Target Crash Population of Automated Vehicles

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Paper Number 15-0430

ABSTRACT

This paper describes a method to determine the target crash population that could be addressed by automated vehicles. The method maps specific automated vehicle functions to five layers of crash information including crash location, pre-crash scenario, driving conditions, travel speed, and driver condition. The focus of this paper is on automated vehicle functions at automation levels 2 through 4 as defined by the National Highway Traffic Safety Administration. This paper identifies the automated vehicle functions and their automation levels, operational characteristics and conditions, and applicable pre-crash scenarios through literature review and relevant research programs. This paper also identifies the approach to query the crash data and account for level 0 and level 1 automated vehicle functions when estimating target crash populations for automated vehicle functions at levels 2 through 4. The application of this method, using the General Estimates System and Fatality Analysis Reporting system crash databases, would express the target crash populations in terms of the annual frequency of all crashes, fatal-only crashes, and involved persons at different injury levels.

INTRODUCTION

Automated vehicles have the potential to reduce motor vehicle crashes and mitigate the severity of injuries by performing driving controls effectively without the constraint of driver inputs. The target crash population (TCP) depends on the automated vehicle function and the level of automation. The National Highway Traffic Safety Administration (NHTSA) has defined the following five levels of automation that are distinguished by the degree of shared control and monitoring authority between the driver and the vehicle [1]:

- *Level 0 – No Automation (L0)*: This level accounts for crash warning systems and secondary automated controls such as wipers, headlights, etc.
- *Level 1 – Function-Specific Automation (L1)*: This level involves one or multiple specific control functions operating independently from each other. The driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control (e.g., adaptive cruise control), the vehicle can automatically assume limited authority over a primary control (e.g., electronic stability control), or the vehicle can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., automated emergency braking).
- *Level 2 - Combined Function Automation (L2)*: The driver cedes primary control of at least two primary control functions designed to work in unison in certain limited driving situations, but is still responsible for monitoring and safe operation of the vehicle. The driver is expected to be available at all times to control the vehicle.
- *Level 3 - Limited Self-Driving Automation (L3)*: The driver can cede full control and monitoring authority of all safety-critical functions under certain traffic and environmental conditions. The driver is expected to be available for occasional control of the vehicle.

- *Level 4 - Full Self-Driving Automation (L4)*: The driver provides navigation input but is not expected to be available for control of the vehicle. The vehicle is designed to safely perform all safety-critical driving functions and monitor roadway conditions for an entire trip.

This paper is focused on the target crash population for L2-L4 automation levels in light vehicles (e.g., passenger cars, vans and minivans, sport utility vehicles, and pickup trucks with gross vehicle weight rating less than 10,000 pounds). It describes a method to determine the target crash population that could be addressed by L2-L4 automated vehicles in general and the incremental target crashes that could not be addressed by crash avoidance applications or L0-L1 automation levels. Using NHTSA's General Estimates System (GES) and Fatality Analysis Reporting System (FARS) crash databases, the application of this method would express the TCP in terms of the annual frequency of all target crashes, fatal-only crashes, and involved persons at different injury levels. The potential safety benefits of automated vehicles would then be projected by multiplying the TCP values with estimates of the crash avoidance effectiveness of various automated vehicle functions. These crash avoidance effectiveness estimates need to be derived from research studies that collect and analyze driver-vehicle-roadway performance data for various automated vehicle systems.

Previous Research

NHTSA has conducted a crash causal study that analyzed 5,471 passenger vehicle crashes within the United States between 2005 and 2007. This analysis determined the pre-crash events and critical factors related to the actions that led to a crash [2]. Results from this study suggest that human error is the critical reason for 93% of crashes. Human errors were categorized into recognition (e.g., inattentive, distracted), decision (e.g., too fast, gap misjudgment), performance (e.g., overcompensation, poor control), and non-performance (e.g., sleepy, ill) errors. Thus, it has been alluded that automated vehicles at all levels of automation can potentially address a part of these crashes by supporting driver attention and response, and providing automatic vehicle control in both normal driving tasks and crash-imminent situations [3].

By compensating for driver error, many presentations and articles viewed the 93% of crashes as a preliminary estimate for the potential target crash population of automated vehicles. This general estimate is made independent of the prospective automated vehicle functions and their automation levels (i.e., L2-L4), and does not account for the crashes that would be avoided with crash avoidance systems and other motor vehicle safety applications (i.e., L0-L1). For example, forward crash warning (FCW) systems (i.e., L0) alert drivers to a potential crash with a slower or stopped lead vehicle. Rear-end crashes are the target crash population for FCW within the operational conditions of the system. On the other hand, an L2 automated car-following function, which controls the headway to lead vehicles and keeps the vehicle within the travel lane, would also target rear-end crashes mostly on highways. Hence, the analysis in this paper seeks to refine this general estimate of target crashes (93% of crashes) by describing a method that identifies target crash populations for individual automated vehicle functions and levels of automation, finds target crash overlaps among automated vehicle functions, and accounts for incremental target crashes between L0-L4 automation levels.

Approach

This paper first identifies and describes the operational conditions of prospective L2-L4 automated vehicle functions as reported in the literature. In addition, this paper lists L0 and L1 systems of interest that may share target crashes with higher levels of automated vehicle functions. Then, these automated vehicle functions and their operations are mapped to the crash information where they may apply. The applicability to crash information is dependent on the operational capabilities of each automated vehicle function and the availability of pertinent information. Key crash information includes the pre-crash scenarios and their characteristics, crash contributing factors of the driving environment and vehicle, and detailed crash causes of the driver. The query of the GES and FARS crash databases

would then yield the numbers of all police-reported and fatal-only crashes, as well as the numbers of injured persons and their injury levels, which could be addressed by L0-L4 functions individually and incrementally. The authors believe that the results will provide reasonable and defendable target crash populations and thus subsequent safety benefit estimates for automated vehicles. This will be accomplished by accounting for safety benefits as estimated from previous benefits studies addressing foundational crash avoidance technologies.

AUTOMATED VEHICLE FUNCTIONS

The automation of primary control systems in motor vehicles can generally support safe driving by improving driver performance overall. As examples of driver support, L2-L4 automated vehicle functions [4]:

- Can aid in driver vigilance; e.g., watch for forward collision or ensure vehicle heading.
- Can decrease total driver workload and mitigate driver fatigue.
- Monitor the driving environment at a constant level of alertness, which may eliminate small driver errors such as steering reversal.
- May offer some protection from distraction.
- May correct or prevent poor decisions of novice drivers.

In above examples, automated vehicle functions may address motor vehicle crashes in any pre-crash scenario caused by driver physiological impairment or driving task errors including driver recognition, decision, and action errors.

Specific L2-L4 automated vehicle functions may have the potential to address target driving situations and pre-crash scenarios caused by different factors. Examples of automated vehicle functions include [5]:

- *Adaptive Cruise Control (ACC) with Lane Keeping, Lane Centering, Lane Change, and/or Merge*: L2 automated functions that keep the vehicle in its intended lane of travel and at desired headway, and perform lane change and/or allow other vehicles to merge onto the roadway.
- *Automatic Parking*: L2-L4 automated functions that assist the driver or fully controls the parking of a motor vehicle.
- *Automated Roadwork Assistance*: L2 automated function that navigates the vehicle through a work zone at limited speeds.
- *Automated Shuttles/Taxis*: L4 automated functions that operate at relatively slow speeds in designated zones including city streets and campuses.
- *Close-Headway Platooning*: L3 automated function that controls the longitudinal and lateral dynamic aspects of the vehicle on highways at all speeds including entering and leaving the platoon.
- *Emergency Stopping Assistant*: L3-L4 automated function that detects incapacitated drivers and safely maneuvers the vehicle to park on the side of the roadway.
- *Highway Driving*: L2-L4 automated functions that perform all driving tasks on highways at varying degrees of complexity relative to the automation level.
- *Traffic Jam Assist*: L2 automated function that performs car-following (i.e., longitudinal control) and lane keeping (i.e., lateral control) on highways at slow speeds.

Table 1 lists key automated vehicle functions for different levels of automation including L0 systems that are considered for the estimation of target crash population. Applicable operational conditions and roadways are also indicated to help map these functions to target crashes. This analysis considers the following L0 functions:

- *Alcohol Detection Technology*: limits the operation of a vehicle if above-limit alcohol levels are detected for the driver.
- *Back-Up Systems*: warns driver of objects and persons when backing up.

- *Blind Spot Warning/Lane Change Warning (BSW/LCW)*: alerts drivers to the presence of vehicles approaching or in their blind spot in the adjacent lane.
- *FCW*: warns drivers of stopped, slowing, or slower vehicles ahead.
- *Intersection Movement Assist (IMA)*: warns drivers of vehicles approaching from a lateral direction at an intersection.
- *Left Turn Assist (LTA)*: warns drivers to the presence of oncoming, opposite-direction traffic when attempting a left turn.
- *Road Departure Crash Warning (RDCW)*: warns drivers of unintentional lane departure. This function also warns drivers when approaching a curve at unsafe speeds.

L1 automated vehicle functions under consideration include automatic parking, automated roadwork assistance, ACC, cooperative ACC (CACC), electronic stability control (ESC), automated emergency braking (AEB), and pedestrian crash avoidance and mitigation (PCAM).

Information about the operational conditions of the automated vehicle functions listed in

MAPPING OF AUTOMATED FUNCTIONS TO CRASH DATA

For specific automated vehicle functions, it is important to determine their applicable crash characteristics. Figure 1 illustrates the process used to map the specific automated vehicle functions to the crash data. This process correlates automated vehicle functions and their capabilities to the crash information available. It should be noted that deficiencies exist in the data collection and reporting process for GES and FARS databases. When applying this mapping process, circumventing these deficiencies would limit the quantity of available data. The following key crash characteristics help to decide on the applicability of automated vehicle functions: crash location, pre-crash scenario, driving environmental conditions, vehicle travel speed, and driver condition.

Location

The location of a crash easily identifies the applicability of an automated vehicle function to a crash. For example, an L0 IMA warning would only be issued at an intersection, L1 automated roadwork assistance function would only activate in a dedicated work zone, or L2 Highway Driving would be limited to highways. Furthermore, the general location of the crash within the crash data can be obtained from variables in the GES and FARS crash databases (e.g., dedicated work zone, non-junction, intersection, entrance/exit ramp, etc.).

Table 1 reflects details available from the literature at the time of this analysis (e.g., maximum speeds). This paper assumes that each automated vehicle function will mature in a timely manner and uses the intended operational capabilities when estimating target crash population (e.g., Close-Headway Platooning was only tested at a speed of 53 mph (85 km/h) and gaps of 5-15 meters, but platooning would plausibly occur at higher highway speeds).

Some automated vehicle functions (e.g., Highway Driving and Automatic Parking) transcend multiple levels of automation. These functions may be designed for minimal or full automation at the discretion of the manufacturer. An automatic parking feature may only control lateral motion when parallel parking or can allow the driver to leave the vehicle and have the vehicle park itself. The information obtained from this analysis was compared to variables in the GES and FARS crash databases to develop a mapping system that enables the correlation of automated vehicle functions to historical crash information.

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Table 1.

Summary of L0-L4 Automated Vehicle Functions.

Automation Level	AV Functions	Operational Conditions	Roadways
L0	Warning Systems (FCW, IMA, LTA, BSW/LCW, RDCW)	Speeds > 25 mph	All Roads
	Back-Up Systems	Reverse Only Low Speeds	All Roads
	Alcohol Detection Technology	Drunk Driver	All Roads
L1	Automated Roadwork Assistance 1	Low Speeds	Work Zone
	Automatic Parking 1	Low Speeds	Urban
	Pedestrian Crash Avoidance and Mitigation	Speeds < 45 mph	All Roads
	Adaptive Cruise Control (ACC)	High Speeds	Highway
	Cooperative Adaptive Cruise Control	High Speeds	Highway
	Electronic Stability Control	Loss of Control	All Roads
	Automated Emergency Braking	Imminent Crash	All Roads
L2	Automated Roadwork Assistance 2	Low Speeds	Work Zone
	Automatic Parking 2	Low Speeds	Urban
	Traffic Jam Assist	Speeds ≤ 37 mph	Urban
	ACC w/Lane Keeping and Lane Change	Speeds < 75 mph	Highway
	ACC w/Lane Keeping, Lane Change and Merge	Speeds ≤ 81 mph	Highway
	ACC w/Lane Centering	Speeds ≤ 100 mph	Highway
	Highway Driving 2	High Speeds	Highway
L3	Automatic Parking 3	Low Speeds	Urban
	Close-Headway Platooning	Speeds ≤ 56 mph	Highway
	Highway Driving 3	High Speeds	Highway
	Emergency Stopping Assistance 3	Incapacitated Driver	Highway
L4	Automatic Parking 4	Low Speeds	Urban
	Automated Shuttles/Taxis	Low Speeds	Urban
	Emergency Stopping Assistance 4	Incapacitated Driver	All Roads

Pre-Crash Scenario

The pre-crash scenarios depict specific vehicle movements and dynamics as well as the critical event occurring immediately prior to the crash [6]. Crash scenarios and their corresponding crash types. Some L0-L1 automated vehicle functions are primarily designed to prevent specific pre-crash scenarios (although secondary pre-crash scenarios may benefit from the same function). For example, an L0 FCW function is designed to prevent rear-end crashes and an L1 PCAM function is designed to prevent pedestrian crashes. Some L2-L4 automated vehicle functions indirectly address specific pre-crash scenarios based on the vehicle maneuvers that are automatically performed. For example, L2 ACC with Lane Centering would prevent rear-end, drifting, and road departure crashes.

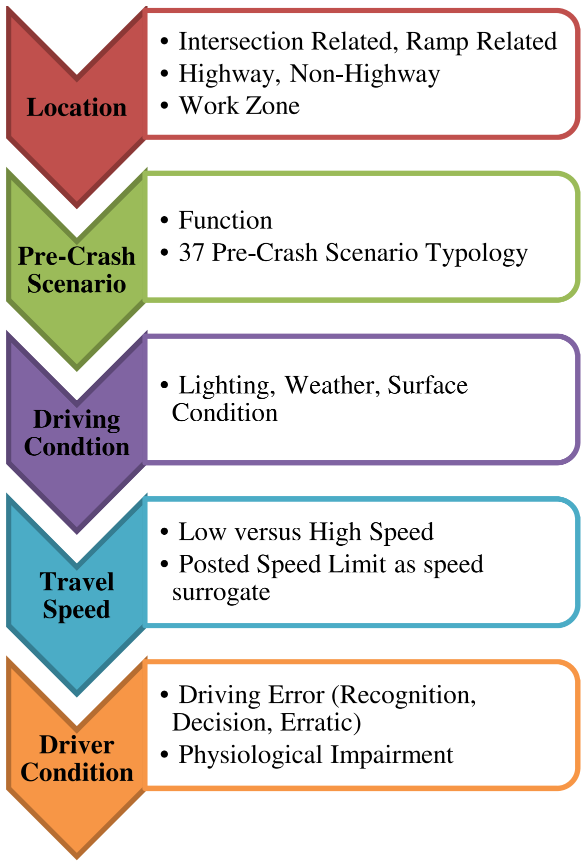

Figure 1. Breakdown Process to Correlate Automated Vehicle Functions to Crash Data.

Table 2.

List of Pre-Crash Scenarios and Corresponding Crash Types.

No	Pre-Crash Scenario	Crash Type
1	Vehicle Failure	Run-Off-Road
2	Control Loss with Prior Vehicle Action	
3	Control Loss without Prior Vehicle Action	
4	Running Red Light	Crossing Paths
5	Running Stop Sign	
6	Road Edge Departure with Prior Vehicle Maneuver	Run-Off-Road
7	Road Edge Departure without Prior Vehicle Maneuver	
8	Road Edge Departure While Backing Up	
9	Animal Crash with Prior Vehicle Maneuver	Animal
10	Animal Crash without Prior Vehicle Maneuver	
11	Pedestrian Crash with Prior Vehicle Maneuver	Pedestrian
12	Pedestrian Crash without Prior Vehicle Maneuver	
13	Pedalcyclist Crash with Prior Vehicle Maneuver	Pedalcyclist
14	Pedalcyclist Crash without Prior Vehicle Maneuver	
15	Backing Up into Another Vehicle	Backing
16	Vehicle(s) Turning – Same Direction	Lane Change
17	Vehicle(s) Parking – Same Direction	
18	Vehicle(s) Changing Lanes – Same Direction	
19	Vehicle(s) Drifting – Same Direction	
20	Vehicle(s) Making a Maneuver – Opposite Direction	Opposite Direction
21	Vehicle(s) Not Making a Maneuver – Opposite Direction	
22	Following Vehicle Making a Maneuver	Rear-End
23	Lead Vehicle Accelerating	
24	Lead Vehicle Moving at Lower Constant Speed	
25	Lead Vehicle Decelerating	
26	Lead Vehicle Stopped	
27	LTAP/OD at Signalized Intersections	Crossing Paths
28	Vehicle Turning Right at Signalized Intersections	
29	LTAP/OD at Non-Signalized Intersections	
30	Straight Crossing Paths at Non-Signalized Intersections	
31	Vehicle(s) Turning at Non-Signalized Intersections	
32	Evasive Action with Prior Vehicle Maneuver	Run-Off-Road
33	Evasive Action without Prior Vehicle Maneuver	
34	Non-Collision Incident	Other
35	Object Crash with Prior Vehicle Maneuver	Object
36	Object Crash without Prior Vehicle Maneuver	
37	Other	Other

By mapping the operational roadway of an automated function to the location of a crash, the pre-crash scenarios are naturally filtered out (e.g., crossing-path crashes don't occur on a highway for Highway Driving functions). The pre-crash scenarios are derived from various pre-crash event variables within the GES and FARS databases.

Driving Condition

The driving condition seeks to identify the environment in which the crash occurred. The environment is simplified to lighting, atmospheric conditions, and roadway surface conditions. All these conditions are readily available within GES and FARS databases. The described breakdown maps automated vehicle functions to crash data regardless of the technology used. However, it is possible that some technologies may be limited or suppressed in severe driving conditions. For example, a camera-based L2 ACC with lane keeping may not be available for operation on snow-covered roadways or an L3 Close-Headway Platooning may not operate at high speeds on wet or slippery roadway surfaces. When projecting the potential safety benefits in the future, driving conditions are crucial to estimating the crash avoidance effectiveness of these automated vehicle functions.

Travel Speed

Some automated vehicle functions are active at certain speeds. For example, an L1 PCAM function may not operate at speeds above 45 mph (72 km/h) or an L2 ACC with lane keeping may not work at speeds less than a typical highway speed (~50 mph or 80 km/h). Although travel speed is not as readily available or accurate in the crash data, this information can be deduced from other variables in the GES and FARS databases. For instance, it can be assumed that the driver is traveling at the speed limit if the travel speed is not a contributing factor to the crash (GES and FARS variable) on a roadway with certain posted speed limit (GES and FARS variable). On the other hand, if speed were referenced as a crash contributing factor, then it is assumed that the driver would be traveling at least +10 mph (16 km/h) over the speed limit. This analysis considers the 45 mph (72 km/h) travel speed as the threshold between "low" and "high" speed categories.

Driver Condition

Ideally, if full automation (L4) were to replace the driver in all motor vehicles then all crashes caused by the driver would be avoided given that the automation performs safely under all these crash conditions. Figure 2 illustrates a detailed breakdown of primary causal factors for light-vehicle crashes. It can be surmised that full automation (L4) could target up to 90% of motor vehicle crashes caused by driver error in driving tasks (i.e., recognition, decision, and action errors) and driver physiological condition (i.e., drunk, asleep, and ill) [7]. This is congruent to the results from the previously mentioned NHTSA study; however, the information provided in Figure 2 is a more detailed breakdown of primary causal factors based on 1992-1993 data from NHTSA crash databases.

Driving task errors in Figure 2 encompass:

- Recognition errors such as inattention, looked but did not see, and obstructed vision.
- Decision errors such as tailgating, unsafe passing, gap/velocity misjudgment, excessive speed, and trying to beat yellow light or other vehicle.
- Erratic actions such as failure to control vehicle, prior evasive maneuver, deliberate violation of traffic control device, and willful unsafe driving act.

Since the reported driver condition can be subjective depending on the combination of information provided in the crash data (e.g., drunk, inattentive, excessive speed) and that extensive human factors testing may be necessary to fully understand the capabilities of these automated vehicle functions as they relate to the driver, this analysis relegates the driver condition to the last layer of the breakdown.

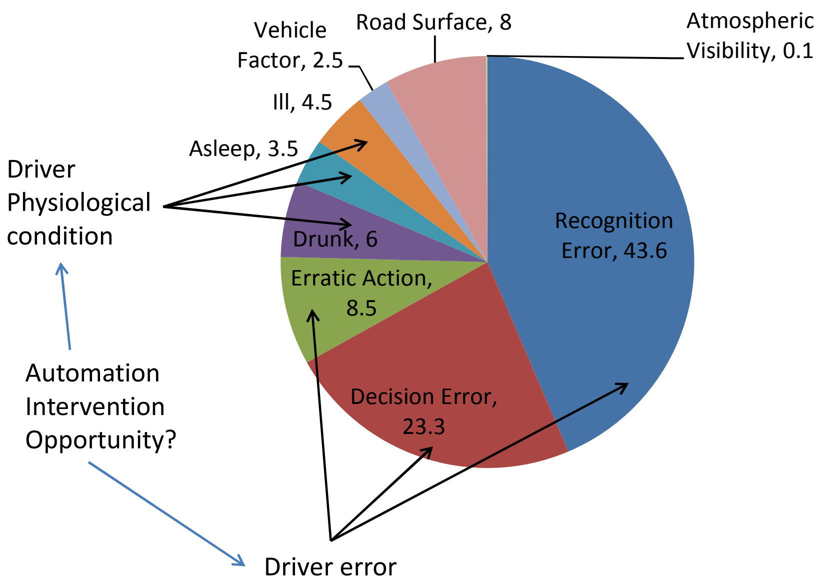

Figure 2. Critical Causal Factors for Light Vehicle Crashes (in % crashes).

Mapping Results

Table 3 shows the results of mapping the L2-L4 automated vehicle functions under consideration to the five layers of crash characteristics. The automated vehicle functions are categorized by level of automation. This mapping aggregates the results for individual automated vehicle functions to their levels of automation. Many of the listed automated vehicle functions overlap on many variables. By applying this method, the analysis should first map each automated vehicle function individually and later aggregate the results so as to directly trace and account for the overlaps.

Table 3.

Mapping of L2-L4 Automated Vehicle Functions to Crash Characteristics.

Automation Level	AV Functions	Location	Pre-Crash Scenarios	Driving Conditions	Travel Speed	Driver Conditions
L2	Automated Roadwork Assistance 2	Work Zone	Rear-End, Pedestrian	All	Low Speed	Recognition, Decision, Erratic
	Automatic Parking 2	Non-Highway	Parking	All	Low Speed	Recognition, Decision, Erratic
	Traffic Jam Assist	Highway	Rear-End, Drifting	All	Low Speed	Recognition, Decision, Erratic
	ACC w/Lane Keeping and Lane Change	Highway	Road Departure, Rear-End, Changing Lanes, Drifting	All	High Speed	Recognition, Decision, Erratic
	ACC w/Lane Keeping, Lane Change and Merge	Ramp, Highway	Road Departure, Rear-End, Changing Lanes, Drifting	All	High Speed	Recognition, Decision, Erratic
	ACC w/Lane Centering	Highway	Road Departure, Rear-End, Drifting	All	High Speed	Recognition, Decision, Erratic
	Highway Driving 2	Highway	Road Departure, Rear-End, Changing Lanes, Drifting	All	High Speed	Recognition, Decision, Erratic
L3	Automatic Parking 3	Non-Highway	Parking	All	Low Speed	Recognition, Decision, Erratic
	Close-Headway Platooning	Highway	Road Departure, Rear-End, Changing Lanes, Drifting	All	High Speed	Recognition, Decision, Erratic
	Highway Driving 3	Highway	Road Departure, Rear-End, Changing Lanes, Drifting	All	High Speed	Recognition, Decision, Erratic
	Emergency Stopping Assistance 3	Highway		All	All	Physiological Impairment
L4	Automatic Parking 4	Non-Highway	Parking	All	Low Speed	Recognition, Decision, Erratic
	Automated Shuttles/Taxis	Intersection, Non-Highway	Crossing Paths, Road Departure, Rear-End, Opposite Direction, Turning, Chagning Lanes, Drifting, Pedestrian, Pedalcyclist	All	Low Speed	All
	Emergency Stopping Assistance 4	All Roads		All	All	Physiological Impairment

TARGET CRASH POPULATIONS

The main focus of the method in this paper is to determine the target crash populations of L2-L4 automated vehicle functions. However, it is logical to consider L0 and L1 functions that are or will be simultaneously implemented in the light-vehicle fleet and will potentially provide considerable safety benefits. Table 4 lists the L0 and L1 functions and their corresponding mapping to crash data. Further research would provide detailed system effectiveness estimates for the listed applications.

Table 4.

Mapping of L0-L1 Automated Vehicle Functions

Automation Level	AV Functions	Location	Pre-Crash Scenarios	Driving Conditions	Travel Speed	Driver Conditions
L0	FCW	Work Zone, Ramp, Intersection, Non-Highway, Highway	Rear-End	All	High Speed	Recognition, Decision
	IMA	Intersection	Straight and Turning Crossing Paths	All	High Speed	Recognition, Decision
	LTA	Intersection	Left Turn Across Path / Opposite Direction	All	High Speed	Recognition, Decision
	BSW/LCW	Work Zone, Ramp, Highway, Non-Highway	Turning and Changing Lanes/ Same Direction	All	Low Speed High Speed	Recognition, Decision
	RDCW (CSW and LDW)	Work Zone, Ramp, Highway, Non-Highway	Road Departure, Drifting (Same Direction and Opposite Direction)	All	High Speed	Recognition, Decision
	Back Up Systems	Non-Highway, Non-Trafficway	Road Departure Backing, Backing into Vehicle	All	Low Speed	Recognition, Decision
	Alcohol Detection Technology					Physiological (Alcohol)
L1	Automated Roadwork Assistance 1	Work Zone	Rear-End, Pedestrian	All	Low Speed	Recognition, Decision, Erratic
	Automatic Parking 1	Non-Highway	Parking	All	Low Speed	Recognition, Decision, Erratic
	PCAM	Work Zone, Intersection, Non-Highway	Pedestrian	All	Low Speed	Recognition, Decision, Erratic
	ACC	Highway	Rear-End	All	High Speed	Recognition, Decision, Erratic
	CACC	Highway	Rear-End	All	High Speed	Recognition, Decision, Erratic
	ESC	All Roads	Control Loss, Rollover	All	All	Recognition, Decision, Erratic
	AEB	All Roads	Rear-End, Pedestrian, Opposite Direction	All	All	Recognition, Decision, Erratic

Accounting for the potential safety benefits of L0 and L1 functions as mapped to crash data in Table 4, L2-L4 automated vehicle functions would target the residual or remaining crashes not addressed or avoided by L0 and L1 functions. The TCP estimates can then be characterized by the level of automation incrementally (i.e., accounting for residual crashes) and independently (i.e., not accounting for target crashes or safety benefits by other levels).

CONCLUSION

This paper described a method to estimate the target crash populations for automated vehicle functions at levels 2 through 4 while accounting for the potential safety benefits that could be accrued from the full deployment of some selected L0 and L1 functions. This method correlated specific automated vehicle functions to five layers of crash data. This paper identified specific automated vehicle functions with detailed operational conditions and mapped each automated vehicle function through five filters within the crash data. Follow-on application of this method by querying the GES and FARS crash databases will generate the TCP estimates.

Automated vehicle functions at all levels of automation were identified and detailed, which included operational speeds, ranges, and locations. The five layers of crash data consisted of crash location, pre-crash scenario, driving condition, travel speed, and driver condition. This paper developed a method to estimate the TCP values that could be addressed by automated vehicle technology. The multiplication of these TCP values with estimates of the crash avoidance effectiveness would project the potential safety benefits of the various automated vehicle functions.

Further research is needed to estimate the crash avoidance effectiveness by analyzing driver-vehicle-roadway performance data collected from past and future research studies for various automated vehicle systems.

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ACRONYMS

ACC	Adaptive Cruise Control
AEB	Automated Emergency Braking
BSW/LCW	Blind Spot Warning/Lane Change Warning
CACC	Cooperative Adaptive Cruise Control
ESC	Electronic Stability Control
FARS	Fatality Analysis Reporting System
FCW	Forward Crash Warning
GES	General Estimates System
IMA	Intersection Movement Assist
LTA	Left Turn Assist
Lx	Automation Level x
NHTSA	National Highway Traffic Safety Administration
PCAM	Pedestrian Crash Avoidance and Mitigation
RDCW	Road Departure Crash Warning
TCP	Target Crash Population