What humanlike errors do autonomous vehicles need to avoid to maximize safety?

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CONTENTS

ABSTRACT

Introduction: The final failure in the causal chain of events in 94% of crashes is driver error. It is assumed most crashes will be prevented by autonomous vehicles (AVs), but AVs will still crash if they make the same mistakes as humans. This study highlighted the types of crashes that may still occur in an all-AV fleet if AVs are not designed to avoid poor choices that currently lead to crashes.

Method: Using the NMVCCS database, five categories of driver-related contributing factors were assigned to crashes: 1) *sensing/perceiving* (i.e., not recognizing hazards), 2) *predicting* (i.e., misjudging behavior of other vehicles) 3) *planning/deciding* (i.e., poor decision-making behind traffic law adherence and defensive driving), 4) *execution/performance* (i.e., inappropriate vehicle control), and 5) *incapacitation* (i.e., alcohol-impaired or otherwise incapacitated driver). Assuming AVs would have superior perception and be incapable of incapacitation, we determined how many crashes would persist beyond those with *incapacitation* or exclusively *sensing/perceiving* factors.

Results: 34% of crashes involved only *sensing/perceiving* factors (24%) or incapacitation (10%). If they could be prevented by AVs, 66% could remain, many with *planning/deciding* (39%), *execution/performance* (23%), and *predicting* (17%) factors. Crashes with *planning/deciding* factors often involved speeding (23%) or illegal maneuvers (15%).

Conclusions: Errors in choosing evasive maneuvers, predicting actions of other road users, and traveling at speeds suitable for conditions will persist if designers program AVs to make errors similar to those of today's human drivers. *Planning/deciding* factors, such as speeding and disobeying traffic laws, reflect driver preferences, and AV design philosophies will need to be consistent with safety rather than occupant preferences when they conflict.

Practical applications: This study illustrates the complex roles AVs will have to perform and the risks arising from occupant preferences that AV designers and regulators must address if AVs will realize their potential to eliminate most crashes.

Keywords: Autonomous; self-driving; guidance; design; recommendations; crashes

1. INTRODUCTION

According to the National Highway Traffic Safety Administration's (NHTSA) National Motor Vehicle Crash Causation Survey (NMVCCS), driver error is the final failure in the chain of events leading to approximately 94% of motor vehicle crashes (Singh, 2015). Crash avoidance systems help to mitigate the human risk element and are reducing the types of crashes they were designed to prevent, with the greatest benefits observed among systems such as automatic emergency braking that act on behalf of the driver (Cicchino, 2017). While the maximum potential of these systems is estimated to be high (Jermakian, 2011; Kusano & Gabler, 2014), more crashes are expected to be prevented by highly automated vehicles (Fagnant & Knockelman 2015; Yanagisawa, Najm, & Rau, 2017). It is widely anticipated in popular media and by some policymakers that autonomous vehicles (AVs) operating without human involvement under all driving conditions, known as Level 5 driving automation (SAE International, 2018), may eliminate nearly all crashes; for example, the 94% figure is frequently cited in U.S. federal policies on autonomous vehicles with the expectation that AVs will be able to avoid the majority of human errors that are known to lead to crashes today (U.S. Department of Transportation, 2018).

Impeding this goal, however, is that AV behavior will be programmed by humans based on idealized human driver behavior to be accepted by riders and other road users (Wei et al., 2019). While it can be assumed that AVs will have a superior ability to perceive the road environment compared to humans, there is no consensus on how AVs should behave on the road with respect to, for example, controlling speed, obeying traffic laws, or predicting the behavior of other road users. It has been argued that if AVs are designed to prioritize traffic safety above all else, there may be circumstances in which an AV may never complete its journey because it became stymied with the inflexibility of being unable to safely proceed while disobeying traffic rules; for instance, by not being able to cross a solid double line to avoid a parked vehicle (Vinkhuyzen & Cefkin, 2016). Another concern is that if AVs are so rigidly law abiding, they could cause other road users to misbehave and act unsafely. It can also be expected that AVs will not be subject to the hazards of alcohol impairment or incapacitation; however, there are other types of humanlike decision-making errors that may put AVs in similar situations that lead to crashes today if they are not explicitly programmed to avoid them.

The aim of this study was to highlight the roles that AVs will need to perform to avoid the errors that presently contribute to crashes and to determine how many crashes might continue to occur in an all-AV fleet if AVs are not deliberately designed to avoid them. The analysis reported in this paper assumed a 100% on-road AV fleet scenario because a mixed fleet will constrain some advantages that AVs may have, given that manually driven vehicles will always pose a threat. Teoh and Kidd (2017) found that vehicles in Google's (now Waymo) autonomous vehicle testing program had considerably fewer police-reported crashes per mile travelled than human-operated vehicles, but the crashes they did have were the result of other vehicles that were driven by humans, for example where the human-operated vehicles rear-ended or sideswiped the Google test vehicles. Although the current paper presents an arguably simplistic analysis of real-world crash data with the assumption of a 100% on-road AV fleet, the objective was to highlight the relative importance of the types of errors AVs need to be specifically programmed to avoid that are beyond the default assumptions of, for example, superior perception or invulnerability to distraction or incapacitation.

Typical driver errors were identified through nationally representative crash data in the NMVCCS database (NHTSA, 2008). Previous studies by NHTSA (e.g., Singh, 2015) focused on only the single critical reason for each crash, which is the immediate reason for the final event in the causal chains that led to the crash, and did not include other contributing factors that were present. However, crashes are typically the result of multiple factors, and therefore the present study analyzed both related factors and critical reasons to obtain a more complete understanding about why crashes occur and how AVs will need to be designed to prevent them.

Safe operation of a vehicle, regardless of whether it is human-operated or autonomously controlled, can be categorized into roles of sensing and perceiving, predicting, planning and deciding, and execution and performance. The analysis reported in this paper identified driver-based factors that undermined the safe implementation of these roles and led to crashes. Ideally, the operator should perceive the road environment around the vehicle and recognize potential hazards in the roadway. The operator must also be constantly monitoring and planning for where the vehicle should be in the road environment and how it should behave with respect to other road users. Decision-making behind vehicle control is also critical with respect to adherence to traffic laws and defensive driving strategies. Finally, the physical actions supporting vehicle control must be safely executed for the given road traffic and environment conditions, and appropriate evasive actions should be performed when a collision is imminent.

2. METHOD

2.1. Sample

Conducted by NHTSA (2008), NMVCCS contains a nationally representative sample of U.S. police-reported passenger vehicle crashes ($N = 5{,}471$) in which at least one of the vehicles involved was towed from the scene and for which emergency medical services were dispatched. These crashes occurred between 6 a.m. and midnight from 2005 to 2007. Detailed cases were established by trained on-scene investigators with a focus on the precrash phase of events to identify relevant contributing factors about the parties and vehicles involved as well as environmental, atmospheric, and roadway conditions at the time of the crash. Investigators assigned a critical reason to a single vehicle per crash that was judged to be the immediate cause for the event that made the crash inevitable. They also identified related factors that were present for each crash and wrote case summaries that described the events leading up to the crash.

2.2. Driver Factor Categories

We used a combination of the critical reason, precrash events, related factors, and case summaries to assign the driver-related contributing factors in each crash to five categories that captured the roles necessary to safely operate a vehicle: 1) *sensing and perceiving*, 2) *predicting*, 3) *planning and deciding*, 4) *execution and performance*, and 5) *incapacitation*.

Sensing and perceiving included driver-related factors concerning inattention, distraction, inadequate surveillance of the road, recognition errors, moving the vehicle when the view of traffic or the roadway was obstructed, headlight failure, and environmental factors that obstructed the view (i.e., fog, glare, and blowing debris). The *predicting* category included factors relating to misjudgment of a gap in traffic or the speed of another road user as well as a false assumption of another road user's actions. *Planning and deciding* included unsafe decision-making factors for the road and environmental conditions, such as speeding, driving too slowly, tailgating, lane weaving, illegal maneuvers, suddenly stopping, and obstructing paths of others, as well as needing to drive more carefully due to road maintenance issues (e.g., potholes) and slick road conditions (including rain or snow). *Execution and performance* factors included inadequate or incorrect evasive maneuvers, panicking or freezing, overcompensation, and poor directional control. *Incapacitation* included factors relating to alcohol impairment (blood alcohol concentration [BAC] of 0.08 or greater) or incapacitation due to drug use, medical impairment, or sleep. The first four categories related to the roles necessary to safely operate a vehicle, and the fifth category included circumstances where a driver who was incapacitated was considered to be incapable of any of these roles.

The variables used to define the contributing factor categories are described in Table A1 of the Appendix. Our classification is similar to that used by NHTSA to group driver-related critical reasons, but they differ in places. We considered some environment- or vehicle-related factors classified by NHTSA to be sensing and perceiving factors if they impaired the driver's perception, or planning and deciding/execution and performance factors if the driver's response to poor conditions may have contributed to the crash. Based on the NMVCCS coding manual descriptions, there was a subset of variables identified in the data set that could have fallen into several of our driver factor categories or none at all, depending on what occurred in the crash (Table A2 in the Appendix). We categorized crashes with these ambiguous variables by reviewing their case summaries.

Unlike most other factors in the NMVCCS database, there is no variable that identifies whether a vehicle was traveling too fast for conditions if speeding was not considered the critical reason for the crash. After reviewing a proportion of case summaries, we identified key terms for crashes in which excess speed was present. Crashes were determined to have speeding as a related contributing factor if the case summary used the phrases "traveling [or travelling] too fast," "too fast for conditions," "associated factors included too fast," "excess speed," or "unsafe speed." If the case summary contained the phrases "too fast" or "high speed," we reviewed the summary to judge if a driver involved in the crash was speeding.

The events that made some crashes inevitable were due to vehicle failures or roadway-related critical reasons that could not have been avoided by a careful driver's response. These crashes were considered to be unavoidable by drivers and were not included in the driver-related contributing factor categories, even if a related variable or keyword was assigned to the crash in the NMVCCS database. For example, if a vehicle crashed because of a tire blowout that occurred while the driver was distracted, distraction was not considered a contributing factor to the crash. The variables that defined unavoidable crashes are outlined in the Appendix (Table A1).

2.3. Analysis

Crashes were weighted in the NMVCCS data set to represent national estimates of over two million crashes that meet the geographic location, time of day, date, and severity criteria of the survey (see NHTSA, 2008 for more details), and we use weighted values in our analyses. We first report the percent of crashes with contributing factors associated with each driver factor category.

It is reasonable to expect, although not certain, that AVs will do a better job of perceiving the environment than humans; however, AVs will still need to be programmed to act safely in response to what they perceive. Likewise, it is also reasonable to assume that, as self-driving vehicles, AVs will not be vulnerable to incapacitation or alcohol impairment issues. Accordingly, we assumed that AVs would prevent crashes that had sensing and perceiving factors only, as well as those with incapacitation factors. Crashes with sensing and perceiving factors were only considered to be addressed by AVs if they did not have other identified driver-related factors, as these additional factors could have contributed to the crash even if the AV had flawless perception. Crashes with incapacitated drivers were considered to be preventable by AVs regardless of the presence of any other driver-related factors, as it was assumed that incapacitation undermines all of the driving roles the operator must perform to safely navigate the road, and the object of the analysis was to determine the percent of crashes that could remain beyond these implicit assumptions. We separated these crashes from the rest of the data set to determine the percentage of crashes that could persist if sensing and perceiving errors and incapacitation no longer contributed to crashes.

3. RESULTS

As shown in Table 1, the majority of crashes had sensing and perceiving factors (62%), followed by planning and deciding factors (41%), execution and performance factors (27%), predicting factors (17%), and lastly incapacitation factors (10%). Two percent of crashes were determined to have unavoidable factors. Four percent of crashes did not have contributing factors that fell into any of these categories, because either there were no associated driver-related factors or the type of driver factor was unknown.

Table 1. Number and percent of crashes with various types of contributing factors

Factor type	Weighted n	Weighted %[a]
Sensing and perceiving	1,353,713	61.8
Planning and deciding	903,359	41.3
Execution and performance	585,404	26.7
Predicting	378,419	17.3
Incapacitation	229,250	10.5
Any driver-related factor	2,066,938	94.4
Unavoidable by driver	41,469	1.9
Type of contributing factors unknown	80,562	3.7
All crashes	2,188,970	100.0

[a] Percentages sum to more than 100 because a crash could have multiple contributing factors.

A total of 34% of crashes had sensing and perceiving errors only (24%) or any incapacitation factors (10%). Sixty-six percent of crashes would still occur if AVs had superior perception and were never incapacitated, but were not designed to avoid other types of human error (Table 2). In particular, 60% of crashes would still occur that had at least one error related to unsafe driver response, including planning and deciding (39%), execution and performance (23%), or predicting (17%) errors.

Table 2. Number and percent of crashes that would remain by driver factor category if crashes related to sensing and perceiving only or to incapacitation categories were eliminated by AVs

Factor type	Weighted n	Weighted %[a]
Only sensing and perceiving	516,652	23.6
Incapacitation	229,250	10.5
Crashes preventable by AVs	745,902	34.1
Planning and deciding	851,882	38.9
Execution and performance	506,700	23.2
Predicting	371,089	17.0
Remaining crashes with a predicting, planning and deciding, or execution and performance factor	1,321,036	60.4
Unavoidable by driver	41,469	1.9
Type of contributing factors unknown	80,562	3.7
All remaining crashes	1,443,068	65.9
All crashes	2,188,970	100.0

[a] Percentages sum to more than 100 because a crash could have multiple contributing factors.

Because planning and deciding errors were the most common driver-related contributing factors that would remain, the specific types of these errors were further examined (i.e., speeding, illegal maneuvers, following too closely, other aggressive driving) and are defined in Table A3 of the Appendix. Speeding was the most common planning and deciding factor (23%), followed by illegal maneuvers (15%), and a similar smaller percentage of crashes were associated with following too closely (3%) and other aggressive driving (3%); some crashes with planning and deciding contributing factors had multiple types of these errors.

4. DISCUSSION

Only about a third of serious crashes could be preventable by AVs if they are not designed to respond safely to what they perceive, which is far less than the 94% of crashes arising from driver error (Singh, 2015) often cited as evidence that AVs may eliminate most crashes. The 2018 crash where a vehicle testing the Uber Advanced Technologies Group's (ATG's) automated driving system fatally injured a pedestrian in Tempe, AZ, (National Transportation Safety Board [NTSB], 2019) highlights the need for self-driving vehicles to not only perceive the environment around them, but also to appropriately predict, plan, decide, and execute behaviors in response to what they perceive. In this particular crash, the automated driving system detected the pedestrian in the road, but it did not correctly predict that she would cross in front of the vehicle. It also did not execute the appropriate evasive maneuver, as it failed to initiate emergency braking immediately when it did determine that a collision was imminent. Errors in performing evasive maneuvers, choosing travel speeds for traffic and road conditions, and predicting the actions of other road users will persist if AVs are designed to make similar errors that human drivers make today.

Intentional decisions as characterized by the planning and deciding category contributed to a considerable proportion of crashes, which supports concerns about AVs having capabilities that could undermine safety. Speed in particular is a key contributing factor to crashes today, as it makes a crash more likely by decreasing the time available to react (Elvik, 2005). While AVs may be able to detect and thus react to hazards more quickly than human drivers (Schoettle, 2017), they will not be able to respond instantaneously. Obeying traffic laws and speed limits is important for a baseline protocol, but defensive driving strategies that further adapt to road and traffic conditions are also paramount to safe AV operation. For example, there will never be a 100% road user conversion to AVs with the presence of cyclists and pedestrians; consequently, AVs will need to modulate their behavior to accommodate other road users, such as slowing down in the presence of pedestrians to account for potentially unexpected behavior (Thornton, Limonchik, Lewis, Kochenderfer, & Gerdes, 2019; Vinkhuyzen & Cefkin 2016). Small differences in speed can have big differences in the risk of death or serious injury to pedestrians (Tefft, 2013), and therefore AVs slowing down in areas with high pedestrian traffic would likely minimize these incidents.

With speeding and illegal maneuvers contributing to many crashes today, it is likely that a design philosophy that emphasizes adherence to traffic laws and defensive driving strategies will at times be at odds with rider preferences (Nordoff et al. 2018). When rider preferences and safety conflict, however, AVs must be programmed to prioritize the latter. Some safety-oriented design principles, such as Mobileye's (2018) Responsibility-Sensitive Safety (RSS) model, have already attempted to formalize this approach to defining decision-making protocols in AVs with respect to, for example, establishing minimum safe distances from road users, anticipating the actions of others, proceeding with caution when sight is restricted, giving right-of-way, and performing appropriate evasive maneuvers.

The goal of this study was to develop design guidance for automated driving programs to help AVs live up to their potential of eliminating most crashes that occur today. We assumed that AVs would not suffer from the same perception errors as human drivers nor be susceptible to incapacitation with physiological causes. Computers cannot become intoxicated by alcohol or drugs, but errors in programming can lead to inactivity that may have similar consequences. The Tempe, AZ, crash also illustrates that inerrant perception is not guaranteed. Even with its four forward-facing cameras, two forward-facing radars, and a 360° field-of-view LIDAR unit, the Uber ATG experimental vehicle variously classified Elaine Herzberg as an unknown object, a vehicle, and a bicycle in the 10 s between its first detecting her and impact, which in turn affected how the system struggled to predict her behavior and thus how it executed avoidance maneuvers (NTSB, 2019). While it is reasonable to expect that AVs will have superior perception to human drivers by the time these vehicles are on the market and out of the testing phase, this crash demonstrates the interconnectivity of the roles that AVs must perform simultaneously.

One consideration that could not be addressed by this analysis is the extent to which the number of crashes due to other factors might increase. For example, AVs will be equipped with more sensing and control hardware than currently available vehicles, and therefore the number of hardware failures leading to crashes might increase. Even in an all-AV fleet scenario, there is the possibility that the distribution of crash risk might change but not be completely eliminated, as certain crash categories could grow while others decline. Moreover, while the technological limitations that exist today will likely change in the future, AVs will still have to be programmed to recognize hardware shortcomings and to respond appropriately; for example, if the sightline is restricted by road geometry, the AV should reduce its speed to proceed with caution until the necessary sight distance is restored.

5. PRACTICAL APPLICATIONS

Even though driver-related factors lead to the majority of crashes, this study shows that merely removing the human driver when implementing a fully autonomous system will not automatically guarantee a reduction in or the elimination of crashes. Our analysis demonstrates that multiple types of factors typically contribute to the chain of events that lead to crashes and illustrates the complexity of the roles that AVs will need to be programmed to perform to avoid the errors that lead to crashes today. Intentional driver decisions that contribute to crashes, such as speeding and illegal maneuvers, emphasize the need for AV designers to program these roles with priority given to safety protocols over occupant preferences when the two conflict. Regulators must establish guidelines that enforce the need for AV design philosophies to go beyond default assumptions that AVs will have superior perception and invulnerability to distraction, impairment by alcohol or other drugs, and incapacitation.

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7. REFERENCES

Cicchino, J.B. (2017). Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accident Analysis &Prevention, 99*, 142–152. doi:10.1016/j.aap.2016.11.009

Elvik, R. (2005).Speed and road safety: Synthesis of evidence from evaluation studies. *Transportation Research Record*, *1908,* 59–69. doi:10.1177/0361198105190800108

Fagnant, D.J., & Kockelman, K. (2015) Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A, 77,* 167–181. doi.org/10.1016/j.tra.2015.04.003

Jermakian, J.S. (2011) Crash avoidance potential of four passenger vehicle technologies. *Accident Analysis &Prevention*, *43,* 732–740. doi:10.1016/j.aap.2010.10.020

Kusano, K.D., & Gabler, H.C.(2014). Comprehensive target populations for current active safety systems using national crash databases. *Traffic Injury and Prevention, 15,*753–761. doi:10.1080/15389588.2013.871003

Mobileye. (2018). *Implementing the RSS model on NHTSA pre-crash scenarios*. Jerusalem, Israel. Retrieved from https://www.mobileye.com/responsibility-sensitive-safety/rss_on_nhtsa.pdf

National Highway Traffic Safety Administration. (2008). *National Motor Vehicle Crash Causation Survey: Report to Congress* (Report No. DOT HS 811 059). Washington, DC.

National Transportation Safety Board. (2019). *Collison between vehicle controlled by developmental automated driving system and pedestrian* (Highway Accident Report NTSB/HAR-19/03). Washington DC.

Nordoff, S., de Winter, J., Madigan, R., Merat, N., van Arem, B., & Happee, R. (2018). User acceptance of automated shuttles in Berlin-Schöneberg: A questionnaire study. *Transportation Research Part F, 58,* 843–854. doi:10.1016/j.trf.2018.06.024

SAE International. (2018). *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles* (Report No. J3016_201806). Warrendale, PA.

Schoettle, B. (2017). Sensor fusion: A comparison of sensing capabilities of human drivers and highly automated vehicles (Report No. SWT-2017-12). Ann Arbor, MI: University of Michigan.

Singh, S. (2015). *Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey.* (Traffic Safety Facts Crash Stats, Report No. DOT HS 812 115).Washington, DC: National Highway Traffic Safety Administration.

Tefft, B.C. (2013). Impact speed and pedestrian's risk of severe injury or death. *Accident Analysis &Prevention*, *50,* 871–878. doi:10.1016/j.aap.2012.07.022

Teoh, E.R., & Kidd, D.G. (2017). Rage against the machine? Google's self-driving car versus human drivers. *Journal of Safety Research., 63,* 57–60. doi:10.1016/j.jsr.2017.08.008

Thornton, S.M., Limonchik, B., Lewis, F.E., Kochenderfer, M.J., & Gerdes, J.C. (2019). Toward closing the loop on human values. *IEEE Transactions on Intelligent Vehicles, 4*(3)*,* 437–446.

U.S. Department of Transportation. (2018). Preparing for the future of transportation: Automated vehicles 3.0. Washington, DC.

Vinkhuyzen, E., & Cefkin, M. (2016). Developing socially acceptable autonomous vehicles. In *2016 Ethnographic Praxis in Industry Conference Proceedings*. 522–534. doi: 10.1111/1559-8918.2016.01108

Wei, C., Romano, R., Merat, N., Wang, Y., Hu, C., Taghavifar, H., Hajiseyedjavadi, F., & Boer, E.R. (2019). Risk-based autonomous vehicle motion control with considering human driver's behavior. *Transportation Research Part C, 107,* 1–14. doi: 10.1016/j.trc.2019.08.003

Yanagisawa, M., Najm, W.G., & Rau, P. (2017). Preliminary estimates of target crash populations for concept automated vehicle functions (Paper No. 17-0266). *Proceedings of the 25th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*.

8. APPENDIX

NMVCSS Variables Used to Define Driver Factor Categories

Table A1. Variables in the NMVCCS database that fell under each driver factor category

Driver factor category	Description	NMVCCS variable	Value
Sensing and perceiving	Inattention	CRITREASON	110
	Internal distraction	CRITREASON	111
	External distraction	CRITREASON	112
	Inadequate surveillance (e.g., failed to look or looked but did not see)	CRITREASON	113
	Other recognition error	CRITREASON	114
	Unknown recognition error	CRITREASON	119
	Turned with obstructed view	CRITREASON	133
	Lights failed	CRITREASON	207
	Vehicle-related vision obstructions	CRITREASON	208
	Signs/signals inadequate	CRITREASON	502
	View obstructed by roadway design/furniture	CRITREASON	503
	View obstructed by other vehicles	CRITREASON	504
	Fog	CRITREASON	521
	Glare	CRITREASON	525
	Blowing debris	CRITREASON	526
	Driver inattention	INATTEN	2,3,4,5,6,7,8
	Inadequate surveillance	SURVEIL	2,3,4,5,6,7,8,9
	Other driver recognition factors	OTRECOG	2,3,4
	Other nondriving activities	OTDRACT	1
	Driver conversing	CONVERSE	2,3,4,5
	Other driver decision factors (crossed with obstructed view and turned with obstructed view)	OTDECISION	2,3
	View obstruction: Related to load	VCONFACT1	1
	View obstruction: Related to vehicle design	VCONFACT2	1

Driver factor category	Description	NMVCCS variable	Value
	View obstruction: Related to other	VCONFACT3	1
	Roadway view obstructions	RWAYFACT2	1
	View obstructed by other vehicle	RWAYFACT3	1
	Sun glare	OTENVFACT1	1
	Headlight glare	OTENVFACT2	1
	Looking for street address	EXTFA3	1
	Looking at building	EXTFA5	1
	Unspecified outside focus	EXTFA6	1
Planning and deciding	Too fast for conditions	CRITREASON	120
	Too fast to be able to respond to unexpected actions of others	CRITREASON	121
	Too fast for curve/turn	CRITREASON	122
	Too slow for traffic stream	CRITREASON	123
	Following too closely to respond to unexpected actions	CRITREASON	125
	Illegal maneuver	CRITREASON	127
	Aggressive driving behavior	CRITREASON	131
	Maintenance problems (potholes, etc.)	CRITREASON	508
	Slick roads	CRITREASON	509
	Rain, snow	CRITREASON	520
	Precrash event of loss of control because too fast for conditions	PREEVENT	6
	Following too closely	TOOCLOSE	2,3,4,5,6
	Illegal maneuvers	ILLMAN	1
	Other driver decision factors (stopped when not required, proceeded with insufficient clearance, and turned without signaling)	OTDECISION	4,5,6
	Aggressive driving act: Speeding	AGGRACT1	1
	Aggressive driving act: Tailgating	AGGRACT2	1
	Aggressive driving act: Rapid/frequent lane changes/weaving	AGGRACT3	1

Driver factor category	Description	NMVCCS variable	Value
	Aggressive driving act: Ignoring traffic control devices	AGGRACT4	1
	Aggressive driving act: Accelerating rapidly from stop	AGGRACT5	1
	Aggressive driving act: Stopping suddenly	AGGRACT6	1
	Aggressive driving act: Obstructing the path of others	AGGRACT10	1
Execution and performance	Inadequate evasive action (e.g. braking only, not braking and steering)	CRITREASON	129
	Incorrect evasive action	CRITREASON	130
	Panic/freezing	CRITREASON	141
	Overcompensation	CRITREASON	142
	Poor directional control (e.g., failing to control the vehicle with skill ordinarily expected)	CRITREASON	143
	Other performance error	CRITREASON	144
	Unknown performance error	CRITREASON	149
	Incorrect/inadequate evasive action	INEVASION	2,3,4,5,6
	Driver performance error	DRPERROR	1
Predicting	Misjudgment of gap or other's speed	CRITREASON	124
	False assumption of other’s actions	CRITREASON	126
	Misjudgment of distance or speed of other vehicle	MISJUDGE	2,3,4
	False assumption of other’s actions	FALSEASMPT	2,3,4,5,6,7
Incapacitation	Sleeping, that is, actually asleep	CRITREASON	100
	Heart attack or other physical impairment of the ability to act	CRITREASON	101
	Other critical nonperformance	CRITREASON	102
	Unknown critical nonperformance	CRITREASON	109

Driver factor category	Description	NMVCCS variable	Value
	Blood alcohol concentration (BAC)	BACTEST	≥0.08
Unavoidable by driver	Brakes failed	CRITREASON	200
	Degraded braking capability	CRITREASON	201
	Tires/wheels failed	CRITREASON	202
	Other tire degradation	CRITREASON	203
	Steering failed	CRITREASON	204
	Suspension failed	CRITREASON	205
	Transmission/engine failure	CRITREASON	206
	Cargo shifted	CRITREASON	210
	Trailer attachment failed	CRITREASON	211
	Jackknifed	CRITREASON	212
	Other vehicle failure	CRITREASON	213
	Unknown vehicle failures	CRITREASON	299
	Signs/signals missing	CRITREASON	500
	Road design: Roadway geometry (e.g., ramp curvature)	CRITREASON	505
	Road design: Sight distance	CRITREASON	506

Related to speeding behavior in the *planning and deciding* category, we also searched the case descriptions for the following key terms to be included in this category: "traveling [or travelling] too fast", "too fast for conditions", "associated factors included too fast", "excess speed", and "unsafe speed". The critical reasons of lights failed, vehicle-related vision obstructions, signs/signals inadequate, view obstructed by roadway design/furniture or other vehicles, fog, glare, and blowing debris, as well as the related factors of view obstructions related to load/vehicle design/roadway/other vehicles/other, sun glare, or headlight glare were considered to be vehicle or environmental factors by NHTSA. We classified these factors as sensing and perceiving because they impaired the driver's perception of the road environment. Similarly, the critical reasons of maintenance problems (e.g., potholes), slick roads, and rain/snow were classified as environmental factors by NHTSA. We identified them as planning and deciding factors because the driver's response to poor conditions in these cases may have contributed to the crash. Rain/snow as a critical reason was categorized as a planning and deciding factor, and not a sensing and perceiving factor, because upon review such cases were found to involve loss of vehicle control and not to have obstructed the driver's view of the road.

NMVCCS Variables Coded Based on Case Summaries

Some factors were coded on a case-by-case basis using the case summaries for all the crashes that did not already have a factor identified for any of the driver error categories outlined in Table A1. Table A2 lists the driver-contributing variables in the NMVCCS database that were coded using the case summaries.

Table A2. Variables in the NMVCCS database that were coded using the case summaries for each driver factor category

Driver factor category	Description	NMVCCS variable	Value
Possibly sensing and perceiving	Body, doors, hood failed	CRITREASON	209
	Atmospheric condition: Fog/smog/smoke	WEATHER3	1
	Exterior factor: Looking at previous crash	EXTFA1	1
	Exterior factor: Looking at outside person	EXTFA4	1
	Exterior factor: Other	EXTFA7	1
	Exterior factor: Looking at animal	EXTFA8	1
	Vehicle condition related factor: Other	VCONFACT11	1
Possibly planning and deciding	Signs/signals erroneous/defective	CRITREASON	501
	Roadway related factor: Lane delineation problems	RWAYFACT6	1
	Roadway-related factor: Narrow road	RWAYFACT8	1
	Roadway-related factor: Roadway condition	RWAYFACT10	1
	Roadway-related factor: Road under water	RWAYFACT12	1
	Roadway-related factor: Slick surface	RWAYFACT13	1
	Roadway-related factor: Road washed	RWAYFACT14	1
	Atmospheric condition: Snow	WEATHER2	1
	Atmospheric condition: Sleet, hail	WEATHER5	1
	Aggressive driving: Other	AGGRACT11	1
Possibly execution and performance	Wind gust	CRITREASON	522
	Severe crosswinds	WEATHER7	1
Possibly sensing and perceiving OR planning and deciding	Road design: Other	CRITREASON	507
	Other highway-related condition	CRITREASON	510
	Other weather-related condition	CRITREASON	523
	Other sudden ambience change	CRITREASON	527

Driver factor category	Description	NMVCCS variable	Value
	Atmospheric condition: Blowing snow	WEATHER6	1
	Roadway-related factor: Traffic signs/signals missing/defective	RWAYFACT1	1
	Roadway-related factor: Other roadway problem	RWAYFACT15	1
Possible sensing and perceiving, planning and deciding, OR execution and performance	Other decision error	CRITREASON	132
	Unknown decision error	CRITREASON	139
	Other decision error	OTDECISION	7
	Atmospheric conditions: Other	WEATHER8	1

Case summaries for crashes with variables that were considered possibly *sensing and perceiving* were reviewed to determine if the variable in question obscured the driver's view (fog/smog/smoke, body/doors/hood failed, vehicle condition-related factor: other) or distracted the driver (exterior factors). If the factor was merely present but did not contribute to the crash by impeding the driver's perception of the road, it was not considered to be a *sensing and perceiving* factor.

Similarly, case summaries with possible *planning and deciding* variables were reviewed to determine if the driver's poor decision in response to the named environmental conditions or aggressive actions contributed to the crash. We additionally reviewed case summaries containing the keywords "too fast" or "high speed" and coded these crashes as having *planning and deciding* errors if speeding was a contributing factor to the crash. Possible *execution and performance* variables included wind gusts and severe crosswinds, and we established from the associated case summaries if drivers lost control of their vehicles due to wind (i.e., the crash was the result of poor vehicle control in that environmental condition).

Some variables could potentially be associated with one of multiple driver roles. We identified from case summaries for crashes with variables that could possibly be *sensing and perceiving* or *planning and deciding* if the variable was associated with the driver being unable to see the roadway, other poor driver decisions due to roadway conditions, or none of these; for crashes with variables that were possibly *sensing and perceiving*, *planning and deciding*, or *execution and performance*, we additionally considered from the case summary if the driver's control of the vehicle contributed to the crash.

Crashes with critical reasons related to the vehicle or environment that were not judged upon review to have a sensing and perceiving, planning and deciding, or execution and performance driver factor were classified as being unavoidable by the driver. This included crashes with the critical reasons of body/doors/hood failed, signs/signals erroneous/defective, wind gust, road design: other, other highway-related condition, other weather-related condition, and other sudden ambience change.

NMVCCS Variables Belonging to Planning and Deciding Category

Common specific errors that constituted to *planning and deciding* errors are defined in Table A3. In addition to the variables listed in the table, crashes with *planning and deciding* contributing factors were considered to have speeding errors if their case summaries contained the key words flagged for speeding that were mentioned earlier in the Appendix.

Table A3. Variables in the NMVCCS database used to define specific factors in the planning and deciding category

Planning and deciding factor	Description	NMVCCS variable	Value
Speeding[a]	Too fast for conditions	CRITREASON	120
	Too fast to be able to respond to unexpected actions of others	CRITREASON	121
	Too fast for curve/turn	CRITREASON	122
	Slick roads	CRITREASON	509
	Rain, snow	CRITREASON	520
	Precrash event of loss of control because too fast for conditions	PREEVENT	6
	Aggressive driving act: Speeding	AGGRACT1	1
	Roadway-related factor: Slick surface	RWAYFACT13[*]	1
	Atmospheric condition: Snow	WEATHER2[*]	1
	Atmospheric condition: Sleet, hail	WEATHER5[*]	1
Illegal maneuvers	Illegal maneuver	CRITREASON	127
	Illegal maneuvers	ILLMAN	1
Following too closely	Following too closely to respond to unexpected actions	CRITREASON	125
	Following too closely	TOOCLOSE	2,3,4,5,6
Other aggressive driving	Aggressive driving behavior	CRITREASON[a]	131
	Aggressive driving act: Tailgating	AGGRACT2	1
	Aggressive driving act: Rapid/frequent lane changes/weaving	AGGRACT3	1
	Aggressive driving act: Ignoring traffic control devices	AGGRACT4	1
	Aggressive driving act: Accelerating rapidly from stop	AGGRACT5	1

Planning and deciding factor	Description	NMVCCS variable	Value
	Aggressive driving act: Stopping suddenly	AGGRACT6	1
	Aggressive driving act: Obstructing the path of others	AGGRACT10	1
	Aggressive driving act: Other	AGGRACT11*	1

*These variables were used to identify crashes with speeding or aggressive driving only if the crash was determined to have a planning and deciding factor through case summary review.

[a] Crashes assigned a critical reason of aggressive driving behavior and the related factor of aggressive driving act: speeding were considered to have speeding errors and not other aggressive driving errors, unless an additional aggressive driving factor was present.