Evaluation of Crash Contributing Factors

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ABSTRACT

Understanding crash contributing factors is essential in safety management and improvement. These factors drive decisions on investments, policy, regulations, and other safety related activities. This paper provides an analysis of factors that contribute to crash occurrence based on two national datasets in the US (CISS and NASS-CDS) for the years 2017-2020 and 2010-2015, respectively. Three taxonomies were applied to provide enhanced understanding of the various factors. These taxonomies were developed based on previous research and practice (e.g., human factors, vehicle factors, and roadway and environmental factors). Statistics for grouping of factor types are provided. Additionally, statistics for specific factors are provided.

The results indicate that human factors are present in over 95% of crashes, roadway and environmental factors are present in over 45% of crashes, and vehicle factors are present in less than 2% of all crashes. In human errors and vehicle maintenance, speeding is involved in over 27% of crashes, distraction is involved in over 18% of crashes, alcohol and drugs are involved in over 8% of crashes, and vehicle maintenance is involved in approximately 0.45% of all crashes. Over 5.8% of crashes involved a driver that "looked but did not see." Weather is involved in over 16% of crashes.

Keywords: Contributing factors; Human Factors; Vehicle Factors; Environmental Factors; Crash Data; Vision Zero

1. INTRODUCTION AND LITERATURE REVIEW

Traffic safety is a basic measure of effectiveness for transportation systems and is closely linked to the human health and economic development, which has become the great concern of modern society. According to the CDC (Centers for Disease Control and Prevention), vehicle-related crashes are the leading cause of death for people aged from 1 to 54 in America (*1*). An estimated 6,756,000 traffic crashes occurred in Unite States during 2019 involving 33,244 motor vehicle fatal crashes and 36,096 deaths (*2*). After 2010, the number of traffic crashes has had an increasing trend and these statistics reveal the need for preventing crashes. To improve traffic safety and prevent the crashes, the proposed countermeasures should consider detailed analysis of contributing factors.

Safety management of the transportation system is a key responsibility of transportation agencies, engineers, planners, and policy makers. Safety management decisions, investments, and policies are driven by many factors including analysis and understanding of factors that influence vehicle related crashes. An example of this is the widely cited statistic related to vehicle collisions is that 94% of collisions are due to driver-related factors (*3*) or that 93% are related to human factors (*4*). These statistics are based on the National Motor Vehicle Crash Causation Survey (where the "critical" factor was assigned to the driver if there were any potential driver-related contributing factors, regardless of other factors) in 2005 (*3*) or from data collected from few counties across US in the 1970's (*4*). With the development of society, the changing driving behaviors (distracted driving by smart phone or other entertainment devices), improvements in automobile technologies (advanced driver-assistance systems), and the roadway network and environment improvements are likely to affect the distribution of crash types and contributing factors.

By understanding the crash factors and how they might influence the sequence of crash events, crash occurrence and crash severities can be reduced by implementing specific countermeasures to target specific contributing factors. Understanding the relative contribution of the factors toward crashes can assist with determining how to best allocate resources to minimize crash frequency. The detailed analysis of vehicle crash contributing factors would help in identifying, developing, and evaluating current and emerging safety countermeasures such as improving geometric design decisions, planning and maintenance of transportation systems, enhancing drivers and engineers training, policy development, legislation, targeted enforcement activities, and developing advanced vehicle technologies.

Numerous studies have attempted to evaluate various contributing factors to crashes. Most of these studies focus on a small number of factors and attempt to link the factors to crash frequency or crash severity. This paper focuses on factors that contribute to crashes occurring; thus, the following literature review does not summarize literature specific to crash severity.

Some previous studies evaluated contributing factors for the specific crash types or type of infrastructure (e.g., intersections, functional class, etc.). For instance, the Volpe center conducted an analysis using the National Automotive Sampling System (NASS) General Estimates System (GES) looking at contributing factors for different crash-imminent scenarios with a focus on alcohol and drug use, impaired and distracted driving, speeding, and hit-and-run behaviors (*5*). Another study used the National Motor vehicle Crash Causation Survey (NMVCCS) to analyze intersection crashes which found that 96% of critical factors contributing to crashes were related to the driver (*6*, *7*). Additional studies estimated driver errors being involved in 99% of crashes (*8*) and 94% of crashes (*3*, *9*, *10*) while driver inattention contributes to more than 40% of crashes (*11*).

Furthermore, a recent study used Fatality Analysis Reporting System (FARS) and Highway Safety Information System (HSIS) data and stratified the analysis of contributing factors based on crash type, area type, roadway type, location type, intersection type, traffic control type, light conditions, road alignment type, and severity (*12*). The factors considered focused mainly on the infrastructure, but also considered weather and other environmental variables. Given the reliance on police-reported data and roadway inventory data, the factors found to be associated with higher crash frequencies included higher traffic volumes, steeper grades, sharper horizontal curves, narrower lanes and shoulders, unpaved or no shoulders, mountainous terrain, higher speed limits, wider crossings at intersections, and the absence of left- and right-turn channelization at intersections.

2. OBJECTIVE

The purpose of this research is to use multiple detailed datasets from recent years that include police-reported crash information, crash reconstruction, hospital data, and interviews of people involved in the collisions to evaluate factors that contribute to vehicle related crashes occurring. This will involve application of multiple taxonomies to the data in order to convey results that include potential interactions, enhance understanding of potential contributing factors for use future crash reduction and other safety management efforts, including Vision Zero (*13*).

3. DATA

The traffic crash data used in this research are from two national crash datasets (collected and maintained by NHTSA): These datasets are the Crash Investigation Sampling System (CISS) and the National Automotive Sampling System Crashworthiness Data System (NASS-CDS, hereafter referred to as CDS). The National Automotive Sampling System was established in the 1970’s and collected data the comprised multiple datasets, including CDS. The purpose of the CDS dataset since 1988 was to enhance knowledge related to vehicle crashworthiness by capturing detailed data including (*14*, *15*):

1. Vehicle crash profiles,
2. Restraint system performance, and
3. Injury mechanisms

Due to changes in data needs for the highway safety community, NHTSA undertook a data modernization effort in 2012 (*16*). This included an update in the purpose of each dataset, variables collected, where data were collected, and the focus of in-depth investigations. In this update, CDS was replaced by the Crash Investigation Sampling System (CISS), which is based on data from 32 geographical areas across the US (CDS was based on data from 24 geographical areas across the US). The stated purpose of the CISS dataset in the efforts to meet the updated data needs of the highway safety community, and thus a focus of the data collection efforts, includes the following (*14*):

1. Identification of emerging issues in traffic safety,
2. Evaluation of vehicle designs and safety systems,
3. Examination of the detailed crash performance of vehicles,
4. Evaluation of the effectiveness of motor vehicle and traffic safety program standards,
5. Design of future crash avoidance and mitigation technologies, and
6. Improving and increasing the knowledge of crash-related injuries and mechanisms.

Both systems (CDS and CISS) are comprised of detailed data collected by expert teams. The data collection includes police-reported crash data, data from hospital and medical records, crash reconstruction data, and data from interviews with people involved in the crash (when possible). It should be noted that both systems require a vehicle to be towed for it to be eligible for inclusion in the dataset, although CDS imposes additional restrictions. Given that the data collection team are not there in an enforcement role, it is likely that the people interviewed provide more accurate information regarding what happened than what was reported to the responding police officers (e.g., distracted driving and other behaviors). The CDS and CISS systems are both intended to be nationally representative and use sampling strategies that result in nationally representative weighted data for the United States (with raw counts of up to 5,000 crashes per year). For details of the sampling design and weighting procedures, see (*14*, *15*).

Given the detailed nature of the CDS and CISS data, these datasets were selected for this research in analyzing crash contributing factors. At the time the research was conducted, CISS data for 2017-2020 were available (2016 had only a limited number of data observations collected, and a full dataset was not published by NHTSA for that year). The final year for the CDS system was in 2015. Thus, to yield the most relevant results, with adequate sample size and recent years of data, CDS data for the years 2010-2015 and CISS data for 2017-2020 were used. This resulted in a total of 11,204 crashes in the CISS data and 21,629 crashes in the CDS data.

The codebooks for CDS and CISS were reviewed to identify variables that can be used to identify factors that potentially contribute to crash occurrence. Factors that potentially influence crash severity, but not crash occurance, were not considered in the analysis. Thus, care was taken to ensure that each factor used could be considered a precipitating factor to a crash occurring. Various factors related to human factors, human errors, vehicle issues, environmental factors, and infrastructure factors were considered and included. It should be noted that while the data include factors that potentially contributed to the crash occurring, it is not known for certain which of the factors present in individual crashes contributed to the crash occurring. Thus, the presence of a factor should not be assumed to automatically be a causal factor. It is only known that the factor was recorded as being present. This applies to all factors including human errors and human factors.

4. METHODS

Given that the objective of this project is to evaluate the factors that potentially contribute to the occurrence of vehicle related crashes, and applying multiple taxonomies for classifying contributing factors, the taxonomies were developed as shown in Figure 1. The first taxonomy, identified in Figure 1 as Taxonomy 1, is based on previous research and the taxonomy used in the Highway Safety Manual (*17*). Additional taxonomies were created to disaggregate the factors for potentially enhancing understanding of the various factors that potentially contribute to crash occurrence. Each of the three taxonomies have similarities: Taxonomy 2 and 3 both stratify into more specific groupings than Taxonomy 1. The human factors and driver errors in taxonomy 2 and distraction, fatigue driving, alcohol drug driving, potential driving behaviors, and speed related behaviors in taxonomy 3, are all the human related factors. The vehicle factors and vehicle maintenance in taxonomy 2 and specific vehicle factors in taxonomy 3 are all grouped into vehicle related factors in taxonomy 1. The environmental factors and infrastructure factors in taxonomy 2 and driving environment, roadway surface conditions and weather in taxonomy 3, are grouped into environment related factors in taxonomy 1.

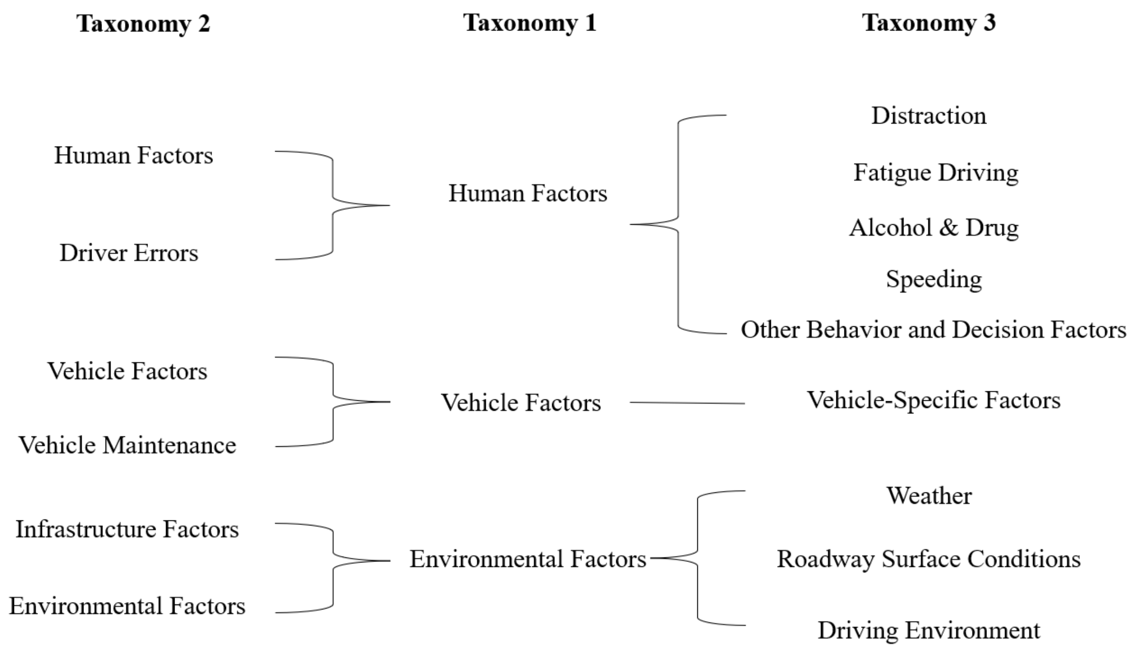

Figure 1. Taxonomies Applied to Categorizing Contributing Factors

There are key differences in some similar factors and groupings across the taxonomies, yet each is categorized differently. The human factors in taxonomy 1 contain the contributing factors related to drivers' age, judgement, driver skill, attention, fatigue, experience, and sobriety. Vehicle factors for taxonomy 1 include all vehicle-related issues that could potentially cause a crash, including factors associated with maintenance issues (e.g., bald tires). In taxonomy 1, the environmental factors include both natural or built environment, aspects of roadway design, and land use.

In taxonomy 2, human factors only represent the crash contributing factors related to human physical limitation, such as reaction time. These are factors that influence policies such as stopping sight distance requirements, which includes conservative values for driver reaction time and deceleration rates based on distributions from driver performance measured by researchers (*18*, *19*). Driver errors in taxonomy 2 include factors associated with driver decisions such as distracted driving, alcohol and drug involved driving, speeding and wrong driving decision. This provides a high-level (aggregate) breakdown of how often these factors are present in crashes. The environmental factors in taxonomy 2 emphasizes the natural environmental factors such as the weather or animals in the road and separates the infrastructure and built environment into its own category.

Taxonomy 3 considers distraction, fatigued driving, alcohol and drug use, and speeding as individual categories with all other behavioral and decision related factors grouped into a single category. This is to provide specific details related to these factors as they are some of the most common driver-related factors. The vehicle factors are no different between taxonomies 1 and 3 due to there being too few vehicle-specific factors to provide additional detail beyond what is provided in the first 2 taxonomies. The environmental factors in taxonomy 3 separates the weather into its own category, which represent the crash occurrence related to the worse weather conditions such as rain, snow, and fog. Roadway surface condition category in taxonomy 3 contains the crash contributing factors for non-dry roadway surfaces. It has some overlap with weather factors but also includes some other slippery roadway surface factors (oily surface, sandy surface, gravel surface and muddy surface). Driving environments of taxonomy 3 captures the possible physical objects (fixed or moving) drivers faced before the vehicle crash occurred such as animals, roadway elements, and other fixed objects surrounding the road.

According to these classifications, the review of variables from the CISS and CDS datasets was conducted. Based on the variable definitions, each value for variables that could potentially be a precipitating factor for a crash was labeled appropriately for each of the taxonomies. Python was then used to obtain weighted statistics (i.e., percentages) using the sample weights in the datasets. It should be noted that the categories, or even sub-categories for taxonomies 2 and 3, are not mutually exclusive (i.e., the sum of percentages do not necessarily add up to 100%). Additionally, most crashes have multiple factors that potentially precipitated the collision. The percentages reported in the results are based on crashes with one or more observed factor within each category. Care was taken to ensure that there was no crash was counted more than once for a single category, even if multiple factors were observed within a single category in the individual crashes. The python code used to process the data is available from the authors on request.

Weighted percentages are based on indicator variables and are computed using Equation 1, as shown below.

$$P = \frac{\sum_{i=1}^{n} x_i w_i}{\sum_{i=1}^{n} w_i} \cdot 100 \quad (1)$$

Where $P =$ the weighted percentage, $x_i =$ the indicator variable value for observation i, $w_i =$ the sample weight for observation i, and $n =$ the number of observations.

Given that the data are based on weighted samples, the effective sample size (n^*) can be estimated using Equation 2, known as Kish's effective sample size (*20*).

$$n^* = \frac{\left(\sum_{i=1}^{n} w_i\right)^2}{\sum_{i=1}^{n} {w_i}^2} \quad (2)$$

The confidence intervals for proportions can be computed using a Wald interval with the effective sample size as shown in Equation 3.

$$CI = p \pm z_{\alpha/2}\sqrt{\frac{p(1-p)}{n^*}} \quad (3)$$

Where $CI =$the confidence interval, $p =$the weighted proportion (i.e., $p = P/100$), $z_{\alpha/2} =$ the 2-tail p-score value for the desired confidence level, and $n^* =$the effective sample size.

5. RESULTS

The results of the analysis for Taxonomy 1 are shown for both CDS and CISS datasets as Venn Diagrams, along with the corresponding Venn Diagram based on the Highway Safety Manual (*17, 21*) in Figure 2. The structure of taxonomy 1 is the same as for the Venn diagram in the HSM, making comparisons straightforward. Figure 2a indicates that, in the HSM, vehicle factors contribute 13% of all crashes. However, Figures 2b and 2c indicate that vehicle factors only contribute to 1.91% and 1.67% of crashes based on the 2017-2020 (CISS data) and 2010-2015 (CDS) data, respectively.

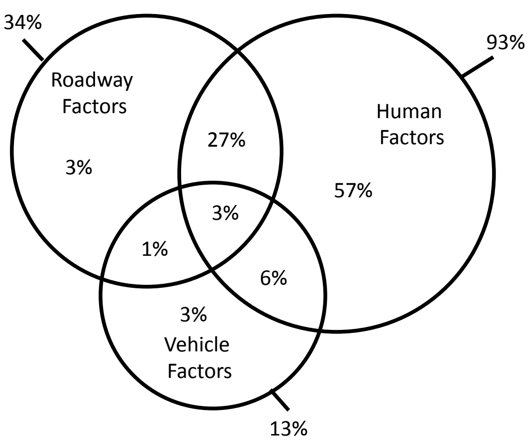

Figure 2a. Venn Diagram of Contributing Factors from the Highway Safety Manual

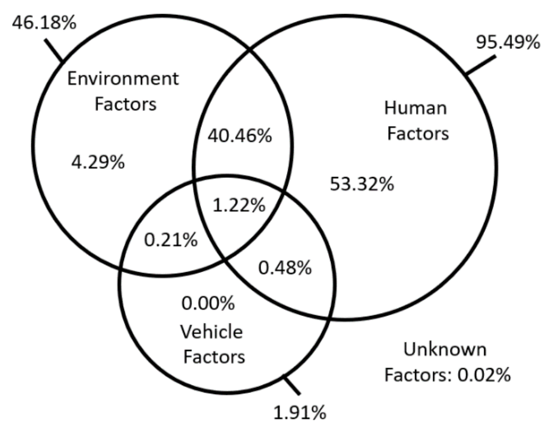

Figure 2b. Venn Diagram of Contributing Factors using the CISS dataset

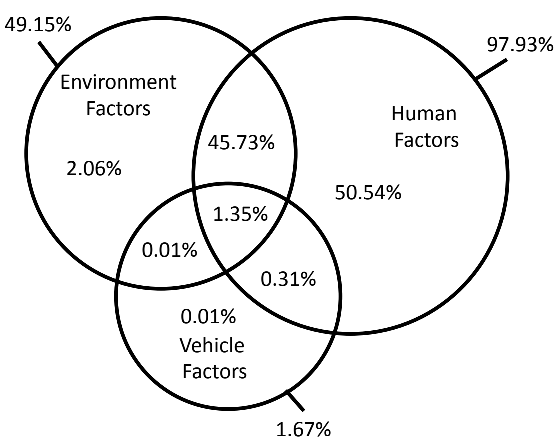

Figure 2c. Venn Diagram of Contributing Factors using the CDS Dataset

These results are not surprising given the improvements in vehicle design and federal regulations that have improved both the quality and safety performance of vehicles. However, with a reduction in crashes resulting from vehicle factors, it makes it more likely that the crashes that occur will have human and roadway/environmental factors as contributing factors. Thus, it is not a surprise that human factors have increased from 93% to 95.49% (CISS) and 97.93% (CDS) or that the roadway/environmental factors have increased from 34% to 46.18% (CISS) and 49.15% (CDS). This is also consistent with NHTSA research (NHTSA, 2015). It should be noted that these factors are a product of the NHTSA data collection process. The human factors are often behaviors that can be influenced by infrastructure design, policies, and training (*22*, *23*). Thus, the fact that 53.32% of crashes in the CISS data and 50.54% in the CDS data only had human factors as contributing factors should not be interpreted as there being over half of all crashes that engineers cannot influence or do anything about. Rather, it can be used to inform the strategies for crash countermeasures and policy development.

The minimal changes in percentages for human factor contributions, even with changes in driver assistance technologies and changes in the potential sources of distractions and other human factors, is potentially due to risk compensation and behavioral adaptation. Risk compensation occurs when behaviors change based on perceived differences in risk. Thus, it is important to evaluate contributing factors in greater detail. Detailed analysis is provided below in taxonomies 2 and 3 as well as detailed regarding specific factors.

The results for taxonomies 2 and 3 provide additional breakdown of factor groupings, as shown in Table 1. Due having more than three groupings in taxonomies 2 and 3, overlap between the groups are not provided. As shown in taxonomy 2, driver errors are present in nearly all crashes while human factors were present in 16.51% and 16.79% of all crashes based on the CISS and

Table 1. Results of Contributing Factors for Each Taxonomy with 95% confidence intervals.

Taxonomy 1			**Taxonomy 2**			**Taxonomy 3**		
Classification	**% CISS**	**% CDS**	**Classification**	**% CISS**	**% CDS**	**Classification**	**% CISS**	**% CDS**
Human Factors	95.49 [94.55, 96.43]	97.73 [97.42, 98.04]	Human Factors	16.51 [14.83, 18.19]	16.79 [16.02, 17.56]	Distraction	20.47 [18.64, 22.30]	20.92 [20.08, 21.76]
						Fatigued Driving	3.05 [2.27, 3.83]	2.71 [2.38, 3.04]
			Driver Errors	95.44 [94.49, 96.38]	97.88 [97.58, 98.17]	Alcohol & Drugs	8.93 [7.64, 10.22]	9.62 [9.01, 10.23]
						Speeding	27.46 [25.44, 29.48]	33.38 [32.41, 34.35]
						Other Behavioral and Decision Factors	87.88 [86.40, 89.36]	89.81 [89.19, 90.43]
Vehicle Factors	1.91 [1.29, 2.54]	1.67 [1.41, 1.93]	Vehicle Factors	1.37 [0.84, 1.90]	1.22 [1.00, 1.45]	Vehicle Factors	1.91 [1.29, 2.54]	1.67 [1.41, 1.93]
			Vehicle Maintenance	0.54 [0.21 0.88]	0.45 [0.31, 0.58]			
Environmental Factors	46.18 [43.92, 48.44]	49.15 [48.12, 50.18]	Infrastructure Factors	32.06 [29.95, 34.18]	34.32 [33.33, 35.28]	Roadway Surface Conditions	19.97 [18.16, 21.78]	23.94 [22.67, 24.41]
			Environmental Factors	27.99 [25.96, 30.03]	30.46 [29.50, 31.40]	Weather	14.34 [12.75, 15.93]	16.95 [16.18, 17.72]
						Driving Environment	36.73 [34.55, 38.91]	36.56 [35.57, 37.55]

CDS datasets, respectively. The taxonomy 3 results for human factors indicated that distraction plays a role in 20.47-20.92% of crashes, fatigued driving is related to 3.05% - 2.71% of vehicle crashes, alcohol and drugs are present in 8.93-9.62% of crashes, and speeding is a factor in 27.46-33.38% of crashes. This presents a notable opportunity for comparison with fatal crashes. For example, FARS data queries for 2010-2020 indicated 99,084 fatal crashes (27.8%) involved speeding, 39,828 (11.2%) involved distracted or drowsy drivers, and 169,159 (47.5%) had drivers with blood alcohol concentrations (BAC) over 0.08 g/dL (note that this is the percentage of crashes with a driver intoxicated at this level, not the number of people killed with BAC at these levels). This indicates that speeding, using the CISS results, is representative of the percentage of fatal crashes that involve speeding (it should be noted that Speeding is based on the posted speed, not on the overall speed or impact speed). It also indicates that distracted driving, fatigued driving, and alcohol/drug use are overrepresented in fatal crashes. Higher fidelity analysis of specific human factors is provided in the Human Factors section, below (5.1).

The taxonomy 2 results for vehicles indicated that vehicle maintenance issues (which could be considered an indirect human factor/error) contributed to approximately 0.45% of all crashes while other vehicle factors were present in 1.37% and 1.22% of all crashes (CISS and CDS, respectively). Further details of vehicle factors and vehicle maintenance are provided in the Vehicle Factors section (5.2).

Infrastructure and environmental factors contribute to a significant proportion of crashes and overlapped in some cases (13.87% of CISS crashes and 15.63% of CDS crashes had both infrastructure and environmental factors, based on taxonomy 2). Based on taxonomy 3, the driving environment was a factor in approximately 36.5% of all crashes, weather contributed to 14.34-16.95% of crashes, and roadway surface conditions contributed to 19.97-23.94% of all crashes. These results are limited to CISS and CDS variables that indicated specific related factors that could potentially directly contribute to crash occurrence. This does not include any potential influence of the roadway environment, driving environment, or weather on human factors or driver errors. Further related discussion is provided in the Roadway and Environmental Factors section (5.3).

5.1 Human Factors

As shown in Figure 2 and Table 1, human factors play a major role on contributing to crashes. The key human factors and human errors from the CISS and CDS data, with associated weighted percentages and confidence intervals, are provided in Table 2. The factors are grouped based on

Distraction, Fatigue Driving, Alcohol and Drugs, Speed Related, and Other Behavior and Decision Factors. Distraction classifications are slightly different between the CISS and CDS data which is why there are some missing values in Table 2.

Table 2. Detailed Statistics for Human Factors with 95% confidence intervals.

Grouping	Factor	% CISS	% CDS
Distraction	Looked but did not see	5.18 [4.18, 6.18]	6.76 [6.24, 7.28]
	Distraction Outside Vehicle	3.39 [2.57, 4.21]	2.91 [2.56, 3.26]
	Other Distraction	-	3.07 [2.72, 3.42]
	Other Inside Vehicle	2.62 [1.90, 3.34]	-
	Unknown Distraction	1.63 [1.06, 2.20]	0.69 [0.52, 0.86]
	Manually Operating an Electronic Communication Device	1.27 [0.76, 1.78]	-
	Device/Control Integral to Vehicle	1.02 [0.56, 1.48]	0.86 [0.67, 1.05]
	Talking on Hand-Held Electronic Device	0.77 [0.37, 1.17]	-
	Other Device Brought into Vehicle	0.81 [0.40, 1.22]	0.97 [0.77, 1.17]
	Inattentive or Lost in Thought	0.86 [0.44, 1.28]	-
	Cell Phone	-	0.79 [0.61, 0.97]
	Passenger	0.63 [0.27, 0.99]	1.45 [1.20, 1.70]
	Smoking Related	-	0.12% [0.05, 0.19]
	Talking on Hands-Free Electronic Device	0.08 [0.00, 0.21]	-
Fatigue Driving	Sleepy	3.05 [2.27, 3.83]	2.71 [2.38, 3.04]
Alcohol & Drugs	Alcohol Involvement	7.08 [5.92, 8.24]	7.74 [7.19, 8.29]
	Drug Involvement	2.72 [1.98, 3.46]	2.86 [2.52, 3.20]
Speed Related	Driving Too Fast for Conditions	5.13 [4.13, 6.13]	6.58 [6.07, 7.09]
	Other Speed-Related	22.86 [20.96, 24.76]	26.53 [25.62, 27.44]
Other Behavior & Decisions		87.88 [86.40, 89.36]	89.81 [89.19, 90.43]

As shown in Table 2, some of the most prominent human factors that contribute to crash occurrence include (not including the “Other Behavior and Decision Factors”):

1. Other Speed-Related factors (22.86% CISS, 26.53% CDS)
2. Alcohol Involvement (7.08% CISS, 7.74% CDS)
3. Looked But Did Not See (5.18% CISS, 6.76% CDS)
4. Driving Too Fast for Conditions (5.13% CISS, 6.58% CDS)
5. Distraction Outside Vehicle (3.39% CISS, 2.91% CDS)
6. Sleepy (3.05% CISS, 2.71% CDS)

It is interesting to note that these prominent factors are all related to speeding behaviors, distraction, alcohol use, and fatigued driving. Previous research has evaluated driver characteristics and other factors that contribute to each of these. For instance, the proportion of US drivers that drive within the speed limits has been evaluated as a function of age (younger drivers more likely to speed), income (higher incomes less likely to speed), gender (females less likely to speed), and education level (high school graduate or grater more likely to speed) (*24*). It has been shown that a driver’s intention to speed is determined primarily by the driver’s attitude toward speeding while little influence came from the drivers’ attitude towards the speed limit (*25*). Additionally, it is often socially acceptable to speed, provided the speeding is within a specific range over the posted speed. Countermeasures for speeding are numerous. Examples include intelligent speed adaptation and intelligent speed assistance systems (in-vehicle systems) (*26*); education of drivers on the effects of speeding on crash involvement, crash severity, and vehicle control (*23*); and automated enforcement (*27*). Speeding can also potentially be influenced by the roadway design (*28*), work zone layouts (*29*), and other infrastructure-related factors (e.g., pavement markings and signage) (*30–32*).

Previous studies found that 10% to nearly 40% of drivers had reported falling asleep (including dozing off) at the wheel at least once in the previous year (*23*). Socioeconomic demands and pressures may require drivers to travel at times when they are fatigued, leading to drowsy driving. This also could be due to other numerous reasons, yet it highlights the need for awareness and countermeasures related to drowsy driving. Countermeasures for drowsy driving could include Advanced Driver Assistance Systems (ADAS) such as Driver Alert (for alerting the driver to fatigue) (*33*), Graduated Driver Licensing (GDL) (*27*), and educating drivers how to recognize drowsiness early and methods for coping or dealing with fatigue (*23*).

Alcohol and drug use has long been understood as a key factor in contributing to crash occurrence and severity (*34*). Countermeasures used in the US that have been shown to be effective are primarily deterrence laws and enforcement such as Administrative License Revocation or Suspension programs, High-Visibility Saturation Patrols, and Alcohol Ignition Interlocks (for reducing recidivism) (*23, 27*).

In the category of Other Behavior and Decision Factors, the specific crash contributing factors involved with pre-crash critical driving event are included, such as the turning behavior, lane changing behavior, driving decision when crossing the intersection or roadway and the vehicle location after critical event. Among almost 45 detailed other driving behavior and decision factors from both datasets, “vehicle departed roadway” was present in 32.73% - 32.42% crashes and left turning movements were another contributing factor related to about 16% of vehicle crashes. For the roadway departure crashes, several strategies in terms of highway designing to reduce this kind of crashes were identified by American Association of State Highway and Transportation Officials (AASHTO), like pavement edge line installation, traffic barrier design improvement, horizontal curve geometric improvement skid-resistive pavement design (*34*). The previous paper also has evaluated the effectiveness of Lane Departure Warning (LDW) system for run-off road crashes (*35*). The left-turning vehicle crashes would be always involved with the misjudgment for the speed of oncoming vehicles and gap selections, which could be improved by driver training and education (*36*).

After reviewing the detailed human related factors, most factors relate to driver's senses or perceptions, prediction, driving decision making, execution and incapacitation (*37*). It is widely anticipated that the use of autonomous vehicles (Level 5: full driving automation) could reduce the crashes contributed by human related factors. It is obvious that the autonomous vehicles could reduce the crashes caused by human physical limitation (like reaction time), driving distraction and alcohol or drug driving. For crashes caused by the driving behaviors (habits) and decision-making factors, the effectiveness of autonomous vehicles in improving safety requires further research. Since the autonomous vehicles' driving behaviors and decision-making are programmed by humans, it could also introduce new safety risks based on the assumptions made during the system development and the limitations of the technologies.

5.2 Vehicle Factors

Vehicle safety is critical to the prevention of crashes. NHTSA has the authority to obtain information on vehicle crashes and other safety data in order to conduct safety recalls and ensure legal compliance for vehicles, starting with the National Traffic and Motor Vehicle Safety Act in 1966 (*38*). From legal requirements and improvements in vehicle design, the percent of crashes which vehicle issues contribute to has been significantly reduced over the last several decades (as indicated in Figure 2). Based on the data from CISS and CDS, the vehicle-related factors that contributed to collisions are provided in Table 3. As indicated, blow out or flat tires are factors in 0.54% and 0.45% of crashes based on CISS and CDS, respectively. Blow outs and flat tires have numerous potential causes including wear, low pressure, hitting potholes or other objects on the roadway, etc. Many of the other factors shown in Table 3 are potentially related to maintenance but could have other causal sources which are not indicated in the datasets. Thus, countermeasures for these factors are difficult to determine beyond education and inspection-related activities.

Table 3. Detailed Statistics for Vehicle Factors with 95% confidence intervals.

Factor	**% CISS**	**% CDS**
Disabling vehicle failure	0.50 [0.18, 0.82]	0.26 [0.16, 0.36]
Non-disabling vehicle problem	0.14 [0.00, 0.31]	0.35 [0.23, 0.47]
Trailer, disconnected in transport	0.03 [0.00, 0.11]	0.06 [0.01, 0.11]
Other cause of control loss	0.70 [0.32, 1.08]	0.52 [0.37, 0.67]
Blow out/ flat tire	0.54 [0.21, 0.87]	0.45 [0.31, 0.59]

5.3 Roadway and Environmental Factors

The grouping of factors that infrastructure owners, engineers, and planners have the most direct control over is roadway and environmental factors. Statistics for key roadway and other infrastructure-specific factors are provided in Table 4. As shown, many of the factors are related to object that can be struck by a moving vehicle. The most common factor is trees with a diameter greater than 10 centimeters (6.23% CISS, 5.67% CDS). Trees and bushes, combined, contribute to 8.52% (CISS) and 8.68% (CDS) of crashes. The other factors in Table 4 are typically manmade objects (some object in the road and poor road may not be manmade). Many of the factors are specific to roadside design. The Highway Safety Manual, Green Book, and Roadside Design Guide are excellent tools for identifying countermeasures for these factors (*17*, *39*, *40*).

Table 4. Detailed Statistics for Roadway and Infrastructure Related Factors with 95% confidence intervals.

Factor	% CISS	% CDS
Tree (>10 cm diameter)	6.23 [5.13, 7.33]	5.67 [5.19, 6.15]
Concrete traffic barrier	3.57 [2.73, 4.41]	4.57 [4.14, 5.00]
Curb	4.95 [3.97, 5.93]	4.25 [3.84, 4.66]
Guardrail Face or End	3.60 [2.76, 4.44]	4.22 [3.81, 4.63]
Poor Road Conditions	2.39 [1.70, 3.08]	2.94 [2.59, 3.29]
Other Fixed Objects	3.35 [2.53, 4.17]	3.66 [3.27, 4.05]
Non breakaway pole or post (> 10 cm diameter and <= 30 cm diameter)	3.12 [2.33, 3.91]	4.51 [4.08, 4.94]
Ditch or Culvert	2.05 [1.41, 2.69]	2.63 [2.30, 2.96]
Embankment	1.88 [1.26, 2.50]	2.04 [1.75, 2.33]
Fence	2.82 [2.07, 3.57]	1.91 [1.63, 2.19]
Non breakaway pole or post (<= 10 cm diameter)	2.77 [2.03, 3.51]	3.75 [3.36, 4.14]
Wall or Building	1.89 [1.27, 2.51]	1.68 [1.42, 1.94]
Cable Barrier	0.96 [0.52, 1.40]	0.48 [0.34, 0.62]
Non breakaway pole or post (> 30 cm diameter)	1.27 [0.76, 1.78]	1.85 [1.27, 2.13]
Object in road	0.85 [0.43, 1.27]	1.12 [0.90, 1.34]
Breakaway Pole or Post	1.45 [0.91, 1.99]	1.31 [1.08, 1.54]
Tree (<= 10 cm in diameter)	1.49 [0.94, 2.04]	1.58 [1.32, 1.84]
Shrubbery or Bush	0.80 [0.40, 1.20]	1.43 [1.19, 1.67]

Statistics for environmental and weather-related factors that contribute to crashes are provided in Table 5. From these factors, the most common is wet pavement (16.05% CISS, 15.29% CISS) followed by rain (11.46% CIS, 9.92% CDS). For wet pavement and rain, potential countermeasures are limited (e.g., providing adequate drainage and friction). Snow and snow on pavement are also key factors, although the percentages shown are national averages and may not be applicable to specific regions within the US. Snow management and removal is often considered by roadway owners in regions that see significant snowfall each year. Other environmental and weather-related contributing factors also contribute to crashes, yet countermeasures for each factor are wither difficult to evaluate (i.e., effectiveness is unknown) or countermeasures are highly specific to local conditions (e.g., snow fences provided in geographical areas with significant snowfall and cross winds to prevent blindness caused by blowing snow).

Table 5. Detailed Statistics for Environment and Weather-Related Factors with 95% confidence intervals.

Factor	% CISS	% CDS
Wet Pavement	16.05 [14.39, 17.71]	15.29 [14.55, 16.03]
Raining	11.46 [10.02, 12.90]	9.92 [9.31, 10.53]
Animal	4.75 [3.79, 5.71]	3.21 [2.85, 3.57]
Snowing	1.88 [1.26, 2.50]	2.23 [1.93, 2.53]
Snow on Pavement	1.74 [1.15, 2.33]	2.16 [1.86, 2.46]
Ice/Frost on Pavement	1.61 [1.04, 2.18]	2.52 [2.20, 2.84]
Fog, Smog, or Smoke	0.41 [0.12, 0.70]	0.51 [0.36, 0.66]
Slush on Pavement	0.27 [0.03, 0.51]	0.59 [0.43, 0.75]
Severe Crosswinds	0.20 [0.00, 0.40]	0.09 [0.03, 0.15]
Sleet or Hail	0.11 [0.00, 0.26]	0.35 [0.23, 0.47]
Freezing Rain/Drizzle	0.19 [0.00, 0.39]	0.06 [0.00, 0.11]
Mud, Dirt, Gravel on Pavement	0.13 [0.00, 0.29]	0.08 [0.02, 0.14]
Blowing Snow	0.06 [0.00, 0.17]	0.93 [0.73, 1.13]
Water on Pavement	0.17 [0.00, 0.36]	0.13 [0.06, 0.20]
Blowing Sand, Dirt, or Soil	0.04 [0.00, 0.13]	0.03 [0.00, 0.07]
Sand on Pavement	0.01 [0.00, 0.06]	0.02 [0.00, 0.05]
Oil on Pavement	0.01 [0.00, 0.06]	0.01 [0.00, 0.03]

6. CONCLUSIONS AND RECCOMENDATIONS

This study applied multiple taxonomies to two national datasets (CISS and CDS) in order to evaluate factors that potentially contribute to crash occurrence. The datasets are highly detailed and involve police-reported crash information, crash reconstruction, hospital data, and interviews of people involved in the collisions. The datasets are collected and maintained by NHTSA with CISS covering the years 2017-2020 and CDS covering the years 2010-2015 (for what was used in this paper). The crashes included in the datasets have weights assigned by NHTSA based on the sampling scheme which is intended to ensure the data are nationally representative. Using the variable definitions, factors that are likely to contribute to crash occurrence were extracted. Weighted statistics were then used to determine overall percentages for each factor on how often they contribute to crashes in the US. It is important to note that simply because a factor was present does not ensure that it precipitated (i.e., caused) the crash.

The findings indicated that, consistent with previous research, more than 95% of crashes have human factors or human errors present. Infrastructure and environmental factors contributed to more than 45% of crashes. Vehicle factors contributed to only 1.67%-1.91% of all crashes, including issues related to maintenance (e.g., bald or worn tires). When comparing the results to those contained in the HSM, the proportion for vehicle factors decreased significantly, which is not a surprise given the data the HSM is based on was collected in the 1970's and vehicle regulations have become more stringent over time. The percentage human factors are similar to the HSM. The roadway and environmental factors are larger than those in the HSM. It was noted that the human factors are often behaviors that can be influenced by infrastructure design, policies, and training (*22*, *23*). Numerous countermeasures exist for specific human factors and errors. The

HSM, Roadway Design Guide, and other resources exist for determining appropriate countermeasures for roadway and environmental factors.

Detailed breakdowns of specific factors in each category were provided. It is anticipated that the results could potentially be used in future safety management and improvement activities including policy making, regulation development, safe systems and systemic safety approaches to safety management, and other Engineering, Education, Emergency Response, Enforcement, Evaluation, and Encouragement activities. The findings could also be used in developing future DAT systems and enhancing existing technologies.

Although this study provides a detailed evaluation of crash contributing factors based on the recent national datasets, there are limitations. First, the sample size is limited in any individual year. The CISS and CDS datasets each record up to approximately 5,000 crashes per year, which are then scaled using weighting factors to represent the US. Due to the sampling locations and sample size, the analysis is limited to represent the US (i.e., some factors may not be representative of specific geographical areas – such as snow and ice in southern States). Additionally, the contributing factors assigned for crashes in this project are based on the variables available in in CISS and CDS datasets. Other factors likely contribute to crash occurrence were not available.

Future research should consider advanced data collection methods and technologies proposed for large scale data collection within specific geographical regions. Additionally, the interrelationships between factors that influence crash frequency and crash severity should be evaluated.

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