factors (2017/2010)

Cost Components	Area (Index Type)	Adjustment Factor
Medical	Medical Care Service (Consumer Price Index)	1.232
EMS	All Items (Consumer Price Index)	1.124
Market Productivity	Total Employee Compensation (Employment Cost Index)	1.156
Household Productivity	Total Employee Compensation (Employment Cost Index)	1.156
Insurance Administration	All Items (Consumer Price Index)	1.124
Workplace	Total Employee Compensation (Employment Cost Index)	1.156
Legal	All Items (Consumer Price Index)	1.124
Congestion	Total Employee Compensation (Employment Cost Index)	1.156
Property Damage	All Items (Consumer Price Index)	1.124
QALYs	Total Employee Compensation (Employment Cost Index)	VSL - 0.881862*Market Productivity – Household Productivity (1)

(1) the formula only applicable to fatality

Table A-3
Based Unit Costs for Police-Reported Crashes (2010 Dollars)

Cost Components	PDO	MAIS0	MAIS1	MAIS2	MAIS3	MAIS4	MAIS5	FATAL
Medical	$0	$0	$2,799	$11,453	$48,620	$136,317	$384,273	$11,317
EMS	$59	$38	$109	$221	$416	$838	$855	$902
Market Prod	$0	$0	$2,726	$19,359	$64,338	$140,816	$337,607	$933,262
Household Prod	$60	$45	$862	$7,106	$22,688	$37,541	$95,407	$289,910
Ins. Adm.	$191	$143	$3,298	$4,659	$15,371	$28,228	$72,525	$28,322
Workplace	$62	$46	$341	$2,644	$5,776	$6,361	$11,091	$11,783
Legal	$0	$0	$1,182	$3,351	$12,402	$26,668	$82,710	$106,488
Congestion	$2,104	$1,416	$1,426	$1,450	$1,490	$1,511	$1,529	$5,720
Property Damage	$3,599	$2,692	$7,959	$8,510	$16,027	$16,328	$15,092	$11,212
QALYs	$0	$0	$23,241	$364,113	$813,444	$2,060,724	$4,594,020	$7,747,082
Total	$6,075	$4,380	$43,943	$422,866	$1,000,572	$2,455,332	$5,595,109	$9,145,998
Relative QALYS	0.0000	0.0000	0.0030	0.0470	0.1050	0.2660	0.5930	1.0000

Appendix B. CRASH SCENARIO DEFINITIONS

Table B-1 presents the 84 fatal crash scenarios and their individual definitions. The primary data elements that were used to discern crash scenarios include sequence of events, event number (EVENTNUM), accident type (ACC_TYPE), pre-event movement (P_CRASH1), and pre-crash critical event (P_CRASH2). Both EVENTNUM and SOE were used to determine the first sequence of event. In addition, vehicle body type (BDYD_TYP) was used to identify PV crashes. Injury severity (INJ_SEV) was used to determine the police-reported injury severity level for an involved person. Vehicle number (VEH_NO) was used to separate 1-vehicle crashes from multiple vehicle crashes (2+ vehicle crashes). Basically, crash scenarios were prioritized by the first SOE, ACC_TYPE, P_CRASH1, and P_CRASH2 and were based on the PV that initiated the first SOE or pre-crash critical movement/event.

In 2006 NHTSA started to harmonize FARS and GES with respect to data structure, data elements, and data attributions. This effort allows a standardized crash scenario definition to be established between FARS and GES using a similar set of variables. However, GES imputed certain police-reported variables to increase their utility. These imputed variables were ended either with "_IM" or "_I". Variables that ended with "_IM" were derived through a sequential regression approach[38] where the covariates are selected automatically using stepwise regression (Shelton, 1993). Variables that ended with "_I" (e.g., BDYTYP_I) were derived through a univariate distribution approach where unknowns were directly distributed proportionally to the relative size of known attributes.

By choice, imputed variables in GES were used whenever available to define non-fatal crash scenarios. These imputed variables are: maximum crash severity (MAXSEV_IM) for discerning injury crashes and property-damage-only crashes, vehicle body type (BDYTYP_IM), pre-event movement (PCRASH1_IM), and injury severity for involved persons (INJSEV_IM). In other words, GES non-fatal crash scenarios were defined by substituting the above imputed variables for the corresponding variables in the definitions provided in Table B-1. Therefore, the Appendix does not separately list the definitions for GES non-fatal crashes.

Each scenario comes with a pre-assigned number and is followed by a brief description (e.g., 2000 Rear-End, Lead Vehicle (LV) Stopped). There is no specific logic with the numbering scheme. The number is used internally in the SAS programing for operational control (i.e., merging and linking among various elements in the SAS database). Generally, a crash scenario would be defined from crashes that excluded all the scenarios above but with some exceptions. The exceptions from this exclusion rule are in the 8000 series for lane change/merge and the 9000 series. Nevertheless, there is not violation to the mutually exclusiveness among these 84 scenarios. The description was prepared to be self-explanatory. For examples, "1V" imbedded implies one vehicle was involved in the crash, "2V+" implies crashes involving at least two vehicles, "1V2Pedestrian" means a single-vehicle crash with impact to a pedestrian,

[38] Beginning in 2010.

“1V2Cyclist” means a single-vehicle crash involving a cyclist, and so on and so forth. The descriptions are not discussed in detail here.

Table B-1
Scenario Definitions for Fatal Crashes

Crash Scenarios	Definition
100 1V Rollover 1st Event	(SOE = 1) and (VE_FORMS = 1)
150 2+V Rollover 1st Event	(SOE = 1) and (VE_FORMS > 1)
200 1V Jackknife 1st Event	(SOE in (51, 70)) and (VE_FORMS = 1)
250 2+V Jackknife 1st Event	(SOE in (51, 70)) and (VE_FORMS > 1)
300 1V2Pedestrian Roadway Departure, Forward Impact	(SOE = 8) and (VE_FORMS = 1) and (ACC_TYPE in (03, 08, 13:16))
302 1V2 Pedestrian, Backup	(SOE = 8) and (VE_FORMS = 1) and (ACC_TYPE in (92, 93))
309 1V2 Pedestrian, Specifics Other/Unknown	(SOE = 8) and (VE_FORMS = 1) and (ACC_TYPE not in above)
350 2+V2 Pedestrian	(SOE = 8) and (VE_FORMS > 1)
400 1V2Cyclist Roadway Departure, Forward Impact	(SOE = 9) and (VE_FORMS = 1) and (ACC_TYPE in (03, 08, 13:16))
402 1V2Cyclist, Backup	(SOE = 9) and (VE_FORMS = 1) and (ACC_TYPE in (92, 93))
409 1V2Cyclist, Specifics Other/Unknown	(SOE = 9) and (VE_FORMS = 1) and (ACC_TYPE not in above)
450 2+V2Cyclist	(SOE = 9) and (VE_FORMS > 1)
500 1V2Animal Roadway Departure, Avoid Animal	(SOE = 11) and (VE_FORMS = 1) and (ACC_TYPE in (03, 08, 13:16))
502 1V2Animal, Backup	(SOE = 11) and (VE_FORMS = 1) and (ACC_TYPE in (92, 93))
509 1V2Animal, Specifics Other/Unknown	(SOE = 11) and (VE_FORMS = 1) and (ACC_TYPE not in above)
550 2+V2Animal	(SOE = 11) and (VE_FORMS > 1)
600 1V2Parked Vehicle Roadway Departure, Forward Impact	(SOE = 14) and (VE_FORMS = 1) and (ACC_TYPE in (03, 08, 11, 14:16))
602 1V2Parked Vehicle, Backup	(SOE = 14) and (VE_FORMS = 1) and (ACC_TYPE in (92, 93))
609 1V2Parked Vehicle, Specifics Other/Unknown	(SOE = 14) and (VE_FORMS = 1) and (ACC_TYPE not in above)
650 2+V2Parked Vehicle	(SOE = 14) and (VE_FORMS > 1)
700 1V2Other Non-Fixed Object Roadway Departure, Forward Impact	(SOE = 18) and (VE_FORMS = 1) and (ACC_TYPE in (03, 08, 13:16))
701 1V2Other Non-Fixed Object Roadway Departure, Traction Loss	(SOE = 18) and (VE_FORMS = 1) and (ACC_TYPE in (02, 07))
702 1V2Other Non-Fixed Object, Backup	(SOE = 18) and (VE_FORMS = 1) and (ACC_TYPE in (92, 93))
709 1V2Other Non-Fixed Object, Other	(SOE = 18) and (VE_FORMS = 1) and (ACC_TYPE not in above)
750 2+V2Other Non-Fixed Object	(SOE = 18) and (VE_FORMS > 1)
800 1V2Fixed Object Roadway Departure, Forward Impact	(SOE in (17, 19:26, 30:35, 38:43, 46:48, 52:53, 57, 59)) and (VE_FORMS = 1) and (ACC_TYPE in (03, 08, 12, 14:16))

Crash Scenarios	Definition
801 1V2Fixed Object Roadway Departure, Traction Loss	(SOE in (17, 19:26, 30:35, 38:43, 46:48, 52:53, 57, 59)) and (VE_FORMS = 1) and (ACC_TYPE in (02, 07))
802 1V2Fixed Object, Backup	(SOE in (17, 19:26, 30:35, 38:43, 46:48, 52:53, 57, 59)) and (VE_FORMS = 1) and (ACC_TYPE in (92, 93))
809 1V2Fixed Object, Other	(SOE in (17, 19:26, 30:35, 38:43, 46:48, 52:53, 57, 59)) and (VE_FORMS = 1) and (ACC_TYPE in (92, 93))
850 2+V2Fixed Object	(SOE in (17, 19:26, 30:35, 38:43, 46:48, 52:53, 57, 59)) and (VE_FORMS > 1)
1000 1V, Roadway Departure (RD)	{(SOE in (63, 64, 79)) and (VE_FORMS = 1)} or (None of SOE above ACC_TYPE in (01, 06, 04, 05, 09, 10))
1001 1V RD, Traction Loss	{(SOE in (63, 64, 79)) and (VE_FORMS = 1)} or (None of SOE above (ACC_TYPE in (02, 07))
1002 1V RD, Avoid Vehicle/Pedestrian/Animal	{(SOE in (63, 64, 79)) and (VE_FORMS = 1)} or (None of SOE above (ACC_TYPE in (03, 08))
1003 1V Forward Impact, Ped or Animal	{(SOE in (63, 64, 79)) and (VE_FORMS = 1)} or (None of SOE above (ACC_TYPE in (02, 07))
1004 1V Forward Impact, End Departure	(Non-of Above SOE) and (ACC_TYPE = 14) and (VE_FORMS > 1)
1005 1V Forward Impact, Specifics Other/Unknown	(Non-of Above SOE) and (ACC_TYPE in (15, 16)) and (VE_FORMS > 1)
1009 1V Other/No Impact	(VE_FORMS = 1) and Non-of Above
1050 2+V, Roadway Departure	(VE_FORMS > 1) and Non-of Above
1100 1V Cross Centerline/Median	(SOE in (65, 68)) and (VE_FORMS = 1)
1150 2+V Cross Centerline/Median*	(SOE in (65, 68)) and (VE_FORMS > 1)
2000 Rear-End, Lead Vehicle (LV) Stopped	(20 ≤ ACC_TYPE ≤ 23) and Not {(P_CRASH1 in (6, 15, 16)) or (P_CRASH2 in (1, 11, 60, 61)) i.e., not making lane change/merge
2001 Rear-End, LV Slower	24 ≤ ACC_TYPE ≤ 27 and Not making lane change/merge
2002 Rear-End, LV Decelerated	28 ≤ ACC_TYPE ≤ 31 and Not making lane change/merge
2003 Rear-End, Other In-lane Vehicle Higher Speed	(32 ≤ ACC_TYPE ≤ 33) and (P_CRASH2 = 53)
2009 Rear-End, Specifics Other/Unknown	(32 ≤ ACC_TYPE ≤ 33) and (P_CRASH2 ≠ 53)
2101 Same Trafficway Same Direction Forward Impact, Loss Control	(34 ≤ ACC_TYPE ≤ 37)
2102 Rear-End Possible, Same Trafficway Same Direction Forward Impact, Avoid Vehicle	(38 ≤ ACC_TYPE ≤ 39)
2103 Same Trafficway Same Direction Forward Impact, Avoid Objects	(40 ≤ ACC_TYPE ≤ 41)
2109 Rear-End Possible, Same Trafficway Same Direction Forward Impact, Specifics Other/Unknown	(42 ≤ ACC_TYPE ≤ 43) and Not making lane change/merge
2200 Same Trafficway Same Direction, Angle-Sideswipe	(44 ≤ ACC_TYPE ≤ 49) and Not making lane change/merge

Crash Scenarios	Definition
2300 Rear-End Possible, Other In-lane Vehicle Stopped	(P_CRASH1 in (1, 2, 3)) and (P_CRASH2 = 50) and None of above
2301 Rear-End Possible, Other In-lane Vehicle Slower	(P_CRASH1 in (1, 2, 3)) and (P_CRASH2 = 51) and None of above
2302 Rear-End Possible, Other In-lane Vehicle Decelerated	(P_CRASH1 in (1, 2, 3)) and (P_CRASH2 = 52) and None of above
3000 Same Trafficway Opposite Direction, Head-On	(50 ≤ AC_TYPE ≤ 53)
3001 Same Trafficway Opposite Direction Forward Impact, Traction Loss	(54 ≤ AC_TYPE ≤ 57)
3002 Same Trafficway Opposite Direction Forward Impact, Avoid Vehicle	(58 ≤ AC_TYPE ≤ 59)
3003 Same Trafficway Opposite Direction Forward Impact, Avoid Object	(60 ≤ AC_TYPE ≤ 61)
3009 Same Trafficway Opposite Direction Forward Impact, Other	(62 ≤ AC_TYPE ≤ 63)
3100 Same Trafficway Opposite Direction, Angle Sideswipe	(64 ≤ AC_TYPE ≤ 67)
3200 Head-On Possible, Other Vehicle Encroaching OD	(P_CRASH1 in (1, 2, 3)) and (P_CRASH2 in (62, 63))
4000 Change Trafficway Vehicle Turing, Turn Across Path, Initial Opposite Direction	(68 ≤ AC_TYPE ≤ 69)
4001 Change Trafficway Vehicle Turing, Turn Across Path, Initial Same Direction	(70 ≤ AC_TYPE ≤ 73) and Not making lane change/merge
4009 Change Trafficway Vehicle Turing, Turn Across Path, Specifics Other/Unknown	(74 ≤ AC_TYPE ≤ 75)
4100 Change Trafficway Vehicle Turing, Turn Into Path, into Same Direction	(76 ≤ AC_TYPE ≤ 79)
4101 Change Trafficway Vehicle Turing, Turn Into Path, into Opposite Direction	(80 ≤ ACC_TYPE ≤ 83)
4109 Change Trafficway Vehicle Turing, Turn Into Path, Specifics Other/Unknown	(84 ≤ ACC_TYPE ≤ 85)
5000 Intersect Paths, Straight Across Path	(86 ≤ ACC_TYPE ≤ 89)
5009 Intersect Paths, Straight Path, Specifics, Specifics Other/Unknown	(90 ≤ ACC_TYPE ≤ 91)
6000 Backing Up to Vehicle/Object	(92 ≤ ACC_TYPE ≤ 92) and Non-of Backing Above
7000 1V Negotiating a Curve	(VE_FORMS = 1) and (P_CRASH1 = 14)
7050 2+V Negotiating a Curve	(VE_FORMS > 1) and (P_CRASH1 = 14)
8000 Lane Change/Merge Before Rear-End	(ACC_TYPE in (20, 24, 28, 32, 33)) and {(P_CRASH1 in (6, 15, 16)) or (P_CRASH2 in (1, 11, 60, 61))

Crash Scenarios	Definition
8001 Lane Change/Merge in Same Trafficway Same Direction Forward Impact	(42 ≤ ACC_TYPE ≤ 43) and {(P_CRASH1 in (6, 15, 16)) or (P_CRASH2 in (1, 11, 60, 61))
8002 Lane Change/Merge in Same Trafficway Same Direction Angle Sideswipe	(44 ≤ ACC_TYPE ≤ 49) and {(P_CRASH1 in (6, 15, 16)) or (P_CRASH2 in (1, 11, 60, 61))
8003 Lane Change/Merge in Change Trafficway Vehicle Turing Initial Same Direction	(70 ≤ ACC_TYPE ≤ 75) and {(P_CRASH1 in (6,16,16)) or (P_CRASH2 in (1,11, 60, 61))
8004 Lane Change/Merge Other	(All Other Crash Types) and {(P_CRASH1 in (6,16,16)) or (P_CRASH2 in (1,11, 60, 61))
9000 Equipment Failure	(SOE = 61) or (P_CRASH2 in (1,2,3))
9020 Loss of Control Due to Tire/Engine/Poor Road	(4 ≤ P_CRASH2 ≤ 9)
9030 2+V, Left/Right Turn, Unspecified	(VE_FORMS > 1) and (P_CRASH1 in (10, 11))
9040 2+V U-Turn	(VE_FORMS > 1) and (P_CRASH1 = 12)
9050 2+V Backing to Moving Vehicle	(VE_FORMS > 1) and (P_CRASH1 = 13)
9060 2+V No Impact	(VE_FORMS > 1) and (ACC_TYPE = 0)
9070 2+V Other	(VE_FORMS > 1) and (ACC_TYPE = 98)
9999 2+V Unknown	(VE_FORMS > 1) and None of above

Appendix C. KABCO to MAIS TRANSLATION

This appendix describes the process of translating KABCO injuries into MAIS injuries. Mathematically, the process can be expressed as a matrix operation as shown below. The 6x1 matrix on the left side of the equal sign represents the derived MAIS injuries, with MAIS0 represents "not injured." The first 1x7 injury matrix on the right side of equation represents the KABCO injuries where the newly introduced symbol U represents "injured, unknown injury severity" and Y represents "unknown whether injured or not." The 7x6 matrix that follows is the KABCO-to-MAIS translator. Each row of the translator corresponds to an injury level, as noted by the leading English characters, e.g., A=Incapacitating Injury. Each column represents the portion of KABCO injuries that would be MAIS level injuries and is noted by numeric numbers. For example, A0 = 0.03420. This means that 3.420 percent of A injuries were translated to MAIS 0 injuries.

The translator was established based on two real-world crash databases that recorded both KABCO and MAIS injuries: 2000 to 2008 CDS[39] and 1984–1986 National Accident Sampling System (old NASS). CDS is a sample of PV tow-away crashes and records injury and other person information only for PV occupants. The old NASS was a nationally representative sample of all crashes of all vehicle types on public roadways and collected information for all involved people (i.e., occupants from PVs and partner vehicles, pedestrians, cyclist, and motorcyclists). However, as the name indicated, the old NASS system is a relatively ancient crash database. Readers can consult many of the regulatory impact analyses that were published by the agency for the use of data and the development of the translator.[40]

$$\begin{pmatrix} MAIS0 \\ MAIS1 \\ MAIS2 \\ MAIS3 \\ MAIS4 \\ MAIS5 \end{pmatrix} = \begin{pmatrix} K & A & B & C & O & U & Y \end{pmatrix} \begin{pmatrix} K0 & K1 & K2 & K3 & K4 & K5 \\ A0 & A1 & A2 & A3 & A4 & A5 \\ B0 & B1 & B2 & B3 & B4 & B5 \\ C0 & C1 & C2 & C3 & C4 & C5 \\ O0 & O1 & O2 & O3 & O4 & O5 \\ U0 & U1 & U2 & U3 & U4 & U5 \\ Y0 & Y1 & Y2 & Y3 & Y4 & Y5 \end{pmatrix}$$

[39] The 2009 and newer CDS was not incorporated to derive the translator due to the data collection policy which did not record injury information for occupants in vehicles older than 10 years.

[40] Readers can access Regulations.gov for these analyses. An example is Preliminary Regulatory Impact Analysis for FMVSS No. 150, Vehicle-to-Vehicle Communication Technology for Light Vehicles.

$$\text{Where}\begin{pmatrix} K0 & K1 & K2 & K3 & K4 & K5 \\ A0 & A1 & A2 & A3 & A4 & A5 \\ B0 & B1 & B2 & B3 & B4 & B5 \\ C0 & C1 & C2 & C3 & C4 & C5 \\ O0 & O1 & O2 & O3 & O4 & O5 \\ U0 & U1 & U2 & U3 & U4 & U5 \\ Y0 & Y1 & Y2 & Y3 & Y4 & Y5 \end{pmatrix} =$$

$$\begin{pmatrix} 0.00000 & 0.00000 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \\ 0.03420 & 0.55192 & 0.20813 & 0.14372 & 0.03969 & 0.01776 \\ 0.08336 & 0.76745 & 0.10884 & 0.03187 & 0.00619 & 0.00101 \\ 0.23414 & 0.68934 & 0.06390 & 0.01072 & 0.00142 & 0.00013 \\ 0.92534 & 0.07258 & 0.00198 & 0.00008 & 0.00000 & 0.00003 \\ 0.21528 & 0.62699 & 0.10394 & 0.03854 & 0.00442 & 0.01034 \\ 0.42930 & 0.41027 & 0.08721 & 0.04735 & 0.00606 & 0.00274 \end{pmatrix}$$

Appendix D. MAPPING TARGET POPULATION WITH TECHNOLOGIES

Table D-1 shows the mapping of an individual crash scenario with corresponding safety systems.

Table D-1
Mapping of Crash Scenarios With Safety Systems

	1	2	3	4	5
Crash Scenarios	**FCW/CIB/DBS**	**LDW/LKA/LCA**	**BSD/BSI/LCM**	**PAEB**	**RAB/RvAB/RTA**
100 1V Rollover 1st Event		●			
150 2+V Rollover 1st Event		●			
200 1V Jackknife 1st Event					
250 2+V Jackknife 1st Event					
300 1V2Pedestrian Roadway Departure, Forward Impact				●	
302 1V2 Pedestrian, Backup					●
309 1V2 Pedestrian, Specifics Other/Unknown				●	
350 2+V2 Pedestrian				●	
400 1V2Cyclist Roadway Departure, Forward Impact				●	
402 1V2Cyclist, Backup					●
409 1V2Cyclist, Specifics Other/Unknown				●	
450 2+V2Cyclist				●	
500 1V2Animal Roadway Departure, Avoid Animal					
502 1V2Animal, Backup					
509 1V2Animal, Specifics Other/Unknown					
550 2+V2Animal					
600 1V2Parked Vehicle Roadway Departure, Forward Impact		●			
602 1V2Parked Vehicle, Backup					●
609 1V2Parked Vehicle, Specifics Other/Unknown		●			
650 2+V2Parked Vehicle		●			

	1	2	3	4	5
Crash Scenarios	**FCW/CIB/DBS**	**LDW/LKA/LCA**	**BSD/BSI/LCM**	**PAEB**	**RAB/RvAB/RTA**
700 1V2Other Non-Fixed Object Roadway Departure, Forward Impact		●			
701 1V2Other Non-Fixed Object Roadway Departure, Traction Loss					
702 1V2Other Non-Fixed Object, Backup					
709 1V2Other Non-Fixed Object, Other					
750 2+V2Other Non-Fixed Object					
800 1V2Fixed Object Roadway Departure, Forward Impact		●			
801 1V2Fixed Object Roadway Departure, Traction Loss					
802 1V2Fixed Object, Backup					●
809 1V2Fixed Object, Other					
850 2+V2Fixed Object					
1000 1V, Roadway Departure		●			
1001 1V RD, Traction Loss					
1002 1V RD, Avoid Vehicle/Pedestrian/Animal					
1003 1V Forward Impact, Ped or Animal					
1004 1V Forward Impact, End Departure					
1005 1V Forward Impact, Specifics Other/Unknown					
1009 1V Other/No Impact					
1050 2+V, Roadway Departure		●			
1100 1V Cross Centerline/Median		●			
1150 2+V Cross Centerline/Median*		●			
2000 Rear-End, Lead Vehicle Stopped	●				
2001 Rear-End, LV Slower	●				
2002 Rear-End, LV Decelerated	●				
2003 Rear-End, Other In-lane Vehicle Higher Speed	●				
2009 Rear-End, Specifics Other/Unknown	●				

	1	2	3	4	5
Crash Scenarios	**FCW/CIB/DBS**	**LDW/LKA/LCA**	**BSD/BSI/LCM**	**PAEB**	**RAB/RvAB/RTA**
2101 Same Trafficway Same Direction Forward Impact, Loss Control					
2102 Rear-End Possible, Same Trafficway Same Direction Forward Impact, Avoid Vehicle					
2103 Same Trafficway Same Direction Forward Impact, Avoid Objects					
2109 Rear-End Possible, Same Trafficway Same Direction Forward Impact, Specifics Other/Unknown					
2200 Same Trafficway Same Direction, Angle-Sideswipe					
2300 Rear-End Possible, Other In-lane Vehicle Stopped	●				
2301 Rear-End Possible, Other In-lane Vehicle Slower	●				
2302 Rear-End Possible, Other In-lane Vehicle Decelerated	●				
3000 Same Trafficway Opposite Direction, Head-On		●			
3001 Same Trafficway Opposite Direction Forward Impact, Traction Loss					
3002 Same Trafficway Opposite Direction Forward Impact, Avoid Vehicle					
3003 Same Trafficway Opposite Direction Forward Impact, Avoid Object					
3009 Same Trafficway Opposite Direction Forward Impact, Other		●			
3100 Same Trafficway Opposite Direction, Angle Sideswipe		●			
3200 Head-On Possible, Other Vehicle Encroaching Opposite Direction					
4000 Change Trafficway Vehicle Turning, Turn Across Path, Initial Opposite Direction					
4001 Change Trafficway Vehicle Turning, Turn Across Path, Initial Same Direction					

	1	2	3	4	5
Crash Scenarios	**FCW/CIB/DBS**	**LDW/LKA/LCA**	**BSD/BSI/LCM**	**PAEB**	**RAB/RvAB/RTA**
4009 Change Trafficway Vehicle Turing, Turn Across Path, Specifics Other/Unknown					
4100 Change Trafficway Vehicle Turning, Turn Into Path, into Same Direction					
4101 Change Trafficway Vehicle Turning, Turn Into Path, into Opposite Direction					
4109 Change Trafficway Vehicle Turning, Turn Into Path, Specifics Other/Unknown					
5000 Intersect Paths, Straight Across Path					
5009 Intersect Paths, Straight Path, Specifics, Specifics Other/Unknown					
6000 Backing Up to Vehicle/Object					●
7000 1V Negotiating a Curve					
7050 2+V Negotiating a Curve					
8000 Lane Change/Merge Before Rear-End			●		
8001 Lane Change/Merge in Same Trafficway Same Direction Forward Impact			●		
8002 Lane Change/Merge in Same Trafficway Same Direction Angle Sideswipe			●		
8003 Lane Change/Merge in Change Trafficway Vehicle Turing Initial Same Direction			●		
8004 Lane Change/Merge Other			●		
9000 Equipment Failure					
9020 Loss of Control Due to Tire/Engine/Poor Road					
9030 2+V, Left/Right Turn, Unspecified					
9040 2+V U-Turn					
9050 2+V Backing to Moving Vehicle					●
9060 2+V No Impact					
9070 2+V Other					
9999 2+V Unknown					

Appendix E. TARGET POPULATION BY CRASH SCENARIOS

Appendix E presents crash statistics in two tables. Table E-1 tabulates crash statistics by crash scenarios where non-fatal MAIS 1-5 injuries are collectively presented. Table E-2 presents individual MAIS level injuries by scenarios.

Table E-1
Crash Statistics by Crash Scenarios

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs
100 1V Rollover 1st Event	4,411	63	3,155	2,104	$1,220,716,587
150 2+V Rollover 1st Event	243	3	337	197	$79,378,538
200 1V Jackknife 1st Event	1,838	4	686	1,442	$134,075,341
250 2+V Jackknife 1st Event	344	1	284	490	$52,685,016
300 1V2Pedestrian Roadway Departure, Forward Impact	60,322	3,264	57,480	1,836	$44,441,262,896
302 1V2 Pedestrian, Backup	2,811	44	2,590	88	$834,166,610
309 1V2 Pedestrian, Specifics Other/Unknown	306	26	264	0	$312,395,297
350 2+V2 Pedestrian	511	259	452	0	$2,678,234,739
400 1V2Cyclist Roadway Departure, Forward Impact	50,094	531	45,529	4,910	$13,525,105,674
402 1V2Cyclist, Backup	439	3	407	48	$91,516,694
409 1V2Cyclist, Specifics Other/Unknown	175	4	172	0	$71,705,766
450 2+V2Cyclist	234	23	169	239	$264,677,663
500 1V2Animal Roadway Departure, Avoid Animal	258,817	51	35,275	248,560	$5,368,396,496
502 1V2Animal, Backup	45	0	3	45	$526,175
509 1V2Animal, Specifics Other/Unknown	185	1	28	184	$8,986,265
550 2+V2Animal	1,913	18	918	2,792	$320,166,414
600 1V2Parked Vehicle Roadway Departure, Forward Impact	59,785	28	10,591	53,799	$1,807,585,264
602 1V2Parked Vehicle, Backup	41,957	2	5,293	40,389	$742,379,633
609 1V2Parked Vehicle, Specifics Other/Unknown	10,975	13	1,712	9,995	$389,028,013
650 2+V2Parked Vehicle	128	3	137	84	$50,430,859
700 1V2Other Non-Fixed Object Roadway Departure, Forward Impact	3,853	11	784	3,414	$229,360,460
701 1V2Other Non-Fixed Object Roadway Departure, Traction Loss	1	0	1	0	$411,757
702 1V2Other Non-Fixed Object, Backup	305	0	32	302	$8,365,380
709 1V2Other Non-Fixed Object, Other	22,656	22	4,489	20,658	$849,571,459

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs
750 2+V2Other Non-Fixed Object	1,703	9	906	2,863	$210,931,898
800 1V2Fixed Object Roadway Departure, Forward Impact	2,054	20	585	1,629	$301,018,970
801 1V2Fixed Object Roadway Departure, Traction Loss	41	1	3	40	$8,531,454
802 1V2Fixed Object, Backup	1,824	2	217	1,732	$57,909,313
809 1V2Fixed Object, Other	9,107	21	2,438	7,379	$593,885,608
850 2+V2Fixed Object	409	5	342	476	$100,050,978
1000 1V, Roadway Departure	966,709	9,751	359,238	679,402	$159,984,589,044
1001 1V RD, Traction Loss	41,585	881	18,506	26,307	$12,126,414,295
1002 1V RD, Avoid Vehicle/Pedestrian/Animal	11,011	14	4,499	7,295	$918,933,516
1003 1V Forward Impact, Ped or Animal	3,942	174	3,852	308	$2,528,172,517
1004 1V Forward Impact, End Departure	15,298	140	6,123	10,418	$2,474,614,130
1005 1V Forward Impact, Specifics Other/Unknown	1,937	78	642	1,481	$893,941,702
1009 1V Other/No Impact	15,655	196	4,907	12,407	$2,812,746,224
1050 2+V, Roadway Departure	43,957	1,021	32,069	55,856	$15,574,093,029
1100 1V Cross Centerline/Median	8,560	75	2,910	6,214	$1,262,853,834
1150 2+V Cross Centerline/Median*	3,427	106	2,678	4,239	$1,481,800,683
2000 Rear-End, Lead Vehicle Stopped	1,099,868	474	561,842	1,719,177	$80,023,139,895
2001 Rear-End, LV Slower	174,217	527	97,402	252,341	$18,930,190,490
2002 Rear-End, LV Decelerated	374,624	155	196,731	587,031	$28,386,370,919
2003 Rear-End, Other In-lane Vehicle Higher Speed	598	3	273	829	$71,434,395
2009 Rear-End, Specifics Other/Unknown	50,105	70	24,951	77,034	$4,268,912,681
2101 Same Trafficway Same Direction Forward Impact, Loss Control	51	0	70	4	$11,397,944
2102 Rear-End Possible, Same Trafficway Same Direction Forward Impact, Avoid Vehicle	1,459	1	937	1,537	$135,121,162
2103 Same Trafficway Same Direction Forward Impact, Avoid Objects	29	0	22	38	$7,444,234
2109 Rear-End Possible, Same Trafficway Same Direction Forward Impact, Specifics Other/Unknown	236	4	82	398	$56,389,474
2200 Same Trafficway Same Direction, Angle-Sideswipe	57,220	105	24,014	97,749	$4,562,157,900
2300 Rear-End Possible, Other In-lane Vehicle Stopped	1,842	37	839	2,510	$493,941,988
2301 Rear-End Possible, Other In-lane Vehicle Slower	813	6	486	1,063	$120,226,679

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs
2302 Rear-End Possible, Other In-lane Vehicle Decelerated	1,475	3	860	1,900	$150,957,924
3000 Same Trafficway Opposite Direction, Head-On	32,751	2,761	37,848	23,992	$35,044,078,412
3001 Same Trafficway Opposite Direction Forward Impact, Traction Loss	221	2	284	182	$58,930,453
3002 Same Trafficway Opposite Direction Forward Impact, Avoid Vehicle	605	13	705	392	$260,893,632
3003 Same Trafficway Opposite Direction Forward Impact, Avoid Object	83	1	154	38	$42,411,902
3009 Same Trafficway Opposite Direction Forward Impact, Other	115	11	69	135	$121,800,681
3100 Same Trafficway Opposite Direction, Angle Sideswipe	62,214	1,042	38,655	86,054	$16,815,824,875
3200 Head-On Possible, Other Vehicle Encroaching OD	4,008	11	2,979	5,019	$588,480,319
4000 Change Trafficway Vehicle Turing, Turn Across Path, Initial Opposite Direction	322,426	989	241,402	376,433	$46,030,838,856
4001 Change Trafficway Vehicle Turing, Turn Across Path, Initial Same Direction	41,474	25	15,721	69,539	$2,445,174,582
4009 Change Trafficway Vehicle Turing, Turn Across Path, Specifics Other/Unknown	36,229	29	11,492	64,338	$1,807,085,232
4100 Change Trafficway Vehicle Turing, Turn Into Path, into Same Direction	175,493	99	73,382	285,887	$11,294,796,342
4101 Change Trafficway Vehicle Turing, Turn Into Path, into Opposite Direction	241,283	542	144,898	327,687	$26,967,146,756
4109 Change Trafficway Vehicle Turing, Turn Into Path, Specifics Other/Unknown	50,270	35	19,228	83,364	$3,015,142,827
5000 Intersect Paths, Straight Across Path	361,501	1,687	263,890	432,227	$56,335,154,383
5009 Intersect Paths, Straight Path, Specifics, Specifics Other/Unknown	10,413	39	5,965	14,994	$1,277,531,511
6000 Backing Up to Vehicle/Object	101,503	23	26,761	189,059	$3,899,263,166
7000 1V Negotiating a Curve	2,468	52	997	1,717	$708,882,760
7050 2+V Negotiating a Curve	1,581	16	689	2,589	$268,258,062
8000 Lane Change/Merge Before Rear-End	48,749	128	26,040	71,977	$5,002,627,200
8001 Lane Change/Merge in Same Trafficway Same Direction Forward Impact	212	4	62	371	$48,646,405

Crash Scenarios	Crashes	Fatalities	MAIS 1-5 Injuries	PDOVs	Societal Costs
8002 Lane Change/Merge in Same Trafficway Same Direction Angle Sideswipe	371,504	332	129,595	651,962	$21,340,330,980
8003 Lane Change/Merge in Change Trafficway Vehicle Turing Initial Same Direction	58,389	40	20,685	99,476	$3,251,117,218
8004 Lane Change/Merge Other	24,216	38	11,924	36,940	$2,079,117,478
9000 Equipment Failure	36,900	254	17,959	35,522	$5,499,495,580
9020 Loss of Control Due to Tire/Engine/Poor Road	2,929	11	1,326	4,741	$321,312,955
9030 2+V, Left/Right Turn, Unspecified	6,057	11	2,279	10,489	$411,527,019
9040 2+V U-Turn	11,337	29	5,192	17,448	$989,657,257
9050 2+V Backing to Moving Vehicle	2,599	1	659	4,714	$99,440,164
9060 2+V No Impact	49	0	41	0	$6,592,221
9070 2+V Other	26,417	76	12,016	41,909	$2,573,967,405
9999 2+V Unknown	2,485	5	1,071	3,821	$184,312,383
Total	5,448,583	26,558	2,633,180	6,894,246	$660,819,140,895

Table E-2
MAIS 0-5 Injuries by Crash Scenarios

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
100 1V Rollover 1st Event	998	2,627	360	129	29	10
150 2+V Rollover 1st Event	288	292	33	9	2	1
200 1V Jackknife 1st Event	236	606	61	16	3	1
250 2+V Jackknife 1st Event	238	251	25	7	1	0
300 1V2Pedestrian Roadway Departure, Forward Impact	73,768	47,077	6,781	2,726	639	257
302 1V2 Pedestrian, Backup	3,403	2,242	253	75	16	5
309 1V2 Pedestrian, Specifics Other/Unknown	179	214	33	13	3	1
350 2+V2 Pedestrian	1,311	362	55	26	6	3
400 1V2Cyclist Roadway Departure, Forward Impact	56,741	38,233	5,018	1,755	389	135
402 1V2Cyclist, Backup	484	352	40	12	2	1
409 1V2Cyclist, Specifics Other/Unknown	178	140	21	8	2	1
450 2+V2Cyclist	302	144	16	6	2	1
500 1V2Animal Roadway Departure, Avoid Animal	7,326	33,112	1,750	327	54	33
502 1V2Animal, Backup	0	3	0	0	0	0

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
509 1V2Animal, Specifics Other/Unknown	0	27	1	0	0	0
550 2+V2Animal	845	815	75	21	4	2
600 1V2Parked Vehicle Roadway Departure, Forward Impact	3,428	9,691	690	163	30	16
602 1V2Parked Vehicle, Backup	1,294	5,009	234	39	6	5
609 1V2Parked Vehicle, Specifics Other/Unknown	277	1,554	120	30	5	3
650 2+V2Parked Vehicle	122	116	15	5	1	0
700 1V2Other Non-Fixed Object Roadway Departure, Forward Impact	354	708	56	16	3	1
701 1V2Other Non-Fixed Object Roadway Departure, Traction Loss	0	0	0	0	0	0
702 1V2Other Non-Fixed Object, Backup	3	31	1	0	0	0
709 1V2Other Non-Fixed Object, Other	1,224	4,101	296	72	14	6
750 2+V2Other Non-Fixed Object	756	819	67	16	3	1
800 1V2Fixed Object Roadway Departure, Forward Impact	167	508	54	17	4	2
801 1V2Fixed Object Roadway Departure, Traction Loss	1	3	0	0	0	0
802 1V2Fixed Object, Backup	18	199	13	4	1	0
809 1V2Fixed Object, Other	672	2,158	204	59	12	6
850 2+V2Fixed Object	214	300	32	8	2	0
1000 1V, Roadway Departure	112,581	307,554	35,914	12,113	2,645	1,012
1001 1V RD, Traction Loss	5,367	15,650	1,954	691	156	56
1002 1V RD, Avoid Vehicle/Pedestrian/Animal	1,508	3,847	456	151	33	11
1003 1V Forward Impact, Ped or Animal	4,566	3,154	459	181	42	16
1004 1V Forward Impact, End Departure	1,586	5,212	632	215	48	16
1005 1V Forward Impact, Specifics Other/Unknown	336	547	63	24	6	2
1009 1V Other/No Impact	3,120	4,256	444	157	36	14
1050 2+V, Roadway Departure	29,686	27,765	3,010	992	218	84
1100 1V Cross Centerline/Median	953	2,492	290	98	21	9
1150 2+V Cross Centerline/Median*	1,883	2,325	253	78	17	6
2000 Rear-End, Lead Vehicle Stopped	613,904	511,272	39,677	8,757	1,547	590
2001 Rear-End, LV Slower	104,695	87,599	7,479	1,846	349	130
2002 Rear-End, LV Decelerated	212,082	178,453	14,231	3,239	570	239
2003 Rear-End, Other In-lane Vehicle Higher Speed	272	242	23	6	1	0
2009 Rear-End, Specifics Other/Unknown	26,095	22,502	1,859	465	89	36

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
2101 Same Trafficway Same Direction Forward Impact, Loss Control	32	63	6	1	0	0
2102 Rear-End Possible, Same Trafficway Same Direction Forward Impact, Avoid Vehicle	1,444	842	74	17	3	1
2103 Same Trafficway Same Direction Forward Impact, Avoid Objects	12	19	2	1	0	0
2109 Rear-End Possible, Same Trafficway Same Direction Forward Impact, Specifics Other/Unknown	29	72	7	2	1	0
2200 Same Trafficway Same Direction, Angle-Sideswipe	20,478	21,793	1,673	428	83	37
2300 Rear-End Possible, Other In-lane Vehicle Stopped	664	744	72	19	3	1
2301 Rear-End Possible, Other In-lane Vehicle Slower	443	439	37	8	1	1
2302 Rear-End Possible, Other In-lane Vehicle Decelerated	1,216	775	65	16	3	1
3000 Same Trafficway Opposite Direction, Head-On	25,006	31,301	4,316	1,683	392	157
3001 Same Trafficway Opposite Direction Forward Impact, Traction Loss	135	247	28	7	1	0
3002 Same Trafficway Opposite Direction Forward Impact, Avoid Vehicle	451	594	76	27	6	2
3003 Same Trafficway Opposite Direction Forward Impact, Avoid Object	65	128	17	6	1	0
3009 Same Trafficway Opposite Direction Forward Impact, Other	72	56	8	4	1	0
3100 Same Trafficway Opposite Direction, Angle Sideswipe	31,174	33,708	3,479	1,126	245	98
3200 Head-On Possible, Other Vehicle Encroaching OD	2,297	2,603	270	83	17	7
4000 Change Trafficway Vehicle Turing, Turn Across Path, Initial Opposite Direction	223,526	212,338	21,439	6,001	1,206	418
4001 Change Trafficway Vehicle Turing, Turn Across Path, Initial Same Direction	14,057	14,437	993	229	42	20
4009 Change Trafficway Vehicle Turing, Turn Across Path, Specifics Other/Unknown	7,544	10,724	621	118	20	8
4100 Change Trafficway Vehicle Turing, Turn Into Path, into Same Direction	61,407	66,841	5,025	1,198	226	93
4101 Change Trafficway Vehicle Turing, Turn Into Path, into Opposite Direction	126,368	128,551	12,109	3,329	669	239

Crash Scenarios	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5
4109 Change Trafficway Vehicle Turing, Turn Into Path, Specifics Other/Unknown	15,985	17,619	1,252	283	52	22
5000 Intersect Paths, Straight Across Path	247,425	232,429	23,208	6,487	1,299	467
5009 Intersect Paths, Straight Path, Specifics, Specifics Other/Unknown	5,262	5,306	487	135	28	10
6000 Backing Up to Vehicle/Object	11,794	25,205	1,268	227	38	24
7000 1V Negotiating a Curve	447	840	106	39	9	3
7050 2+V Negotiating a Curve	509	615	53	16	4	1
8000 Lane Change/Merge Before Rear-End	26,823	23,400	1,997	507	97	39
8001 Lane Change/Merge in Same Trafficway Same Direction Forward Impact	51	57	4	1	0	0
8002 Lane Change/Merge in Same Trafficway Same Direction Angle Sideswipe	96,858	119,573	7,820	1,735	317	150
8003 Lane Change/Merge in Change Trafficway Vehicle Turing Initial Same Direction	15,215	19,058	1,275	279	50	22
8004 Lane Change/Merge Other	10,683	10,754	890	221	41	18
9000 Equipment Failure	11,579	15,589	1,677	536	115	42
9020 Loss of Control Due to Tire/Engine/Poor Road	1,082	1,181	103	31	7	3
9030 2+V, Left/Right Turn, Unspecified	1,788	2,108	139	27	5	1
9040 2+V U-Turn	4,108	4,723	364	84	16	5
9050 2+V Backing to Moving Vehicle	365	622	31	5	1	0
9060 2+V No Impact	56	37	3	1	0	0
9070 2+V Other	10,153	10,787	910	248	50	21
9999 2+V Unknown	1,117	989	67	12	2	1
Total	2,251,184	2,341,730	215,022	59,747	12,057	4,625