

Target Population for Intersection Advanced Driver Assistance Systems in the U.S.

Kristofer D. Kusano and Hampton C. Gabler
Virginia Tech

ABSTRACT

Intersection crashes are a frequent and dangerous crash mode in the U.S. Emerging Intersection Advanced Driver Assistance Systems (I-ADAS) aim to assist the driver to mitigate the consequences of vehicle-to-vehicle crashes at intersections. In support of the design and evaluation of such intersection assistance systems, characterization of the road, environment, and drivers associated with intersection crashes is necessary. The objective of this study was to characterize intersection crashes using nationally representative crash databases that contained all severity, serious injury, and fatal crashes. This study utilized four national crash databases: the National Automotive Sampling System, General Estimates System (NASS/GES); the NASS Crashworthiness Data System (CDS); and the Fatality Analysis Reporting System (EARS) and the National Motor Vehicle Crash Causation Survey (NMVCCS).

Straight Crossing Path (SCP), Left Turn Across Path Opposite Direction (LTAP/OD), and Left Turn Across Path Lateral Direction (LTAP/LD) made up 78% to 98% of all crossing path crashes. Furthermore, between 73% and 95% of these top three crossing path scenarios occurred at intersections. The analysis in this paper, therefore, focused on SCP, LTAP/OD, and LTAP/LD crashes at intersections, referred to as simply intersection crashes for the remainder of this summary.

This paper quantified traffic control devices, speed limits, environmental conditions, alcohol involvement, and driver age in intersection crashes. Using the additional driver and crash contributing data included in the NMVCCS data, this paper also quantified critical reason for crashes, maneuvers approaching the intersection and avoidance maneuvers in intersection crashes. The results of this study are crucial for the design and evaluation of I-ADAS.

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INTRODUCTION

Intersection crashes are a frequent and dangerous crash mode on U.S. roads. Intersection crashes account for 23% of all crashes and 15% of fatal crashes [1]. Driver assistance systems are becoming available to mitigate the effects of other crash modes, such as rear-end and road departure collisions. Forward Collision Warning (FCW) and Lane Departure Warning (LDW) both warn drivers if vehicle detects a potentially dangerous situation. Present warning systems and early automated systems, e.g. Collision Imminent Braking, rely completely on vehicle-based sensors. Intersection Driver Assistance Systems (I-ADAS) are beginning to also be introduced that warn or assist the driver to avoid collisions near intersections. Because these early system are not cooperative and rely on vehicle-based sensors, I-ADAS have been difficult to design and are not as widely available as other driver assistance systems. In parallel with continued sensor development, cooperative systems that use short range wireless communication to determine when vehicles are in potentially dangerous situations (i.e. Vehicle-to-Vehicle, V2V, and Vehicle-to-Infrastructure, V2I) may enhance the abilities of I-ADAS.

Because intersection scenarios can vary greatly, the design of I-ADAS should target crash scenarios that are most frequent and most harmful in order to maximize effectiveness. In order to achieve this goal, designers need to identify the characteristics of intersection crashes that may affect system performance. For example, the configuration of vehicles colliding, the geometric design of intersections, environmental conditions, and driver conditions that contributed to the crashes. Systems should be evaluated in conditions that simulate real-world collisions, including all severity levels from property damage to fatal crashes. This characterization of the most typical scenarios encountered in crashes most likely to be mitigated by an active safety system is called the target population.

The objective of this study is to identify the characteristics of intersection crashes using U.S. nationally representative crash databases. Recent changes to the U.S. Department of Transportation crash databases allow for the first time a direct comparison of data across multiple severity levels. This approach will identify the conditions under which intersection crashes occur and any differences between crash severity levels that would be missed if the data were examined separately.

METHODOLOGY

Data Sources

The sources for this study were nationally representative crash databases that are collected with support of the U.S. Department of Transportation: The National Automotive Sampling System (NASS) General Estimates System (GES), the NASS Crashworthiness Data System (CDS), and the Fatality Analysis Reporting System (FARS). This study also used the National Motor Vehicle Crash Causation Survey (NMVCCS), a special database focusing on crash causation.

Table 1 describes the sample selection, approximate number of cases per year, and use for the each database in the current study. A field investigation is done for each NASS/CDS and NMVCCS crash, whereas GES and FARS cases are aggregated by investigators from police accident reports. The on-scene investigations in CDS included collection of medical records for injured occupants. Therefore, CDS was used to characterize serious injury crashes in this study. NMVCCS had the additional requirement that investigators must have been on the scene of the crash before it was cleared by emergency responders. This allowed NMVCCS investigators to interview witnesses, occupants, and first responders about the details of the crash. As a result of being on scene at the crash, NMVCCS crashes have detailed contributing factor and driver information not available in the other databases.

Table 1. Description of Nationally Representative Crash Databases

Characteristic	GES	CDS	FARS	NMVCCS
Sample	All police reported crashes	Tow-away crashes	Census of Fatal Crashes	EMS Activated Crashes
Number of Cases Per Year (Approximate)	50,000	4,000	33,000	2,000
Study Use	All Crashes	Serious Injury Crashes	Fatal Crashes	Crash Causation

Data from these crash databases are publically available for download from the National Highway Traffic Safety Administration (NHTSA, <ftp://ftp.nhtsa.dot.gov/>). For the GES and FARS databases, years 2011 and 2012 data were aggregated. Both of these databases underwent extensive revisions starting in year 2011. As a result, comparison with previous years is difficult. For the CDS database, years 2008 to 2012 - the last 5 years of data available - were aggregated. Presented results are either proportions of the entire samples or annualized estimates. After the 2011 standardization, the variables in GES and FARS are similar, but not identical, to the CDS values. In order to facilitate comparison, CDS variables were individually recoded to match the GES and FARS values.

Serious injury crashes were extracted from NASS/CDS. A serious injury crash was defined as at least one involved occupant suffering a Maximum Abbreviated Injury Scale (AIS) score of 3 or greater. The AIS is an anatomic injury scale that rates the severity of injuries a trauma victim suffers [2]. The AIS is derived from medical records by

trained coding specialists and therefore is considered more accurate than other on-scene injury scales, e.g. KABCO [3]. The AIS 1998 coded values were used as included in the NASS/CDS data.

The CDS, GES, and NMVCCS databases are probability sampled datasets. The sample designers assign each crash a weighting factor that corresponds to the number of similar collisions that occurred during the sample period. In order to make the estimates presented in this study nationally representative, the weights were used in all analyses for CDS, GES, and NMVCCS unless otherwise noted.

Previous work and Pre-Crash Scenarios

Several characterizations of intersection crashes using NHTSA crash databases have been performed in the past. Najm et al. used GES data from case year 1999 to characterize six (6) intersection scenarios, as shown in Figure 1 [4]. The scenarios were: Straight Crossing Path (SCP); Left Turn Across Path, Opposite Direction (LTAP/OD); Left Turn Across Path, Lateral Direction (LTAP/LD); Left Turn Into Path (LTIP); and Right Turn Into Path (RTIP). One limitation of this past study was that it examined only the GES database. The study was also done before a recent overhaul of the GES database that added more detailed pre-crash variables that were available in previous years of GES. A similar taxonomy was developed by Ragland and Zabysny using GES data [5]. Other efforts have also been performed using other crash data sources, such as state-level crash data [6].

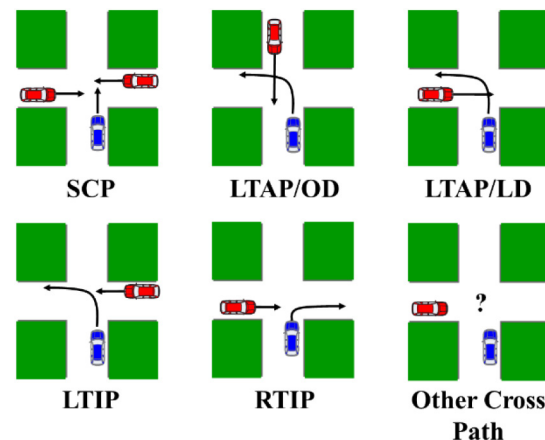


Figure 1. Crossing Path Pre-crash Scenarios. Scenarios are Straight Crossing Path (SCP); Left Turn Across Path, Opposite Direction (LTAP/OD); LTAP, ~ Lateral Direction (LTAP/LD); Left Turn Into Path (LTIP); Right Turn Into Path (RTIP).

Variables in crash databases often focus on describing the objects contacted during the crash events. In the design of driver assistance systems, however, the pre-crash circumstances are also of interest. In order to group crashes that had similar pre-crash circumstances, pre-crash scenarios develop under a previous study were used [1]. These pre-crash scenarios were derived from examining pre-crash critical event, pre-crash vehicle movement, and accident type variables for the first vehicles involved in a harmful event. The pre-crash scenarios assign each crash to one of 19 primary crash scenarios, with multiple sub-scenarios below each primary scenario. The basis of the pre-crash scenarios was worked out by Najm using variables for NASS/CDS [1]. These pre-crash scenarios

were refined and adapted for use for the FARS, GES, and NMVCCS datasets. For consistency, the same naming conventions for intersection crash scenarios shown in [Figure 1](#) were used for this study.

RESULTS

Selected Cases

[Table 2](#) summarizes the frequency of crashes included in each database. All crashes from the NMVCCS, GES, and FARS databases were included in this study. Crashes from the CDS database were restricted to only those that involved at least one seriously injured occupant. Only 2.2% of weighted collisions and 12.5% of all collisions involved a seriously injured occupant in CDS.

Table 2. Selected Cases from National Representative Crash Databases

Estimate	Data Source	Weighted	N
Total Cases	NMVCCS (2005-2007)	2,188,970	5,470
	All Severity (GES 2011-2012)	10,931,367	116,764
	Serious Injury (CDS 2008-2012)	216,983	2,890
	Fatal (FARS 2011-2012)	-	60,667
Annualized Average	NMVCCS (2005-2007)	875,588	2,188
	All Severity (GES 2011-2012)	5,465,683	58,382
	Serious Injury (CDS 2008-2012)	43,397	578
	Fatal (FARS 2011-2012)	-	30,334

[Table 3](#) summarizes the annualized frequency of crossing path pre-crash scenarios. In total, crossing path crashes accounted for 34% of NMVCCS, 22% of all severity, 25% of serious injury, and 14% of fatal crashes.

Table 3. Crossing Path Pre-Crash Scenarios (Weighted and Annualized)

Group	NMVCCS	All Severity	Serious Injury	Fatal
Non-Cross Path	577,043	4,254,587	32,459	26,163
SCP	103,333	360,201	3,294	1,901
LTAP/OD	113,833	315,248	3,990	1,319
LTAP/LD	74,096	210,707	2,910	664
LTIP	1,692	84,370	237	73
RTIP	832	80,959	158	55
Other Cross Path	4,759	159,612	349	160
Total	875,588	5,465,683	43,397	30,334

In the NHTSA crash databases, intersections are defined as a crossing or connection of two or more roadways that is not classified as driveway or alley and is not part of an interchange (i.e. area around a grade separation). [Figure 2](#) shows the proportion of crossing path crashes that occurred at intersections, driveways, or other/unknown junction configurations. There was little difference between the NHTSA databases, so [Figure 2](#) shows the average across all data sources. See [Figure A1](#) in the [Appendix](#) for the distribution of intersection type by crash database and crash scenario. Crossing path crashes predominantly occurred at intersections. LTAP/LD, LTIP, and RTIP crashes occurred more often near drive ways (20% to 25%, respectively) compared to SCP and LTAP/OD crashes (4% and 14%, respectively).

Crossing path crashes that occur at intersections and driveways likely have different characteristics. Road design standards often dictate sight requirements at intersections, whereas driveways can enter roadways with obstructed sight. Drivers may also behave differently at intersections that are controlled by traffic control devices, e.g., stop signs or traffic signals, than at driveways that almost never have control devices. Because crossing path crashes at intersection are the most frequent scenario, they will likely be the first target population that I-ADAS are designed to mitigate. These early systems may have benefits for those crashes that occurred at driveways. The remainder of this report will focus on crashes that occurred at intersections.

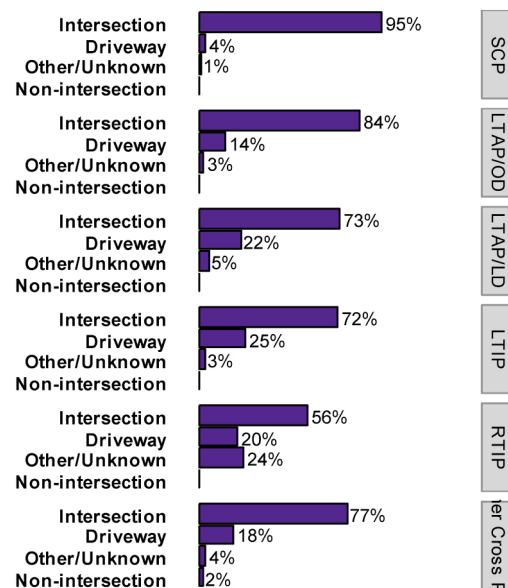


Figure 2. Proportion of Intersection Crashes by Junction Type.

The SCP, LTAP/OD, and LTAP/LD accounted for between 78% and 98% of cross path crashes in each data source, as shown in [Figure 3](#). In these three most frequent scenarios, crashes in and around intersections were most frequent. The remainder of this report will focus on the results for SCP, LTAP/OD, and LTAP/LD crashes in and around intersections. The following analysis will only cover cross path crashes that occurred at intersections. [Table A1](#) in the [appendix](#) tabulates the number of crashes at intersections for each crossing path scenario.

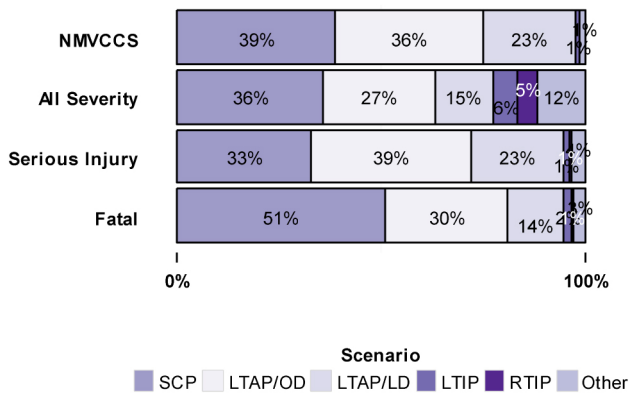


Figure 3. Distribution of Cross Path Crashes In and Around Intersections.

Characteristics of SCP, LTAP/OD, and LTAP/LD Crashes

Road Conditions

An important parameter for I-ADAS is the intersection type that a crash occurred at. Figure 4 shows 5 traffic control scenarios identified in the data.

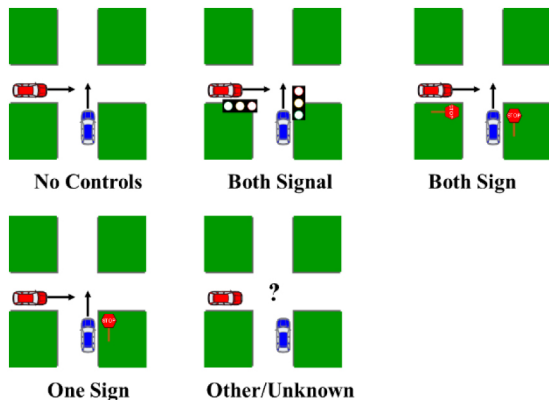


Figure 4. Traffic Control Device Scenarios at Intersections.

The traffic control devices present in intersection crashes are shown in Figure 5. There were few differences between data sources and as a result Figure 5 shows percentages averaged over the three data sources. Traffic control device by data source is shown in the appendix. Almost all (94%) of LTAP/OD crashes occurred at either signalized (67%) or uncontrolled (27%) intersections. In comparison, one signed and one uncontrolled leg was the most common for SCP and LTAP/LD (46% and 58%, respectively), followed by signal controlled intersections (42% and 28%).

Surface and lighting conditions were also examined. Independent of data source and scenario, almost all intersection crashes occurred on dry surfaces (83%-90%) and in light (62%-73%) or dark but lighted (16%-30%) conditions. Distributions of surface and lighting conditions are shown in Figure A2 and Figure A3, respectively, in the appendix. The fact that most crashes occurred on dry roadways indicates shorter stopping distances on wet roadways may not be important in system design. Both daylight and dark but lighted conditions should be considered during system design and evaluation.

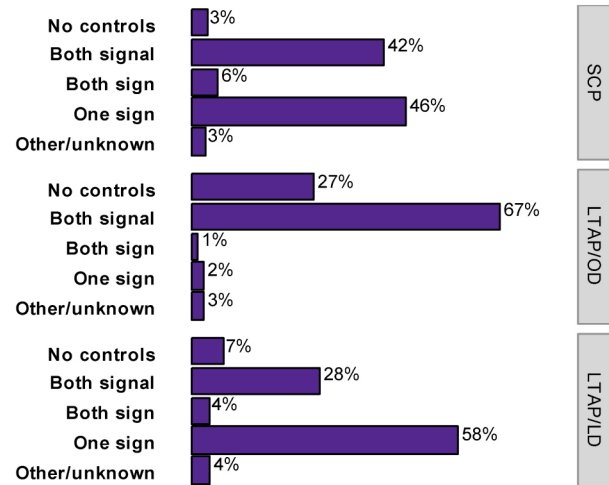


Figure 5. Traffic Control Devices Present in Intersection Crashes.

Figure 6 shows the distribution of posted speed limit in SCP, LTAP/OD, and LTAP/LD intersection crashes. If the intersecting roads had different speed limits, the higher of the two is displayed in Figure 6. All severity and NMVCCS crashes occurred at speed limits below 50 mph (78% and 84%, respectively). Serious injury and fatal crashes, however, occurred more frequently at speed limits of 50 mph and above. Speed limit by scenario is shown in the appendix.

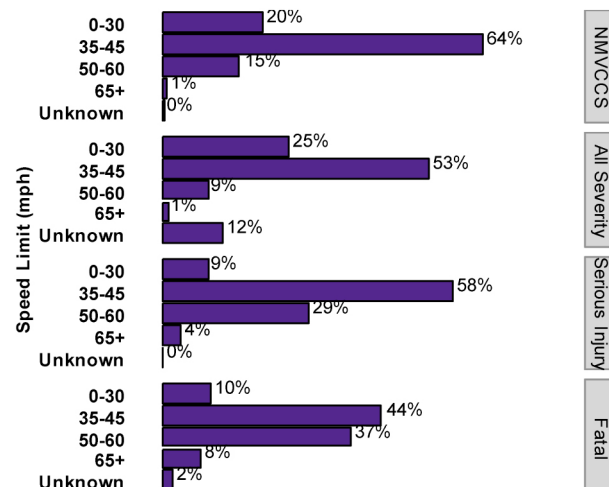


Figure 6. Distribution of Posted Speed Limit for SCP, LTAP/OD, and LTAP/LD Crashes at Intersections.

Driver Conditions

Figure 7 shows the police reported alcohol involvement reported in SCP, LTAP/OD, and LTAP/LD intersection crashes. Alcohol involvement was aggregated by crash. For example, if either driver had police reported alcohol, the crash was labeled as "alcohol". A large number of crashes, between 4% and 36%, had "not reported" or "unknown" alcohol involvement. The trend, however, is that serious injury and fatal crashes had larger proportion of alcohol involvement compared to all severity and NMVCCS crashes. Alcohol involvement by crash scenario and data source is shown in the appendix.

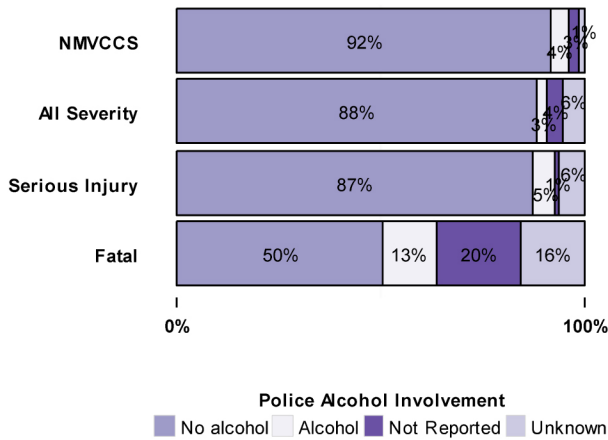


Figure 7. Police Reported Alcohol Involvement in SCP, LTAP/OD, and LTAP/LD Intersection Crashes.

Figure 8 shows age group involvement for intersection crashes and two other common crash scenarios, rear-end and single vehicle crashes. Intersection crashes have been identified as particularly dangerous crash mode for older drivers because of a combination of difficulty of navigating complex traffic scenarios as well as increased frailty leading to increased injury risk [8, 9]. The data suggests that older drivers (65+ years) are more likely to be involved in serious injury or fatal intersection crashes compared to rear-end and single vehicle crashes. The differences are less, however, for NMVCCS and all severity crashes. These results do not distinguish between crash involvement and injury tolerance risk for age groups. Age group involvement for each intersection scenario is shown in the [appendix](#).

Most Frequent Characteristics for SCP, LTAP/OD, and LTAP/LD Crashes

A need for the designers and evaluators of I-AD AS are target or application scenarios. Because the crash characteristics examined in the previous section are not independent of one another, in order to identify target scenarios the most frequent combinations of traffic control device, surface condition, lighting condition, and speed limit were compiled. [Table A2](#), [Table A3](#), and [Table A4](#) in the [appendix](#) show the most frequent combinations for SCP, LTAP/OD, and LTAP/LD crashes that occurred at intersection, i.e., not at driveways or other interchanges. The tables were compiled by averaging the rank ordering of each combination across the four data sources and taking the top 20 scenarios.

SCP crashes occurred on roads where both approaches had signals or there was one sign and one free approach on dry roads during daylight, as shown in [Table A2](#). The main difference between data sources was speed limit. The most common fatal crash scenario had one sign controlled approach with a speed limit between 50 and 60 mph, which corresponded to the 13th ranked NMVCCS and 10th ranked all severity scenarios. The most frequent NMVCCS, all severity, and serious injury crashes had speed limits between 35-45 mph.

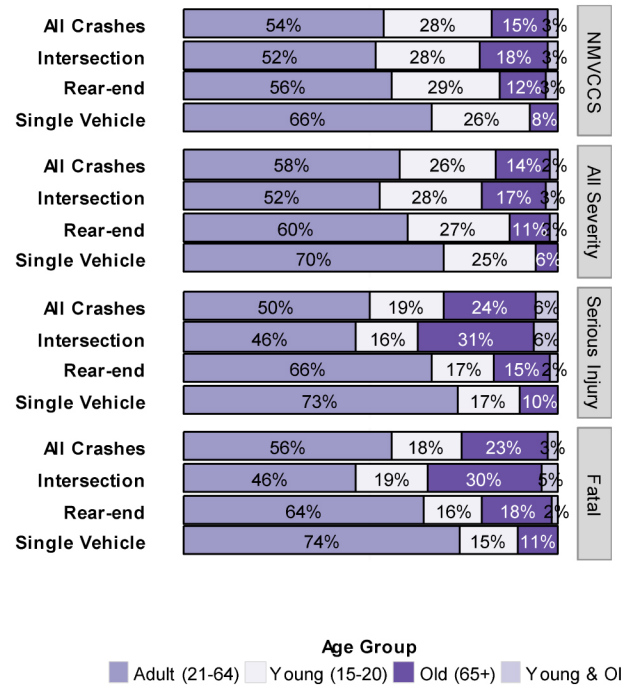


Figure 8. Age Group Involvement in Intersection (SCP, LTAP/OD, and LTAP/LD), Rear-end, and Single Vehicle Crashes.

There were fewer differences between databases for LTAP/OD crashes compared to the SCP crashes, as shown in [Table A3](#). Both approaches controlled by a signal at 35-45 mph speed limits were most common. A scenario with dark but lighted lighting condition was ranked 2nd, indicating lighting might be more important in LTAP/OD than SCP crashes. Crashes at uncontrolled intersections were the 3rd rank scenario.

Like LTAP/OD, LTAP/LD crashes had similar rankings across data sources, as shown in [Table A4](#). One approach controlled by a sign and both approaches controlled by a signal were the most common traffic control devices. A dark but lighted scenario was the 4th ranked scenario.

Crash Causation and Driver Behavior using NMVCCS

Because NMVCCS investigators were at the scene with emergency responders, the database contains crash contributing factors and driver behavior data not in any other database. This section presents results for 1,768 SCP, LTAP/OD, and LTAP/LD crashes in intersections from the NMVCCS database, which accounted for 635,500 weighted collision during the study.

Figure 9 shows the critical reason coded by the NMVCCS investigator in intersection crashes (SCP, LTAP/OD, and LTAP/LD) compared to all other crashes in NMVCCS. The NMVCCS coding manual lists over 100 critical reason that investigators could assign to a crash. To simplify presentation, we have group critical reason into categories. Examples of category groupings are shown in the [appendix](#). The leading cause of intersection crashes was distraction and recognition errors (56%), followed by judgment errors (21%),