Secondary Crash Research

A Multistate Analysis

June 2023

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16. Abstract

Traffic incidents can lead to driver distractions and traffic queues that can then result in subsequent or secondary crashes. A secondary crash is defined as a crash that occurs as a result of an original crash either within the crash scene or within the queue or backup in either direction. Programmatic approaches to identify and document the occurrence of secondary crashes through traffic crash reports and advanced traffic management systems are on the rise nationally. This research leveraged these data collection approaches to create a multistate dataset on secondary crashes to better understand factors surrounding the occurrence of these types of crashes through descriptive statistics and case studies.

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Unclassified	Unclassified	66	N/A

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Please view an online version of the SI Conversion table here.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

ARNOLD	All Road Network of Linear Referenced Data
API	Application Programming Interface
ATMS	advanced traffic management system
CAD	computer-aided dispatch
EDC-4	Every Day Counts Round 4
FDOT	Florida Department of Transportation
FHP	Florida Highway Patrol
FHWA	Federal Highway Administration
KABCO	scale: K = fatal injury, A = suspected serious injury, B = suspected minor injury, C = possible injury, and O = no apparent injury
MMUCC	Model Minimum Uniform Crash Criteria
NHTSA	National Highway Traffic Safety Administration
SSP	safety service patrol
TIM	traffic incident management
TMC	traffic management center

CHAPTER 1. INTRODUCTION

Traffic incidents can lead to driver distractions and traffic queues that can then result in subsequent or secondary crashes. The Federal Highway Administration (FHWA) defines a secondary crash as "A crash that occurs as a result of an original crash either within the crash scene or within the queue or backup in either direction."(1) Secondary crashes are not limited to multilane highways and urban areas; they can occur on any type of roadway—wherever traffic incidents happen. The primary crash does not have to block lanes or involve injuries. Sometimes secondary crashes occur near primary events that are quite minor in nature. Secondary crashes are dangerous to motorists at or near existing incident scenes, and they also place at risk the incident responders and others on the scene of those incidents.

Secondary traffic crashes are undeniable issues for safety and mobility and worthy of research. Until recently, however, only a few States have collected data on secondary crashes to support research analyses and validation. Instead, researchers have taken various approaches to identify secondary crashes within existing crash datasets, including spatiotemporal approaches, queuing model approaches, speed contour plot approaches, and shockwave approaches.(2) In recent years, however, a more pragmatic approach has emerged where secondary crashes are identified at the time of their occurrence and are manually entered directly into data systems. The three most common methods of recording secondary crashes at the time of their occurrence include the following:

- **Traffic crash reports—**In 2017, the nonregulatory 5th edition of the Model Minimum Uniform Crash Criteria (MMUCC) included a new data element and attribute: C2. Crash Classification, S3. Secondary Crash (yes or no).(3) The MMUCC defines a secondary crash as "A motor vehicle traffic crash within a traffic incident scene or within a traffic queue in either direction resulting from a prior traffic incident." In 2017–18, FHWA's Every Day Counts Round 4 (EDC-4) included an innovation called "Using Data to Improve Traffic Incident Management (TIM)." As a result of that effort, several participating States added the MMUCC secondary crash data element to their statewide traffic crash report forms. A recent review of State traffic report forms and associated instruction manuals shows that 18 States and the Florida Highway Patrol (FHP) have incorporated the secondary crash data attribute into their crash report forms.(4)
- **Advanced traffic management system (ATMS)—**Traffic management centers (TMC) or traffic operations centers use ATMS software to detect, track, and manage roadway events and the associated traffic flow and safety. ATMS software is increasingly equipped with fields that link different roadway events and characterize crashes as secondary. Though TMCs often manage limited roadway networks, the experience of TMC operators usually leads to a better understanding of how crashes relate to other crashes or traffic incidents, which can increase the reliability of secondary crash reporting.
- **Computer-aided dispatch (CAD) systems—**Public safety agencies, including law enforcement, fire, emergency medical services, and 911 call centers, use CAD systems to manage resources and to catalog events. An opportunity exists to share data between transportation agency ATMS and public safety CAD integration. Time and location data can support linkages between roadway crashes to identify secondary crashes.

The addition of a data element to capture secondary crashes provides an opportunity for analysis that previously could not be conducted. An approach that combines crash data from multiple States that collect secondary crash data could potentially shed light on secondary crashes in a unique way.

RESEARCH OBJECTIVE

This research project sought to better understand why, when, and where secondary crashes occur. Specifically, the objectives of this project were to (1) conduct research into the number of secondary crashes based on roadway type and causation (to the extent possible), including a deeper review of the causation and potential countermeasures in one or more States; and (2) to develop case studies on the most common types of secondary crashes.

OVERVIEW OF APPROACH

The research approach involved collecting, preparing, and analyzing multistate data on secondary crashes by using both quantitative and qualitative methods. More specifically, the team conducted the following steps to meet the objectives of the research:

- Gathered crash data from States that collect data on secondary crashes via their traffic crash reports
- Uniformized the disparate crash data gathered from the States
- Enriched the crash data with detailed roadway and weather data
- To the extent possible, verified the secondary crashes by conducting a spatial–temporal analysis of the crash data
- Conducted descriptive statistics on the verified secondary crashes
- Conducted a cluster analysis to identify groups of similar types of secondary crashes
- Selected one or more States and conducted a deeper review into the causations of secondary crashes and potential countermeasures
- Developed case studies of common secondary crash types

More details of the methods used are provided throughout the report.

ORGANIZATION OF REPORT

Following this introductory chapter, this report is organized as follows:

- Chapter 2: Collection, Uniformization, and Enrichment of Secondary Crash Data—This chapter details from which States and how much crash data were gathered, as well as how these data were uniformized and enriched to arrive at a consistent database of crashes. The chapter also details the steps taken to verify the crashes marked as secondary in the data from the States.

- Chapter 3: Analysis of Secondary Crash Data—This chapter presents the results of descriptive statistics, a cluster analysis, and a comparison of the original and the verified secondary crash datasets. Charts are presented to show the number of verified secondary crashes categorized by 13 different variables (e.g., day of week, weather, and distance between primary and secondary crashes).
- Chapter 4: Secondary Crash Case Studies—This chapter describes the qualitative approach that was used to review more than 250 narratives from secondary crash reports from Florida and how these crashes were classified into 6 typical types of secondary crashes. Six case studies demonstrate each of the six most common types of secondary crashes through descriptions, crash report diagrams, and camera images.
- Chapter 5: Conclusions and Possible Next Steps—This chapter provides conclusions from the research and considerations of potential next steps to further the understanding of secondary crashes.

CHAPTER 2. COLLECTION, UNIFORMIZATION, AND ENRICHMENT OF SECONDARY CRASH DATA

GATHER CRASH DATA

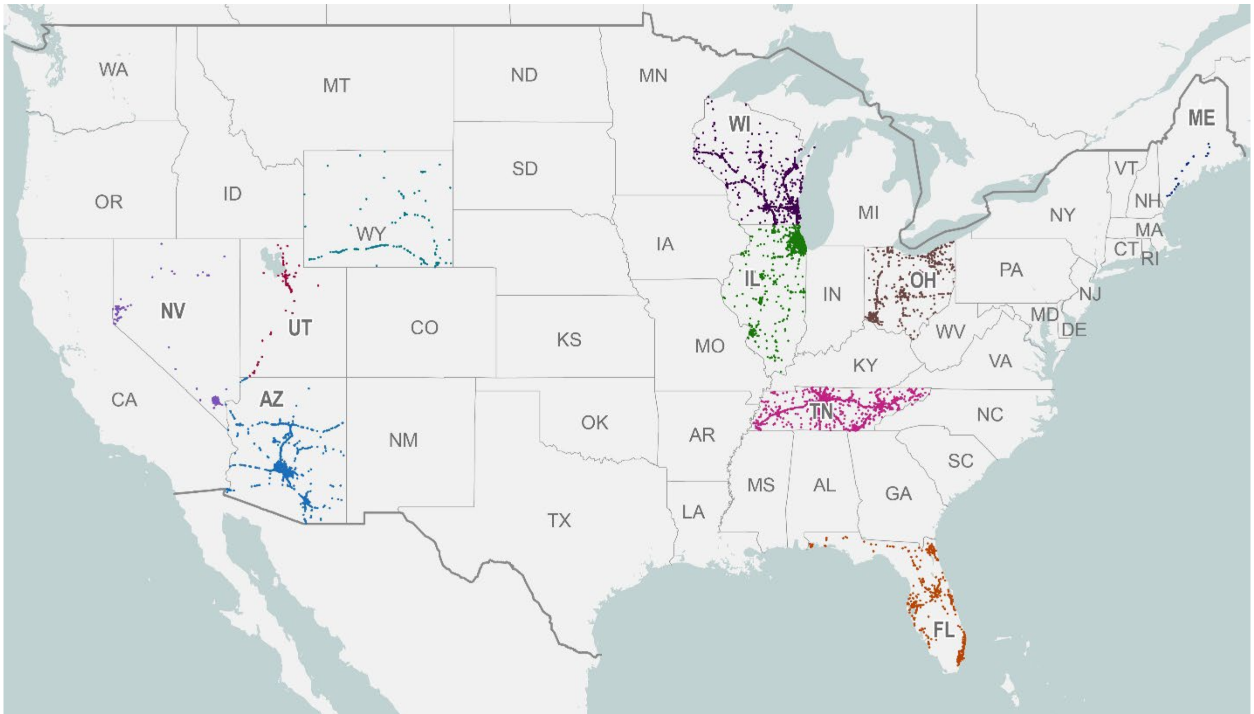
The first step in the research process was to identify and gather crash data from States that include a data element for secondary crashes on their traffic crash reports. Through work done for other projects, including FHWA's EDC-4 Using Data to Improve TIM initiative, the team was aware of multiple States' collecting data on secondary crashes. As such, the team contacted these States, explained the nature of the study, and requested multiple years of raw crash data from each State. As some States had been collecting data on secondary crashes longer than others, the date ranges of the data collected across the States were not consistent. Table 1 lists the States that provided raw crash data, the years of data provided by each State, the total number of crashes in the data provided, the total number of crashes marked as secondary in the data provided, and the percentage of secondary crashes based on the data provided by the State. As shown in the table, the team received a total of 31 years and 7 months of data from the 10 States, which included more than 5 million total crashes and more than 50,000 crashes marked as secondary. A map of the secondary crashes that contained geolocation information is shown in figure 1.

Table 1. Summary of crash data gathered from States.

State	Crash Data Years	Number of Crashes in State Crash Data	Number of Crashes Marked as Secondary in State Crash Data	Percentage of Secondary Crashes Based on State Data %
Arizona	Jan. 2018–Dec. 2020	824,867	16,093	1.95
Florida	Nov. 2017–Dec. 2019	653,140	1,264	0.19
Illinois	Jan. 2019–Dec. 2020	560,053	18,110	3.23
Maine	Sept. 2018–Dec. 2020	63,896	63	0.10
Nevada	Sept. 2018–Dec. 2020	162,688	3,030	1.86
Ohio	Jun. 2018–Sept. 2020	765,415	2,158	0.28
Tennessee	Nov. 2014–Dec. 2020	1,647,315	7,425	0.45
Utah	Jan. 2017–Dec. 2019	189,524	182	0.10
Wisconsin	Jan. 2017–Dec. 2020	539,445	3,062	0.57
Wyoming	Jan. 2017–Dec. 2020	54,701	469	0.86
Total	**31 years + 7 months**	**5,461,044**	**51,856**	**0.94**

UNIFORMIZE CRASH DATA

The next step was to uniformize the data so that the data from the various States could be analyzed as a whole. Given that each State uses its own traffic crash report form with different data elements and attributes, the research team needed to create a uniform data schema that it could use across the States. This process was largely manual and involved a review of all the data elements and attributes used across the 10 States and the identification and mapping of similar fields to standardized data elements and attributes in the uniform data schema. This process naturally led to the collapsing of some fields for some States and was sometimes subjective.



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 1. Map. Geolocation of crashes marked as secondary in the State crash data.

ENRICH CRASH DATA

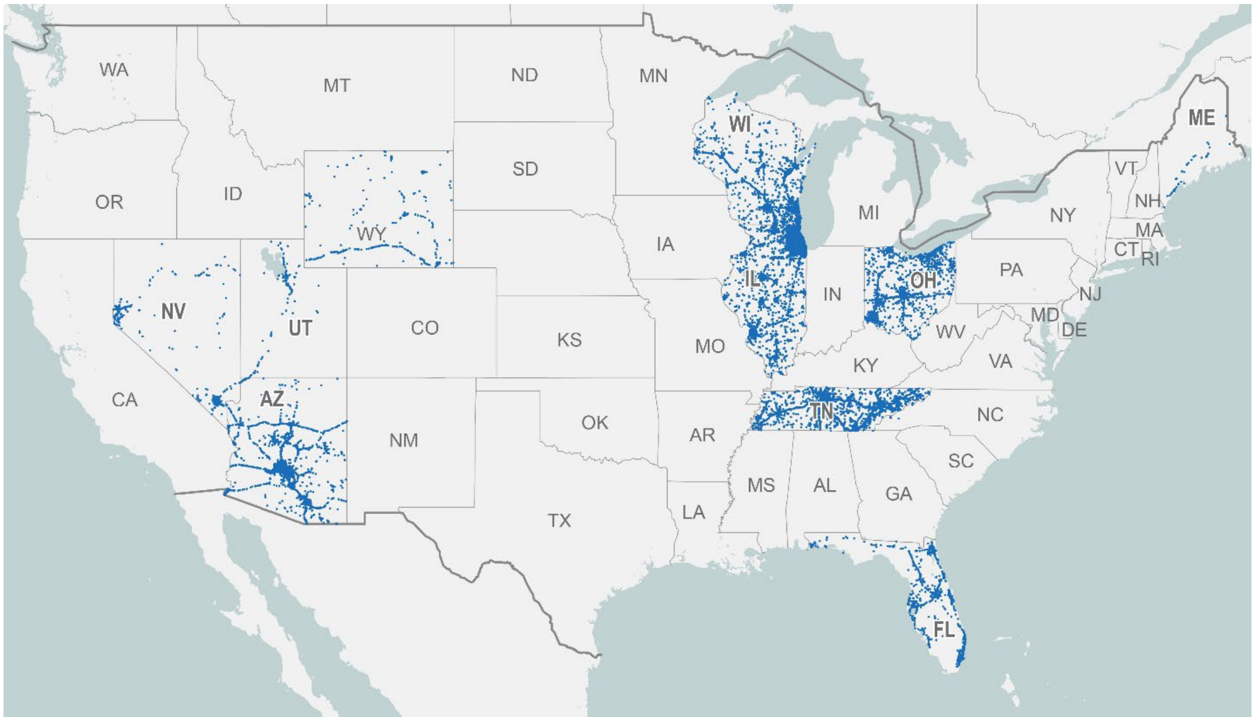
Next, the team enriched the crash data with detailed roadway and weather data. The All Road Network of Linear Referenced Data (ARNOLD) data from each State added more detailed data on the roadway, and Dark Sky (a third-party weather data provider[(5)]) added more detailed weather information. The team integrated the crash and ARNOLD data by using the geolocations (i.e., latitude and longitude) of the crashes and “snapping” them to the ARNOLD network. The team reviewed the location coordinates to verify whether the coordinates could be successfully matched to the ARNOLD roadway data and then verified the latitudes and longitudes for 50,392 (97.1 percent) of the secondary crashes (the remaining 2.9 percent of the secondary crashes were deemed to have erroneous spatial attributes).

To enrich the crash data with weather data, the team placed a call to the Dark Sky historical weather application programming interface with the date, time, and geolocation of the crashes. The team then added columns to the uniform database the data returned by Dark Sky.

VERIFY SECONDARY CRASH DATA

Once the data were uniformized and enriched, the team conducted a step-by-step process in an attempt to verify the secondary crash designation in the original crash data received from the States. The following bulleted items outline the steps taken and the findings associated with each step:

- The team performed a spatial–temporal analysis to determine whether the secondary crashes were proximate in space and time to other crashes that might be considered the primary crashes. For this analysis, the team searched for crashes that occurred within 2 hours (prior to) and within 2 kilometers (in either direction) of each secondary crash. For about 31 percent of the secondary crashes, the team could not identify in the data a primary crash candidate within 2 hours or 2 kilometers. While these crashes indeed may have been secondary, the team could not easily verify them and so removed them from subsequent steps, reducing the number of secondary crashes to 34,693.
- The team then checked the time stamps of the remaining secondary crashes to verify (1) that a time stamp was present; and (2) that the time stamps were properly formatted and without error. The team removed 10 percent of the secondary crashes in this step due to missing or incorrect time stamps, leaving a total of 31,105 crashes.
- Next, the team compared the route identifiers of the secondary crashes and the identified primary crash candidates to verify that the crashes had occurred on the same route. Only 14,195 of the identified primary crash candidates had occurred on the same route as the secondary crashes. While it is possible that a secondary crash could occur on a different road (e.g., cross-street) or facility (e.g., on-ramp), it was assumed for this process that most secondary crashes occur on the same route and proximate to the primary crashes.
- While a previous step included searching for potential candidates for primary crashes that had occurred prior to secondary crashes, the team found that the remaining dataset had about 3 percent of potential primary crashes that occurred after the matched secondary crashes. Removing these secondary crashes further reduced the verified secondary crash dataset to 13,788.
- The crash data from Wisconsin were different from the crash data received from all other States; the data included a primary-secondary crash relationship, which the team identified within the data as an attribute of both the primary and secondary crashes. As such, the team added 1,660 secondary crashes from Wisconsin to the dataset, bringing the verified secondary crashes dataset to 15,448 across the 10 States. These crashes are shown in figure 2.



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 2. Map. 15,448 verified secondary crashes.

Table 2 shows the crashes marked as secondary in the original data received from the States, the number of secondary crashes that were verified via the process just presented, the percentage of the original marked secondary crashes that were verified, and the overall percentage of secondary crashes based on the verified data.

Table 2. Summary of original and verified secondary crashes across States.

State	Crashes Marked as Secondary in State Crash Data	Verified Secondary Crashes	% Marked Secondary Crashes Verified	% Secondary Crashes (Verified/ Total Crashes)
Arizona	16,093	6,688	41.6	0.81
Florida	1,264	848	67.1	0.13
Illinois	18,110	1,781	9.8	0.32
Maine	63	35	55.6	0.05
Nevada	3,030	520	17.2	0.32
Ohio	2,158	676	31.3	0.09
Tennessee	7,425	2,907	39.2	0.18
Utah	182	126	69.2	0.07
Wisconsin	3,062	1,660	54.2	0.31
Wyoming	469	207	44.1	0.38
Total	**51,856**	**15,488**	**29.8**	**0.28**

Note: Data collected as described in table 1.

SUMMARY AND DISCUSSION

This chapter summarized the steps the research team took to gather, uniformize for analysis, and verify the secondary crash data. From the crash data gathered from the 10 States, just under 52,000 crashes were marked as secondary. This number represents about 1 percent of the total crashes that occurred during the same time period across the 10 States.

Prior to conducting analyses on the secondary crash dataset, the research team wanted to verify the secondary crashes to the extent possible. With the verification methodology used, the team reduced the secondary crash dataset from nearly 52,000 crashes to 15,488 (only 30 percent of the original data). It should be noted, however, that while 70 percent of the secondary crashes could not be verified through the identification of candidate primary crash, some of these crashes are likely secondary. For example, some of the secondary crashes may have resulted from primary noncrash incidents, in which cases a primary crash would not be present in the crash data. Likewise, some of the secondary crashes may have resulted from crashes for which crash report forms were completed. Some of the secondary crashes may have occurred outside the time (2-hour) and space (2-kilometer) window set for the spatial–temporal analysis, or they may have occurred on facilities different from those of the primary crashes. Verification of any of the crashes marked as secondary in the original data would require a review of the crash report narratives, which could be resource intensive. Instead, the team applied a verification approach that resulted in a dataset of secondary crashes that, while greatly reduced from the original data, was verified with relatively high confidence. As such, the results of the analyses presented in chapter 3 should be more representative of secondary crashes than the original data, as they should contain fewer crashes that were erroneously coded as secondary.

CHAPTER 3: ANALYSIS OF SECONDARY CRASH DATA

This chapter presents and discusses the analyses and findings of the secondary crash datasets, including descriptive statistics and a cluster analysis.

DESCRIPTIVE STATISTICS

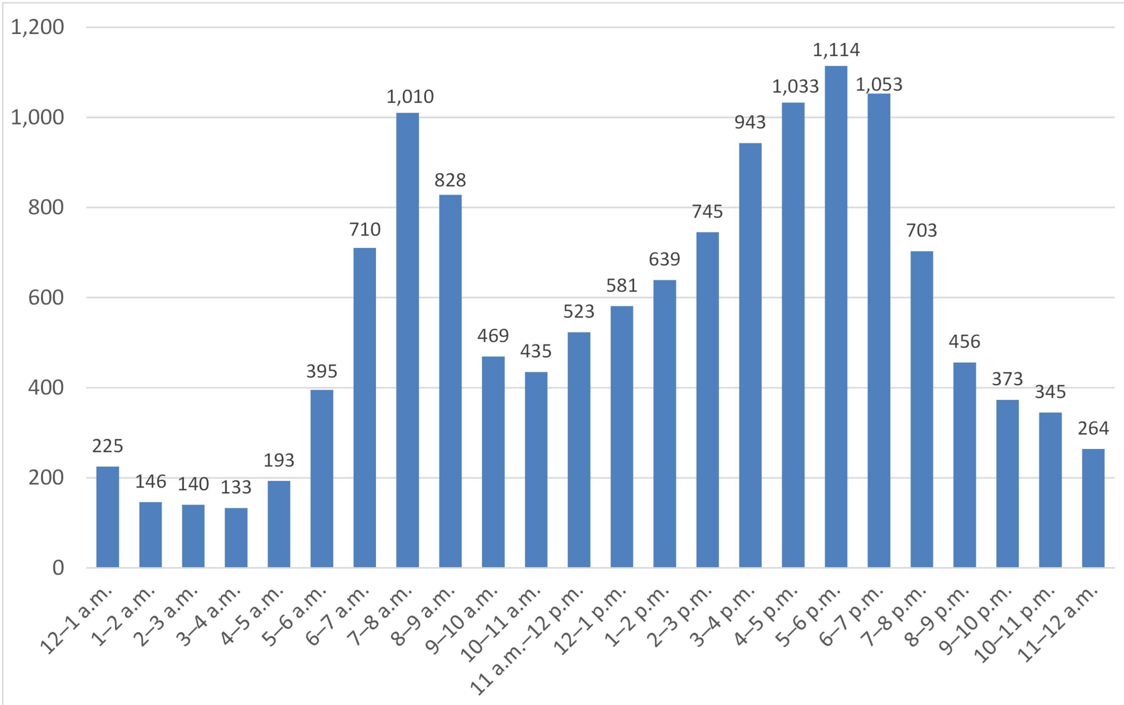
Verified Secondary Crash Dataset

The team conducted analyses of the verified secondary crash dataset to determine the number of secondary crashes by the following variables, and each is presented and discussed herein:

- Time of day
- Day of week
- Month of year
- Injury severity
- Roadway type
- Manner of crash
- Distance between linked primary and secondary crashes
- Time between linked primary and secondary crashes
- Urban versus rural
- Lighting conditions
- Weather conditions
- Atmospheric temperature
- Contributing circumstances

Figure 3 shows the occurrence of the verified secondary crashes by time of day. The distribution of secondary crashes follows the typical distribution of crash occurrence and traffic volumes across a 24-hour day, with the morning peak occurring from 7:00 to 8:00 a.m. and the PM peak occurring from 4:00 to 7:00 p.m.

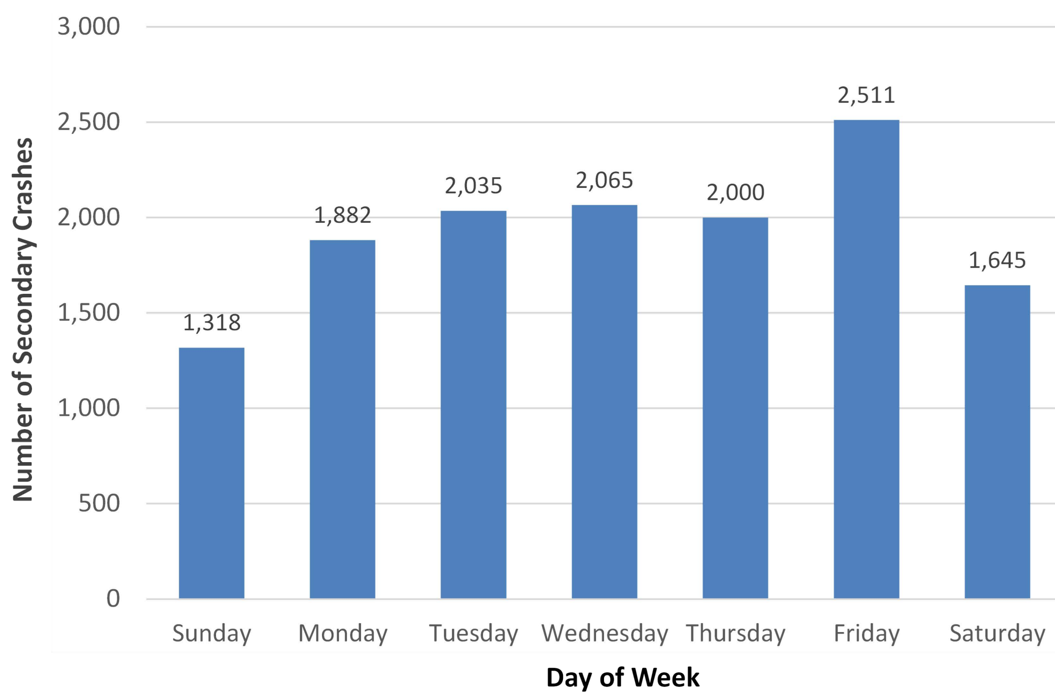
Figure 4 shows the occurrence of the verified secondary crashes by day of week. While the distribution of the crashes generally follows a uniform distribution across the week (especially Tuesday through Thursday), more of the secondary crashes occurred on a Friday, while fewer of the secondary crashes occurred on a Sunday. A statistical test comparing the observed distribution of crashes with a uniform distribution (i.e., the expected distribution of crashes) showed that a statistically significant difference existed between the two.



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 3. Bar chart. Secondary crashes by time of day.

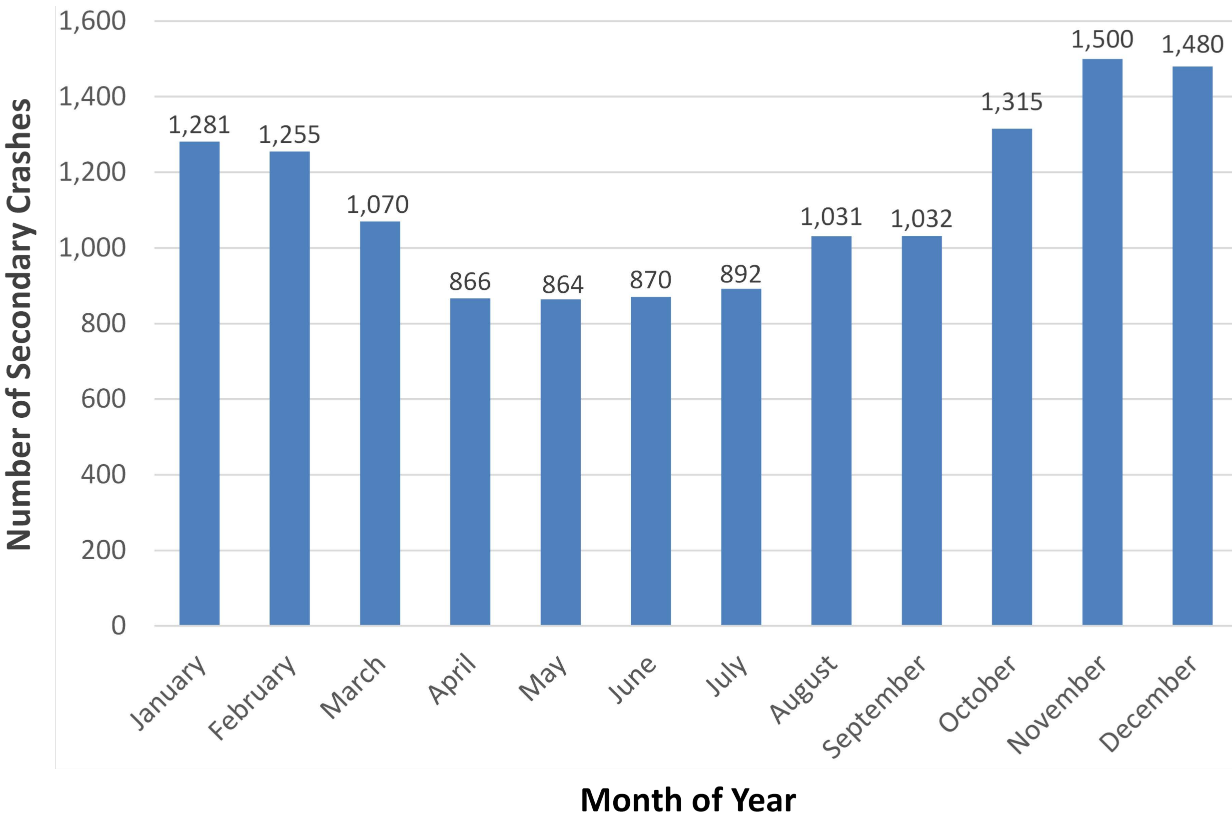


Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 4. Bar chart. Number of secondary crashes by day of week.

Figure 5 shows the occurrence of the verified secondary crashes by month of the year. The chart shows that fewer verified secondary crashes occurred in April through July and that more verified secondary crashes occurred in November and December. A statistical test showed a significant difference between the distribution of expected and verified secondary crashes across months. One explanation could be inclement weather conditions that occur in the fall and winter months.



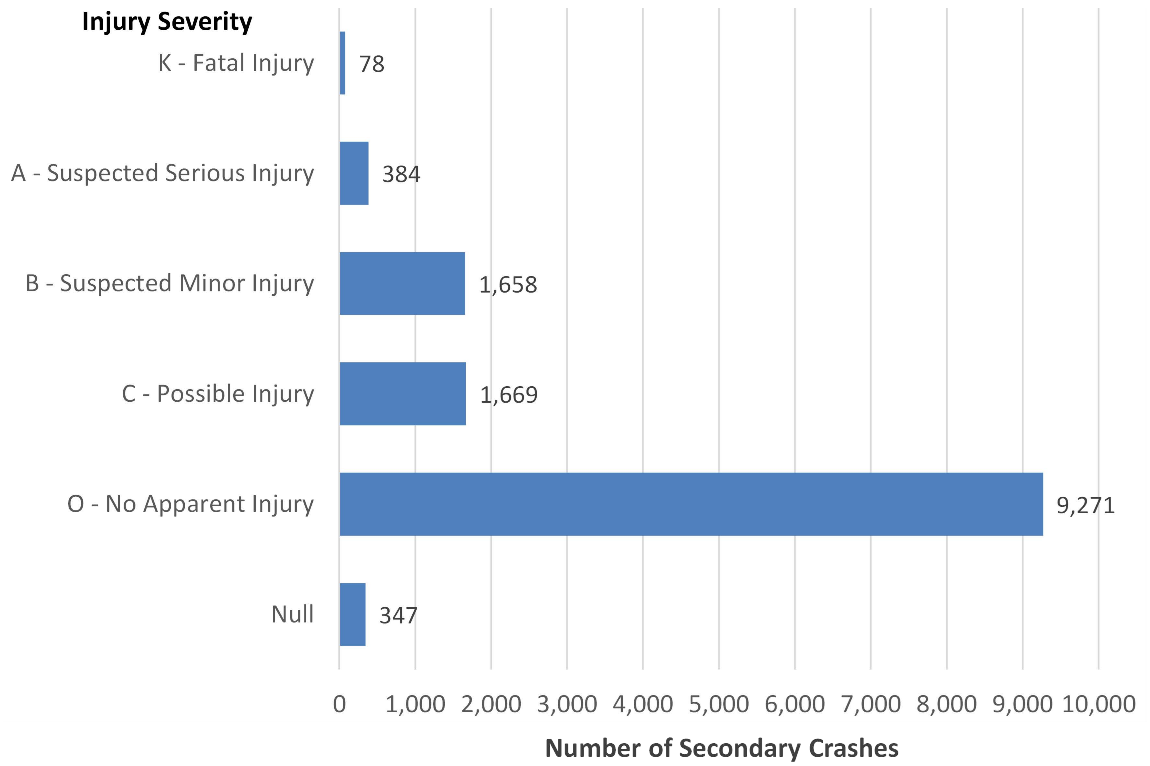
Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 5. Bar chart. Number of secondary crashes by month of year.

Figure 6 shows the number of verified secondary crashes by injury severity (according to the KABCO scale: K = fatal injury, A = suspected serious injury, B = suspected minor injury, C = possible injury, and O = no apparent injury). Most of the secondary crashes (71 percent) involved no apparent injury, and less than 1 percent of the secondary crashes involved fatal injuries.

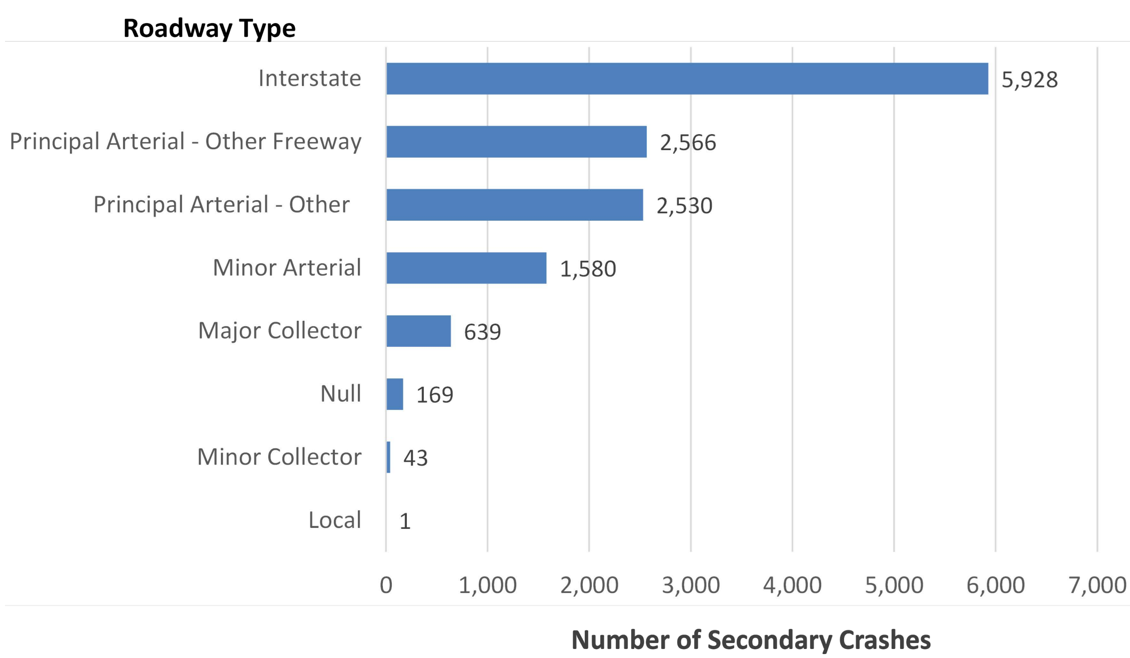
Figure 7 shows the number of verified secondary crashes by roadway type. Nearly 45 percent of the verified secondary crashes occurred on Interstate Highways, while about 38 percent of the verified secondary crashes occurred on principal arterials.



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 6. Bar chart. Number of secondary crashes by injury severity.

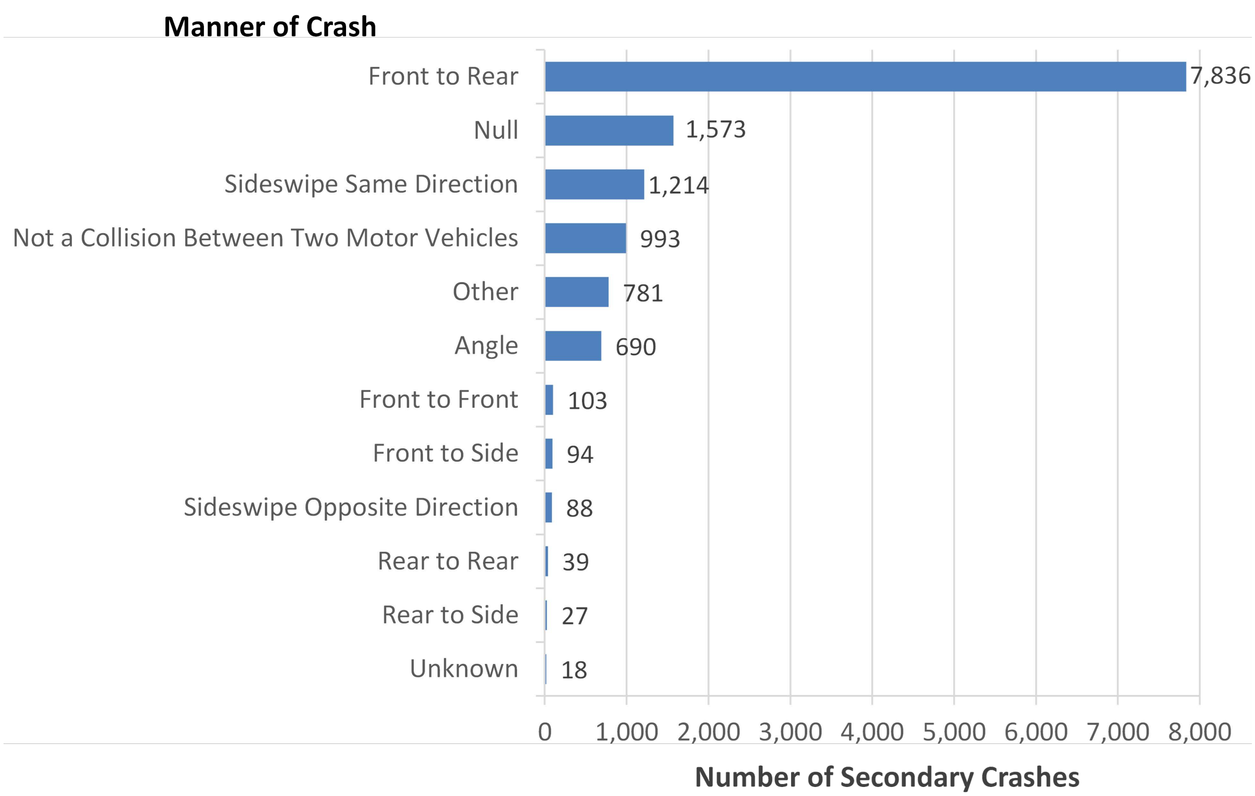


Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 7. Bar chart. Number of secondary crashes by roadway type.

Figure 8 shows the number of verified secondary crashes by manner of crash. Just under 66 percent of the secondary crashes (with known values for manner of crash) were classified as "front to rear," which makes sense given that many secondary crashes are back-of-queue crashes due to congestion caused by a primary incident. About 10 percent of the verified secondary crashes were classified as "sideswipe same direction," which also makes sense given that drivers may swerve left or right to avoid striking a stopped or slowing vehicle due to a prior traffic incident. A little more than 8 percent of the secondary crashes were classified as "not a collision between two motor vehicles." These crashes could involve drivers' veering off the road to avoid the primary crash or associated traffic queue and striking other objects, striking debris from a prior crash, or even striking a responder at a prior incident. About 8.8 percent of the crashes, however, fall into categories that may bring into question whether they were indeed secondary crashes, including "angle" crashes (5.81 percent), "front-to-front" crashes (0.87 percent), "front-to-side" crashes (0.79 percent), "sideswipe opposite direction" crashes (0.74 percent), "rear-to-rear" crashes (0.33 percent), and "rear-to-side" crashes (0.23 percent). Crashes of these natures could theoretically happen as secondary crashes (e.g., if a primary crash resulted in a vehicle's being spun around to face the opposite direction of traffic flow, then a secondary crash could involve a "sideswipe-opposite-direction" or a "front-to-front" crash); however, some (e.g., rear to rear or rear to side) seem more unlikely for secondary crashes and may suggest that the crashes were not secondary in nature. A review of the narratives for these crashes could confirm whether they were secondary crashes.

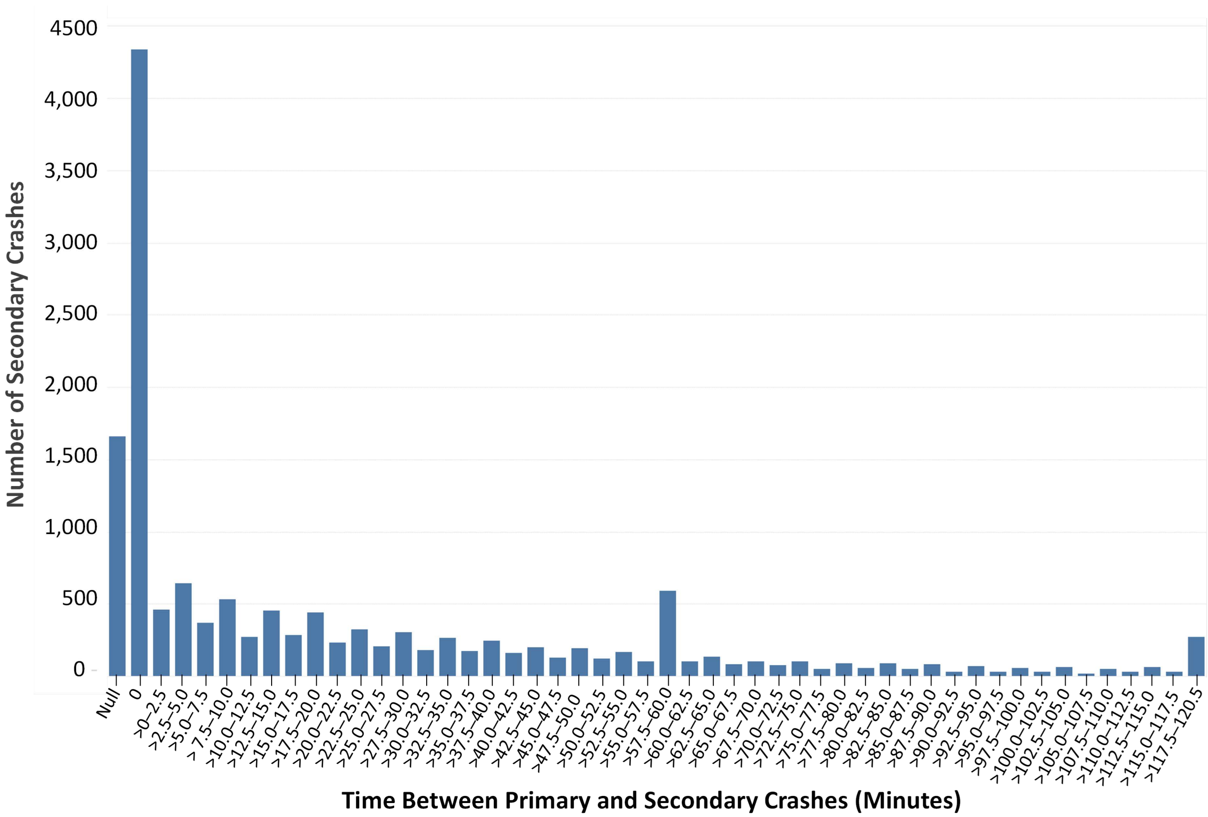


Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 8. Bar chart. Number of secondary crashes by manner of crash.

Figure 9 shows the number of secondary crashes by the time between the occurrence of the linked primary and secondary crashes. The chart shows that about 30 percent of the linked primary and secondary crashes had the same time of occurrence on the crash reports. It is interesting to note the up-and-down nature of the bins, with the bins that end in “5” or “0” (5, 10, 15, 20, 25, etc.) including more linked primary–secondary crashes than the bins ending in “2.5” or “7.5” (2.5, 7.5, 12.5, 15.5, 17.5, etc.), both of which consistently decrease until the bin that ends in 60 minutes, which shows an unnatural spike in the distribution (about 4 percent of the linked primary and secondary crashes occurred 60 minutes apart). There is another unnatural spike at the 120-minute mark (nearly 2 percent of the linked primary and secondary crashes occurred 120 minutes apart). These results suggest some bias in the data collection (e.g., rounding to the nearest 5 minutes or 60 minutes). However, most of the secondary crashes occur very soon following the primary crashes (about half occurred within 20 minutes of the primary crashes), with a decreasing number of linked primary and secondary crashes’ occurring as time going on (apart from the 60- and 120-minute marks as previously noted).

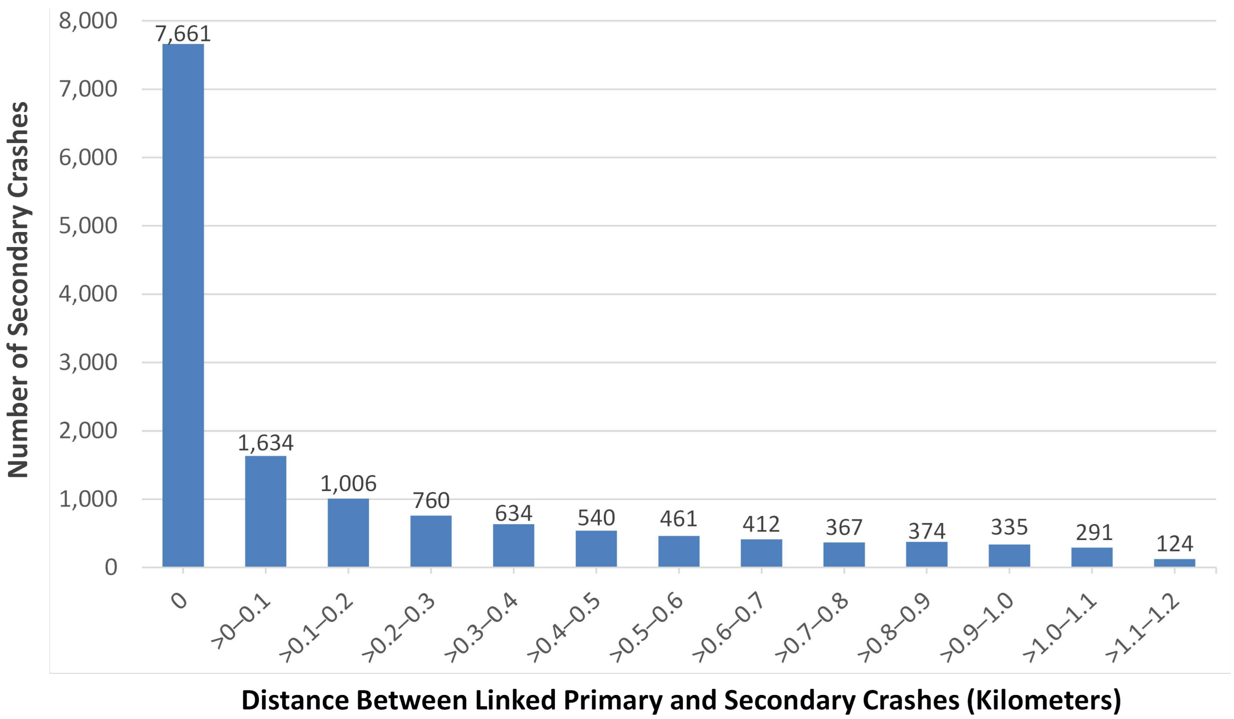


Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 9. Bar chart. Number of secondary crashes by time between linked primary and secondary crashes.

Figure 10 shows the number of secondary crashes by the distance between the occurrence of the linked primary and secondary crashes (as recorded on the crash reports). The chart shows that 52.5 percent of the linked primary and secondary crashes had the same latitudes and longitudes, with decreasing numbers of secondary crashes as the distance between the primary and secondary crashes increased. About 84 percent of secondary crashes reportedly occurred within a half kilometer of the primary crashes.



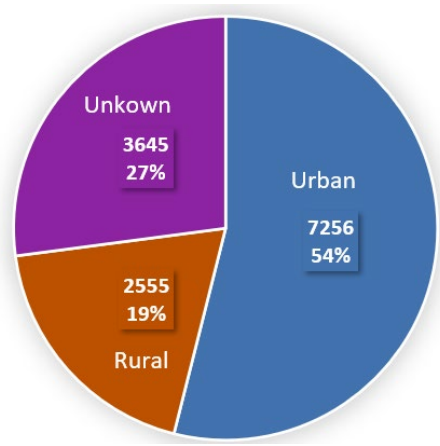
Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 10. Bar chart. Number of secondary crashes by distance between linked primary and secondary crashes.

Figure 11 shows the numbers and percentages of verified secondary crashes by whether they occurred in an urban, rural, or unknown area. Most of the secondary crashes (54 percent) occurred in urban areas, and 19 percent occurred in rural areas. For more than a quarter of the verified secondary crashes (27 percent), the rural or urban attribute was missing.

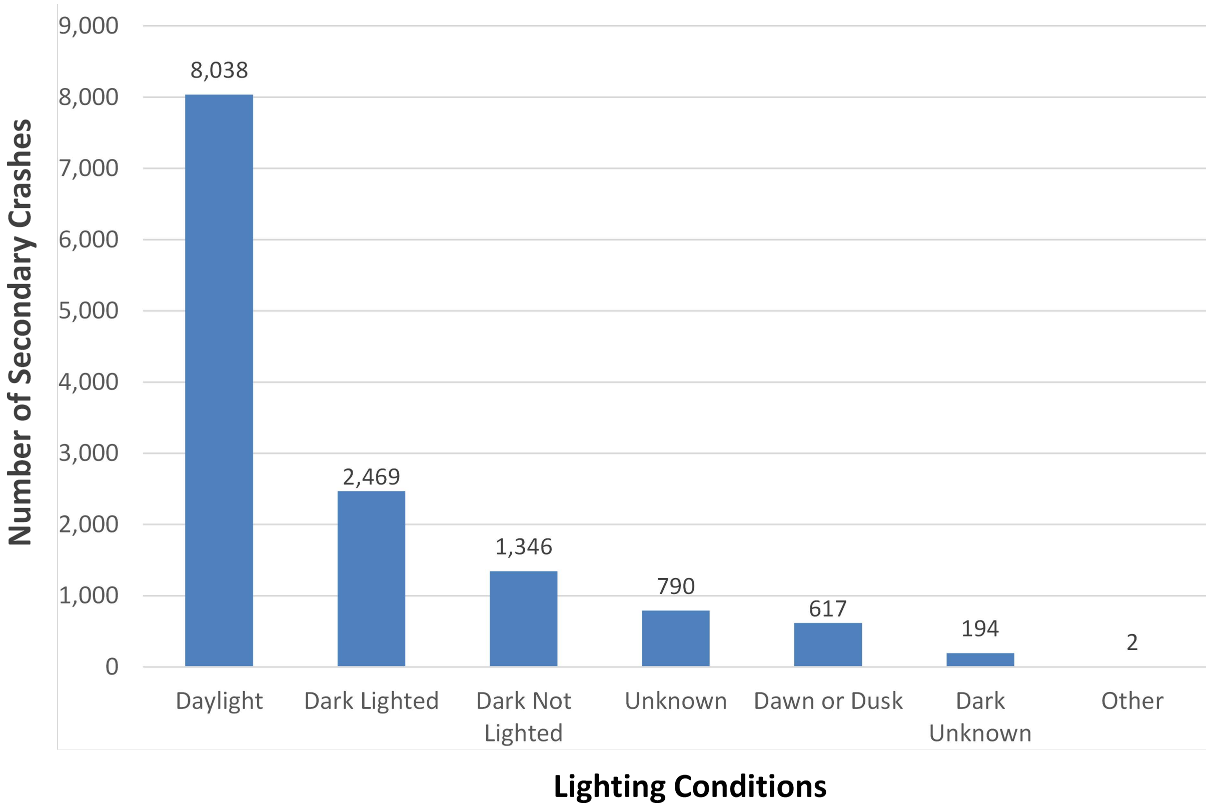
Figure 12 shows the number of verified secondary crashes by lighting conditions. Nearly 60 percent of the secondary crashes occurred in daylight conditions. Another 18 percent occurred in dark but lighted conditions. About 11 percent of the secondary crashes occurred in dark conditions. And less than 5 percent occurred around dawn or dusk.



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 11. Pie chart. Secondary crashes by urban versus rural.



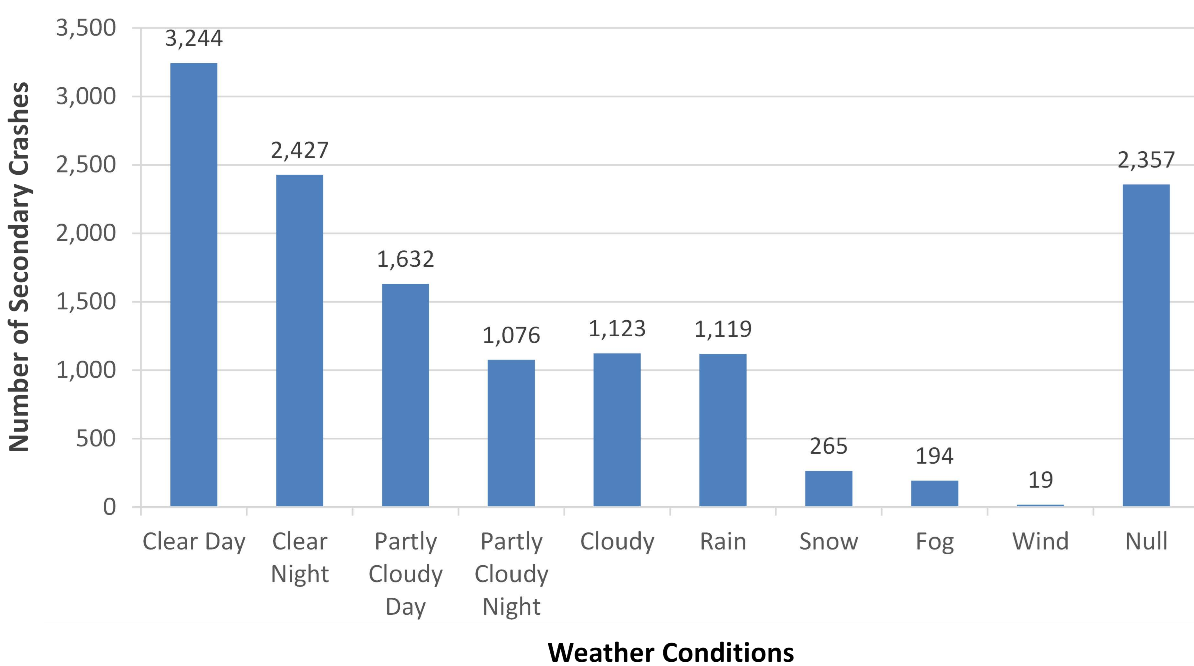
Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 12. Bar chart. Number of secondary crashes by lighting conditions.

Figure 13 shows the number of verified secondary crashes by weather conditions. About one-quarter of the secondary crashes (24 percent) occurred in clear, daytime conditions, while another 21 percent occurred in partly cloudy or cloudy, daytime conditions. Around 26 percent of the secondary crashes occurred in clear or partly cloudy, nighttime conditions. Only about 12 percent of the secondary crashes occurred during inclement weather conditions, with rain being the most common (8.3 percent). Weather data attributes were missing for nearly 18 percent of the secondary crashes.

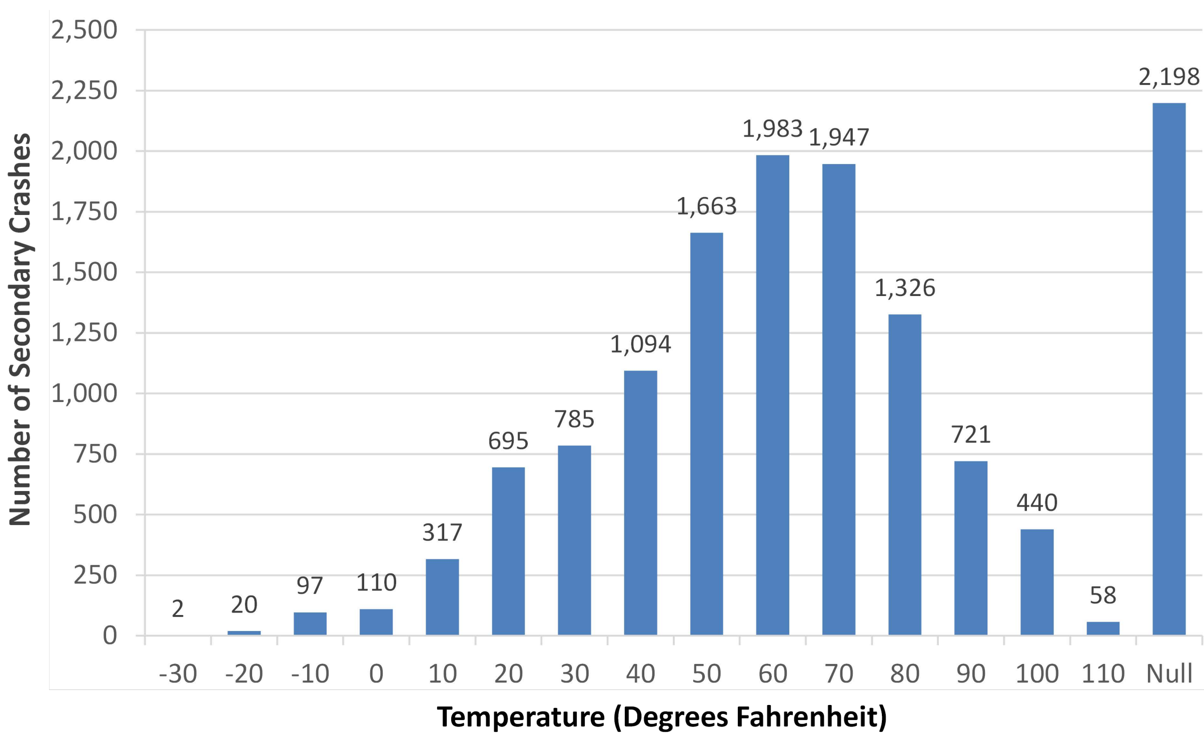
Figure 14 shows the number of verified secondary crashes by atmospheric temperature. The graph shows a bell-shaped distribution around an average of about 60 degrees Fahrenheit. While most of the secondary crashes occurred during fair temperatures, the longer tail to the left indicates that slightly more secondary crashes occurred in colder weather conditions compared with hotter weather conditions.



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 13. Bar chart. Number of secondary crashes by weather conditions.

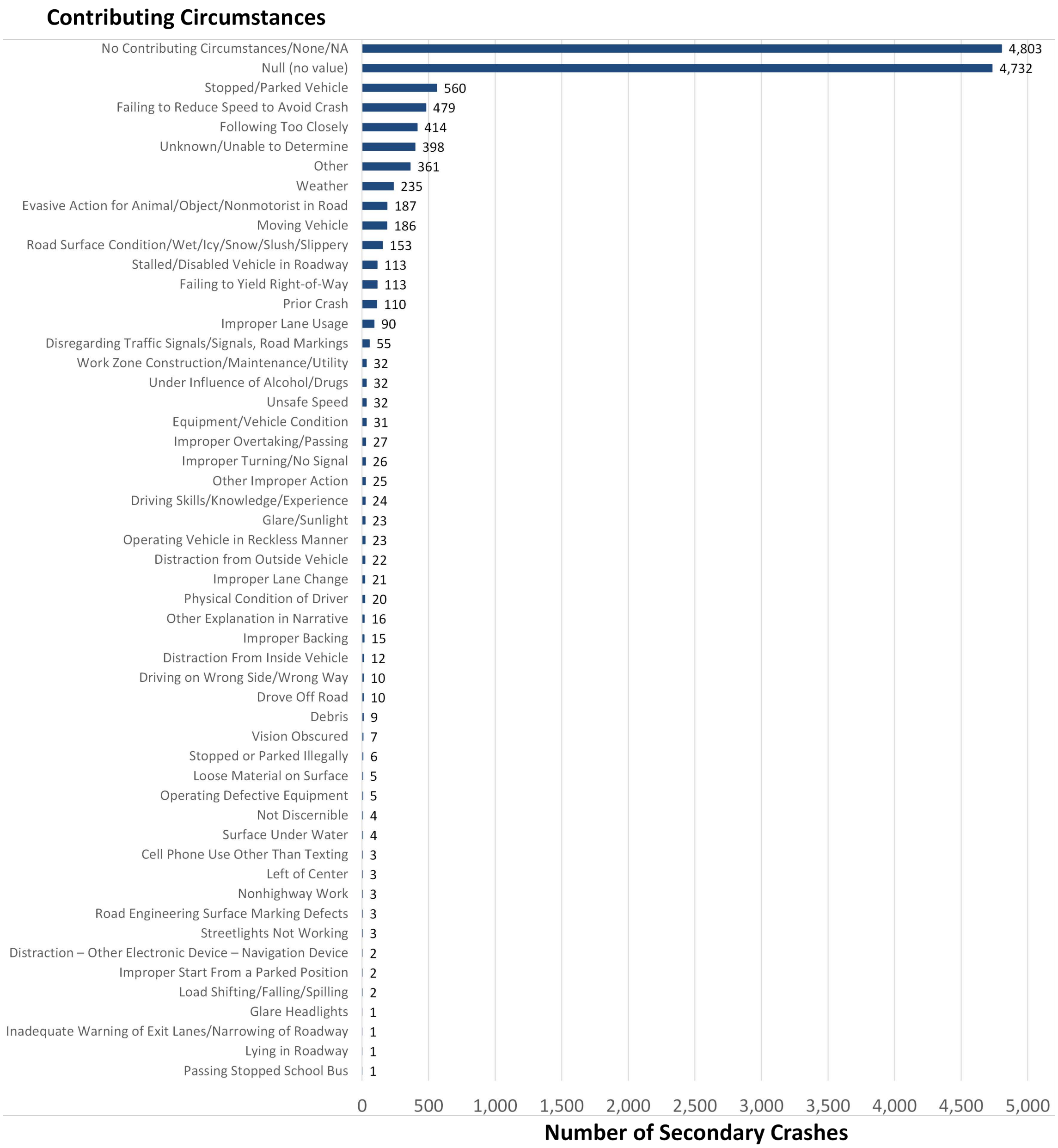


Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 14. Bar chart. Number of secondary crashes by atmospheric temperature.

Figure 15 shows the number of verified secondary crashes by contributing circumstances. Most of the secondary crashes (71 percent) had either "unknown" or "null" values for contributing circumstances. Of the 3,920 secondary crashes with attributes for contributing circumstances, the highest percentage of any attribute was for "stopped/parked vehicle," at 14.3 percent, followed by "failing to reduce speed to avoid crash" (12.2 percent), "following too closely" (10.6 percent), and "weather" (6.0 percent) as the top contributing circumstances; however, due to the wide range of contributing circumstances used by the 10 States (101 different attributes for contributing circumstances), in total these make up only 43 percent of the secondary crashes with attributes for contributing circumstances.



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

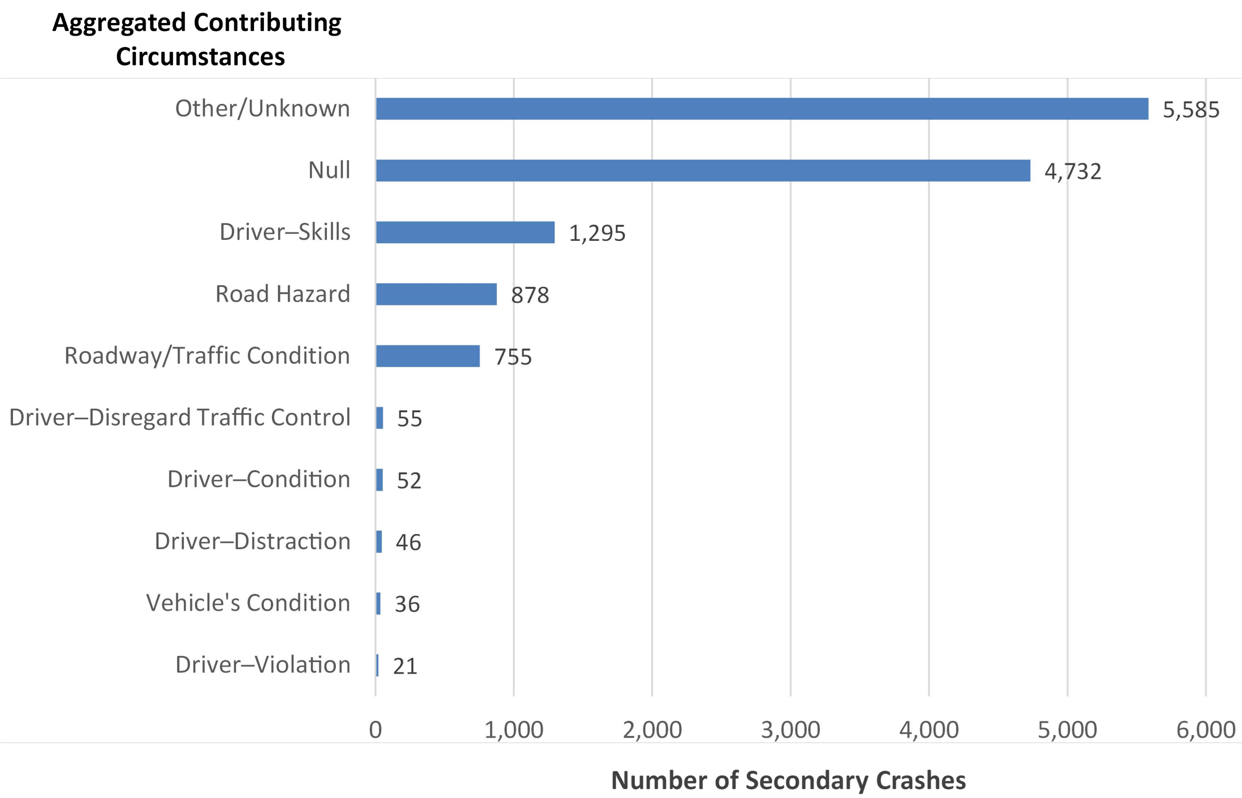
Figure 15. Bar chart. Number of secondary crashes with various contributing circumstances.

To account for this, the team distilled the 101 attributes for contributing circumstances into 9 new aggregated attributes. Table 3 lists the new, aggregated attributes for contributing circumstances and shows how the original 101 contributing circumstances attributes (numbered across the States' attributes) were mapped to the new attributes. Figure 16 shows the data from figure 15 collapsed into the aggregated attributes for contributing circumstances. Disregarding crashes with unknown and null attributes for contributing circumstances, 41 percent of the crashes had contributing circumstances related to "driver skills (e.g., driver experience, failure to reduce speed, failure to yield right-of-way, following too closely, and improper lane usage). Twenty-eight percent of the secondary crashes had contributing circumstances related to a "road hazard" (e.g., object, vehicle, animal, or nonmotorist in the roadway). Just under a quarter of the secondary crashes (24.1 percent) had contributing circumstances associated with a "roadway/ traffic condition" (e.g., prior crash, moving vehicle, road surface condition, or weather). Only 6.7 percent of the secondary crashes had contributing circumstances associated with "driver disregard of traffic control," "driver condition," "driver distraction," "vehicle condition," or "driver violation."

Table 3. Recategorized attributes for contributing circumstances.

New Contributing Circumstances Attributes	Original Contributing Circumstances Attributes
Road hazard	1, 2, 4, 14, 31, 33, 40, 46, 55, 56, 57, 70, 71, 76, 80, 87, 97, 90
Roadway/traffic condition	19, 32, 49, 51, 52, 53, 54, 58, 59, 66, 67, 68, 74, 75, 77, 81, 85, 86, 89, 92, 93
Driver—disregard traffic control	5, 6, 7, 82, 83
Driver—skills	11, 15, 16, 17, 18, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 42, 45, 60, 64, 99, 100, 101
Driver—violation	10, 12, 47, 50, 88, 91, 96
Driver—condition	20, 48, 62
Driver—distraction	3, 8, 9, 65, 84, 94, 98
Vehicle's condition	13, 41, 95
Others/unknown	34, 35, 36, 37, 38, 39, 43, 44, 61, 63, 69, 72, 73, 78, 79

Note: Data collected as described in table 1.



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

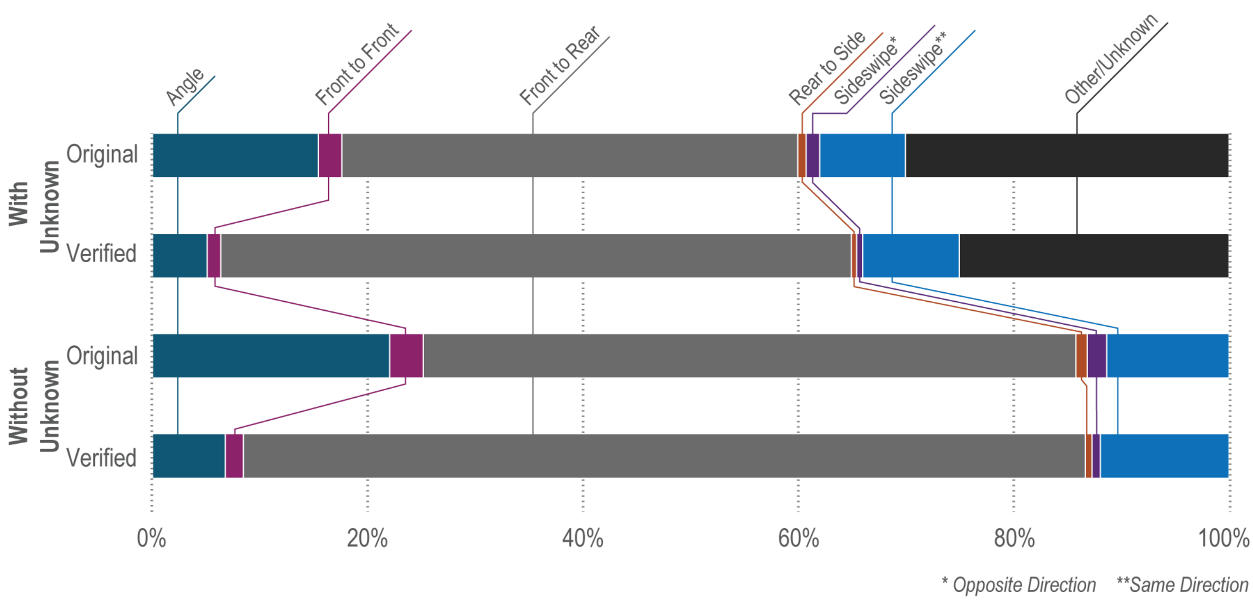
Figure 16. Bar chart. Number of secondary crashes by aggregated contributing circumstances.

Comparison of Original Versus Verified Secondary Crash Datasets

There was a large discrepancy between the original secondary crash dataset (as received from the States) and the verified secondary crash dataset resulting from the spatial–temporal analysis to link secondary crashes to potential primary crashes. Only about 30 percent of the crashes identified as secondary by law enforcement officers on the crash reports could be verified through the spatial–temporal analysis. While some of the crashes identified as secondary crashes in the original dataset may have occurred because of prior noncrash incidents (thus not being verified by the presence of primary crashes), it is questionable that these crashes constitute as much as 70 percent of all secondary crashes. Therefore, the findings from the spatial–temporal analysis raise concerns about the veracity of the secondary crash data collected by law enforcement officers via crash reports.

To check for similarities and differences between the original and verified secondary crash datasets, as well as to identify specific attributes associated with larger numbers of secondary crashes, the team ran descriptive statistics on both datasets for multiple data elements of interest. As previously mentioned for contributing circumstances, the team developed aggregated data elements and attributes and mapped each State's unique way of coding of contributing circumstances to the aggregated categories. The team then compared the counts and percentages of secondary crashes for each data element and attribute for the original datasets and the verified datasets. Given the substantial number of missing or unknown data attributes, the team also examined the counts and percentages of secondary crashes with and without these unknown values.

The results show a difference in the percentage of secondary crashes across the attribute categories for some data elements. An example is shown in figure 17, which compares original and verified secondary crash datasets for "manner of crash," with and without unknown or missing values. The top two bars include the crashes with unknown values for manner of crash, showing about 30 percent missing in the original dataset and about 25 percent missing in the verified dataset. When these missing values are removed in the bottom two bars, it is easier to compare the differences between the original and verified datasets. The bottom two bars show that most of the secondary crashes in both the original and verified datasets were "front to rear." However, the verified dataset contains a higher percentage of front-to-rear crashes (78.2 percent) than does the original dataset (60.6 percent). Similarly, the original dataset contains more "angle" and "front-to-front" crashes than does the verified dataset (original, 22.0 percent versus verified, 6.8 percent for angle crashes and original, 3.1 percent versus verified, 1.7 percent for front-to-front crashes). The differences between the two datasets are the results of angle and front-to-front crashes' being removed in the spatial–temporal analysis because a potential primary crash was not identified. These results show a better alignment between the verified dataset and what could be expected for secondary crashes based on observations in the field (i.e., more likely to be rear-end crashes than angle or front-to-front cashes), partially validating the results of the spatial–temporal analysis and potential quality issues with the data collection.

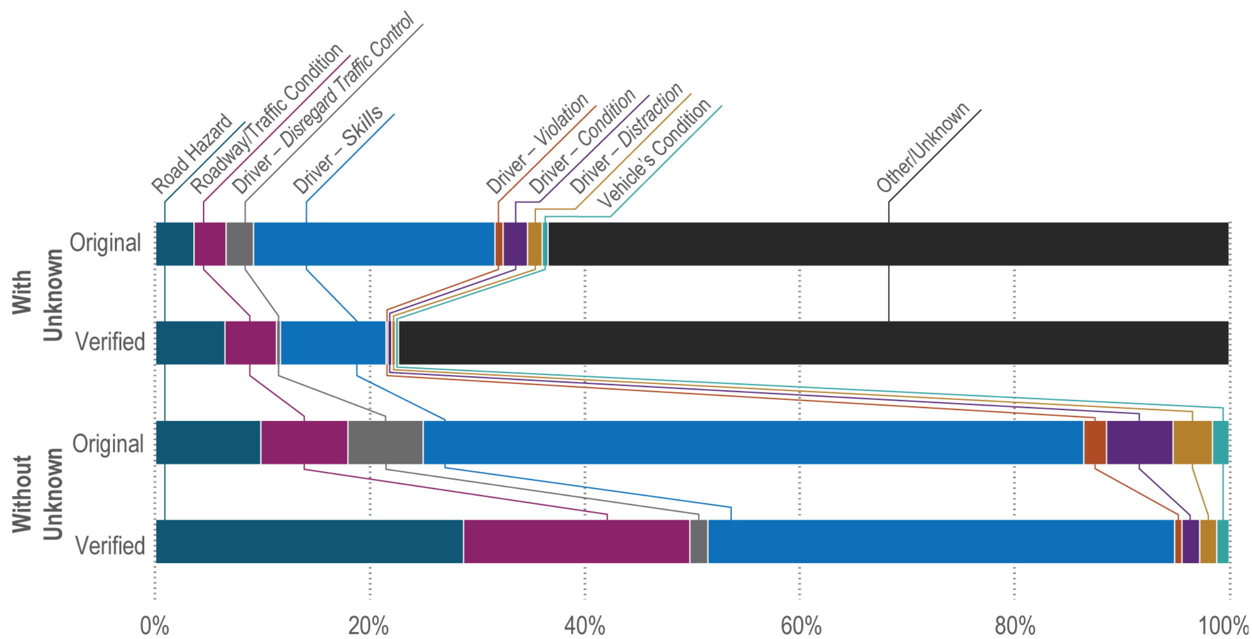


Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 17. Bar chart. Comparison of manner of secondary crashes between original and verified datasets, with and without unknown data attributes.

Similarly, a comparison of secondary crash contributing circumstances between the original and verified datasets and with and without unknown data attributes is shown in figure 18. The top two bars show that a large portion of the secondary crashes in both the original and the verified datasets had unknown or missing values for contributing circumstances (about 63 percent and 77 percent, respectively). When the unknown values are removed in the bottom two bars, it can be observed that for most of the secondary crashes (62 percent), driver skills were a contributing factor, while all other factors contributed to less than 10 percent of the secondary crashes. In the verified dataset, on the other hand, "road hazard" and "roadway/traffic condition" contributed to 29 percent and 21 percent of the secondary crashes, respectively, in addition to about 43 percent of secondary crashes with driver skills as a contributing factor. These findings also align with expectations: secondary crashes occur as results of primary incidents, which cause road hazards and roadway/traffic conditions.



Source: Federal Highway Administration.

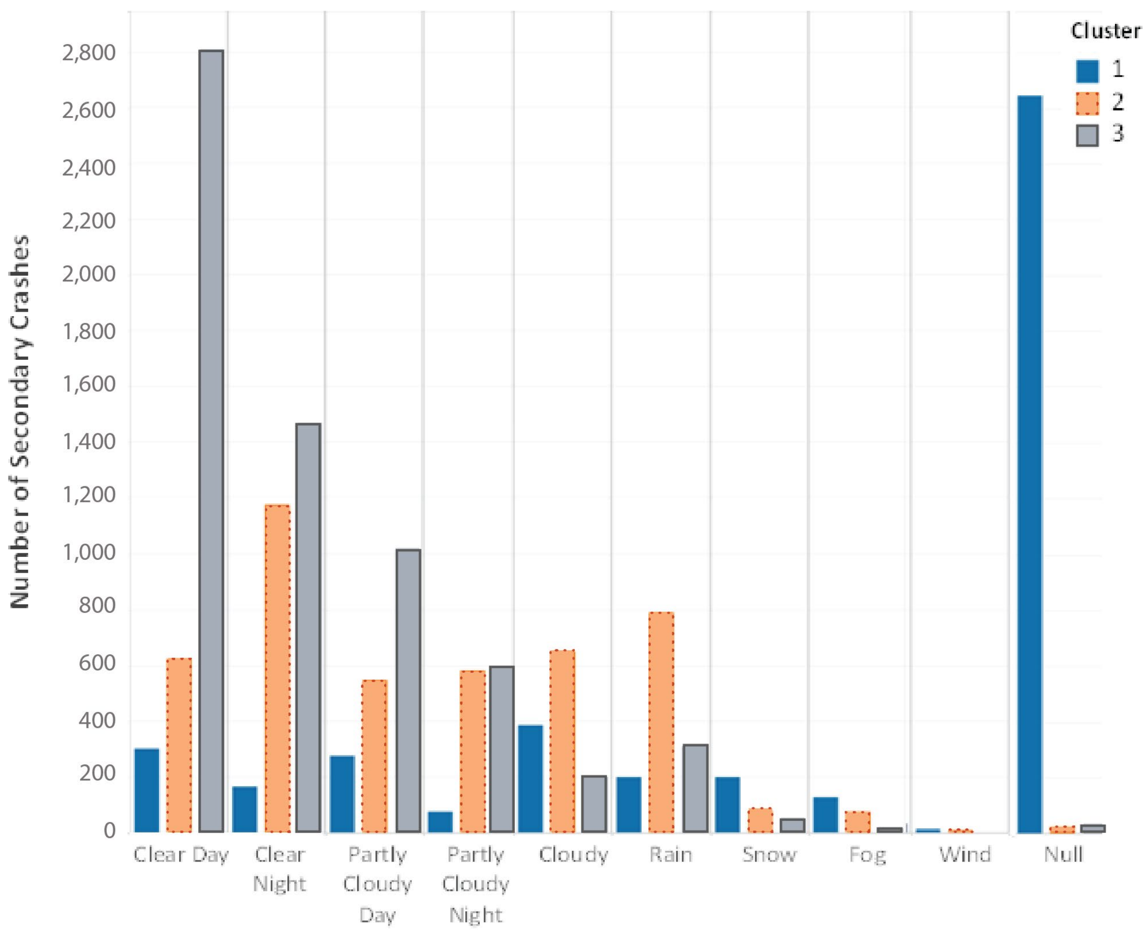
Note: Data collected as described in table 1.

Figure 18. Bar chart. Comparison of circumstances of secondary crashes between original and verified datasets, with and without unknown data attributes.

CLUSTER ANALYSIS FOR CRASH FACTORS

The team performed a cluster analysis on the verified dataset to determine whether there were any natural groupings of secondary crashes around the crash data elements and attributes. The cluster analysis was based on a k-prototype clustering algorithm, which is a hybrid clustering algorithm that can process both categorical and numerical data. To run this cluster analysis, the team had to fill in all missing categorical data with "unknown" and all missing numeric data with "−1."

The results of the cluster analysis for each data element and attribute used in the analysis showed two general trends. First, for data attributes with many "unknown" values, these unknown values influenced the formation of the clusters. An example is shown in figure 19, which shows cluster analysis results for weather conditions. The figure illustrates that, while each of the three clusters contains secondary crashes of all the weather attributes, cluster 1 contains most of the secondary crashes with unknown values for weather. Examination of the other two cluster results finds that cluster 3 contains most of the secondary crashes that occurred in clear (both day and night) and partly cloudy (day) conditions, while cluster 2 contains more of the secondary crashes that occurred in cloudy and rainy conditions. It also can be seen that cluster 1, along with most of the secondary crashes with unknown weather conditions, contains more of the secondary crashes that occurred in snowy and foggy conditions.

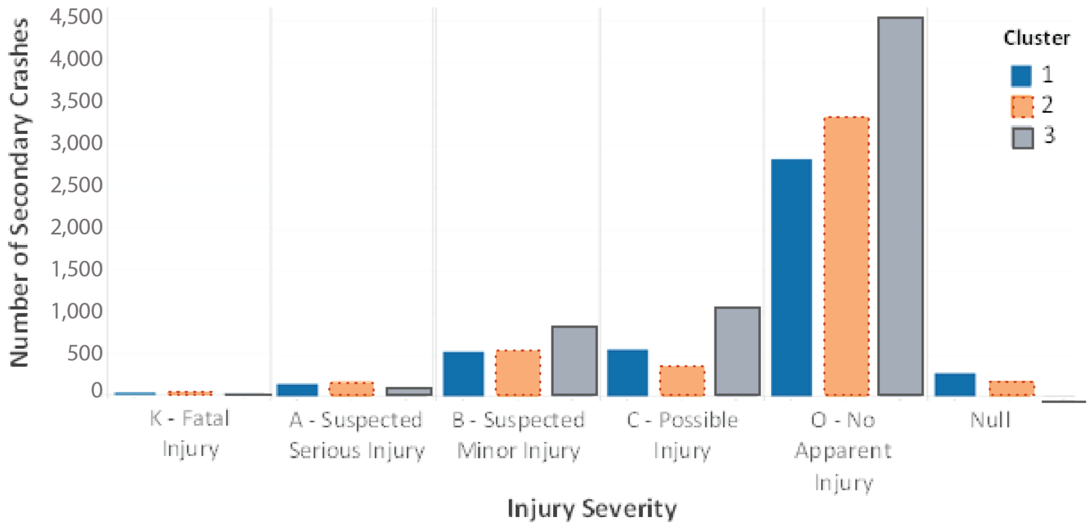


Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 19. Bar chart. Cluster results for weather conditions.

The second general trend observed from the results of the cluster analysis was that, for some of the data elements used in the analysis, the results showed that there were secondary crashes in all three clusters across all the attributes and that the distribution of the secondary crashes across the data attributes within each cluster generally followed the overall distribution of the data. An example is shown in figure 20. This figure shows the cluster analysis results across the injury severity categories (KABCO). Each of the clusters contains secondary crashes for all severity categories, and these distributions generally follow those of the overall (unclustered) data (shown in figure 6).



Source: Federal Highway Administration.

Note: Data collected as described in table 1.

Figure 20. Bar chart. Cluster results for injury severity.

Examination of the cluster analysis results across all data elements and attributes did not show any prominent clustering of the secondary crashes that would lead to the classification of secondary crash types. However, the team made the following observations for the three clusters:

- **Cluster 1: "Unknown but Unique" cluster**—Cluster 1 is characterized primarily by the secondary crashes with the unknown data attributes; however, this cluster also contains slightly more secondary crashes that occurred on a Monday, in February, and in snow, ice, and foggy conditions (although this cluster contains most of the secondary crashes with unknown weather conditions). Cluster 1 contains a higher proportion of secondary crashes that occurred on lower classification roadways (i.e., principal arterials—other, minor arterials, and major collectors). Cluster 1 contains a slightly lower proportion of secondary crashes that occurred in November and on a Friday, the month of the year and day of the week with a plurality of the secondary crashes overall.
- **Cluster 2: "Mixed, Wet" cluster**—Cluster 2 is a mix between the characteristics of clusters 1 and 3. This cluster contains some of the secondary crashes with unknown values (e.g., contains most of the secondary crashes with unknown urban or rural location) and contains many of the most typical types of secondary crashes seen in the data (e.g., occurred on Interstate Highways). Cluster 2 is set apart from clusters 1 and 3 in that it contains proportionally more of the secondary crashes that occurred in cloudy, wet, rainy, and dark/not lighted conditions. Cluster 2 also contains a slightly higher proportion of secondary crashes that occurred on a Sunday.
- **Cluster 3: "Expected" cluster**—Cluster 3 is characterized primarily as the most typical secondary crashes present in the data, following the expected distributions, as observed in the findings from the descriptive statistics (e.g., occurred in urban areas, on major highways, or in clear/partly cloudy and dry conditions). Secondary crashes in cluster 3 contain few unknown data attributes. Cluster 3 contains a slightly higher proportion of the secondary crashes that occurred in March.

SUMMARY AND DISCUSSION

This chapter shows the results of descriptive statistics (across 13 variables) and a cluster analysis run on the verified secondary crash dataset and compares the descriptive statistics of the original secondary crash dataset with the verified secondary crash dataset. Due to the completeness of the crash data, the cluster analysis was inconclusive, but the descriptive statistics indicated some patterns, as well as the severity of secondary crashes. The results also showed that the verified dataset is more representative of what would be expected for secondary crashes than is the original dataset, providing some validation of the secondary crash verification process used in this research.

Additionally, the integration and analysis of the crash data resulted in several lessons learned. These lessons learned—and any associated possible next steps—are as follows:

- The discrepancies in data structure between States present a significant challenge in consolidating and analyzing the data. Despite the potential to manually process data, schema changes at the State level and/or year-to-year variations are still present.
- Manual identification and coding of secondary crashes can lead to subjective assessments that thereby cannot be applied uniformly. Synthetic approaches to secondary crash identification are no more precise, and therefore, the segregating of secondary crashes are likely to continue to present challenges.
- While cluster analysis did not present the expected findings, a similar analysis conducted on a more complete dataset across multiple States might return more informative results.
- Comparisons of frequencies of attributes within data elements from the original dataset and the verified dataset show a greater proportion of attributes that would be expected for secondary crashes. The methods the research team used may prove useful in extracting datasets that are more likely to contain secondary crashes. This process could use additional refinement, as more States update how they report and code secondary crashes.

CHAPTER 4. SECONDARY CRASH CASE STUDIES

To further the understanding of the types of secondary crashes that occur, the team performed a qualitative analysis of crash report narratives where "secondary crash" was noted on the crash report. The team relied on crash report narratives to which they had approved access, which was limited to crash reports from the FHP. The team reviewed 275 reports of crashes marked as secondary that occurred from June to December 2019. As this was a qualitative review conducted on a subset of data from one State, the results are not generalizable; however, to the extent possible, the team found connections between the outcomes of the qualitative analysis described herein and the outcomes of the quantitative analysis presented in chapter 3.

The team took an inductive approach to review the crash report narratives and classify the secondary crashes (i.e., the secondary crash types discussed herein were results of the review of the narratives and were not predetermined). Of the 275 secondary crash narratives reviewed, the team coded 18.5 percent as an "unknown" secondary crashes because the narrative did not cite a primary event to the secondary crash. The team reviewed the remaining 81.5 percent (224 secondary crashes) of the crash report narratives for commonalities and differences. This in-depth qualitative analysis resulted in six primary categories of secondary crashes, including:

- **Type 1: Rear-end in slowing traffic or queue adjacent to or upstream of prior crash—** This type of secondary crash involves a driver's running into the back of another vehicle that has slowed down or stopped in congestion caused by a prior crash. It is not uncommon for traffic incidents to cause traffic to slow down and, subsequently, for queues to form, as traffic incidents can decrease the effective capacity of the roadway (e.g., lane closure and drivers' rubbernecking). When this happens, drivers can be caught off guard, leading to rear-end crashes. These secondary crashes can occur adjacent to or upstream of the primary incident. About 66 percent of the verified secondary crashes analyzed (and presented in chapter 3) were classified as "front-to-rear" crashes, although there are other rear-end secondary crashes that do not occur in slowing traffic or associated queues (see type 2).
- **Type 2: Crash with vehicle involved in prior crash—**This type of secondary crash involves a driver's running into a vehicle involved in a prior crash. When traffic crashes occur, the vehicles involved often block travel lanes. Before responders arrive to begin warning approaching drivers and to protect the primary crash scene, the vehicles involved in the primary crash are susceptible to being struck. Often, these crashes are rear-end in nature, but they can include other types of crashes. For example, if a vehicle involved in a primary crash comes to rest perpendicular to the travel lanes or even facing in the opposite direction of travel, if the vehicle gets struck by an oncoming vehicle, the secondary crash can present as front to side, front to front, sideswipe opposite direction, or even side to side.
- **Type 3: Single vehicle versus fixed object—**This type of secondary crash involves the driver of a vehicle striking a fixed object while approaching a prior traffic incident. These crashes could involve drivers' veering off the road to avoid running into the primary crash or associated traffic queue and instead striking a fixed object, such as a concrete median barrier or a guardrail. About 8 percent of the verified secondary crashes analyzed (and presented in chapter 3) were classified as "not a collision between two motor vehicles," which would include this type of secondary crash, along with secondary crash types 4 and 6.

- **Type 4: Collision with debris from prior crash—**Traffic crashes often leave debris on the roadway. This type of secondary crash occurs when drivers passing by the primary crash scene strike debris from the primary crash (not the vehicles themselves).
- **Type 5: Lane change sideswipe near prior incident—**This type of secondary crash involves the driver of a vehicle sideswiping another vehicle when making a lane change maneuver at or upstream of a primary incident. These secondary crashes can occur when responders close one or more lanes of traffic due to the primary incident, requiring approaching drivers to change lanes. Likewise, Move-Over laws require drivers to slow down or change lanes when approaching stationary emergency vehicles, highway maintenance vehicles, or towing vehicles with flashing lights; and these maneuvers can result in this type of secondary crash. About 10 percent of the verified secondary crashes analyzed (and presented in chapter 3) were classified as "sideswipe same direction."
- **Type 6: Collision with responder at prior incident (i.e., responder struck-by crash)—** This type of secondary crash involves a collision with a responder (or responder vehicle) at a prior incident. These types of crashes also are known as responder struck-by crashes. As traffic incident responders work a primary incident, they and their response vehicles can be struck by approaching or passing motorists.

In the review of the crash report narratives that described the manner of the secondary crash in relation to the primary crash, types 1 and 2 were the most common, representing more than 75 percent of the secondary crashes reviewed. The remaining secondary crash types are still notable and worthy of discussion.

The six primary types of secondary crashes are discussed in more detail in this chapter in the form of case studies. The case studies are as follows:

- Case Study Involving Secondary Crash Type 1: Rear-End in Slowing Traffic or Queue Adjacent to or upstream of Prior Crash
- Case Study Involving Secondary Crash Type 1: Rear-End in Queue Upstream of Prior Crash and Type 2: Crash With Vehicle Involved in Prior Crash
- Case Study Involving Secondary Crash Type 4: Collision With Debris From Prior Crash
- Case Study Involving Secondary Crash Type 5: Lane Change Sideswipe Near Prior Incident
- Case Study Involving Secondary Crash Types 1 and 4 and Type 6: Collision With Responder at Prior Incident
- Case Study Involving Secondary Crash Types 1, 2, 5, 6 and Type 3: Single Vehicle Versus Fixed Object

Each case study includes an overview of an actual primary–secondary crash event, the number and type(s) of secondary crash(es) involved in the incident, a description of the primary crash, description(s) of the secondary crash(es), possible contributing factors to the secondary crash(es), diagrams from crash reports, and still shots from videos taken from intelligent transportation systems equipment along the roads where the crashes occurred. Each case study ends with a brief discussion, including potential countermeasures to mitigate the occurrences of the secondary crashes.

CASE STUDY INVOLVING SECONDARY CRASH TYPE 1: REAR-END IN SLOWING TRAFFIC ADJACENT TO PRIOR CRASH

This case study focuses on a primary crash that led to a type 1 secondary crash: a rear-end crash with slowing traffic adjacent to a prior crash. Probable factors contributing to this secondary crash include driver inattention or distraction and following too closely.

Description of Primary Incident

On a clear Wednesday morning around 7:45 a.m. on June 22, 2022, a Toyota Tundra pickup truck was following a Nissan Maxima on an entrance ramp to a suburban Interstate Highway. The morning rush led to slowing traffic at the on-ramp. As the Maxima slowed for traffic ahead, the driver of the Tundra failed to stop and crashed into the rear of the Tundra.

There were no injuries in the crash, and both vehicles sustained functional damage. The driver of the Tundra pulled onto the grassy area on the left side of the entrance ramp, and the driver of the Maxima pulled onto the shoulder on the right side of the entrance ramp (figure 21, image 1). The crash was reported to law enforcement about 5 minutes after it occurred, and an officer was dispatched within 5 minutes of notification.

Around 8:37 a.m. a law enforcement officer arrived on the scene and resolved the “split scene” (i.e., crash-involved vehicles stopped so that vehicles must pass between them) by directing the driver of the Tundra to move to the right shoulder. The officer parked his vehicle on the right shoulder behind the two vehicles involved in the crash and continued to use emergency lights to provide advance warning for approaching drivers (figure 21, image 2).

All images source: Florida Department of Transportation.

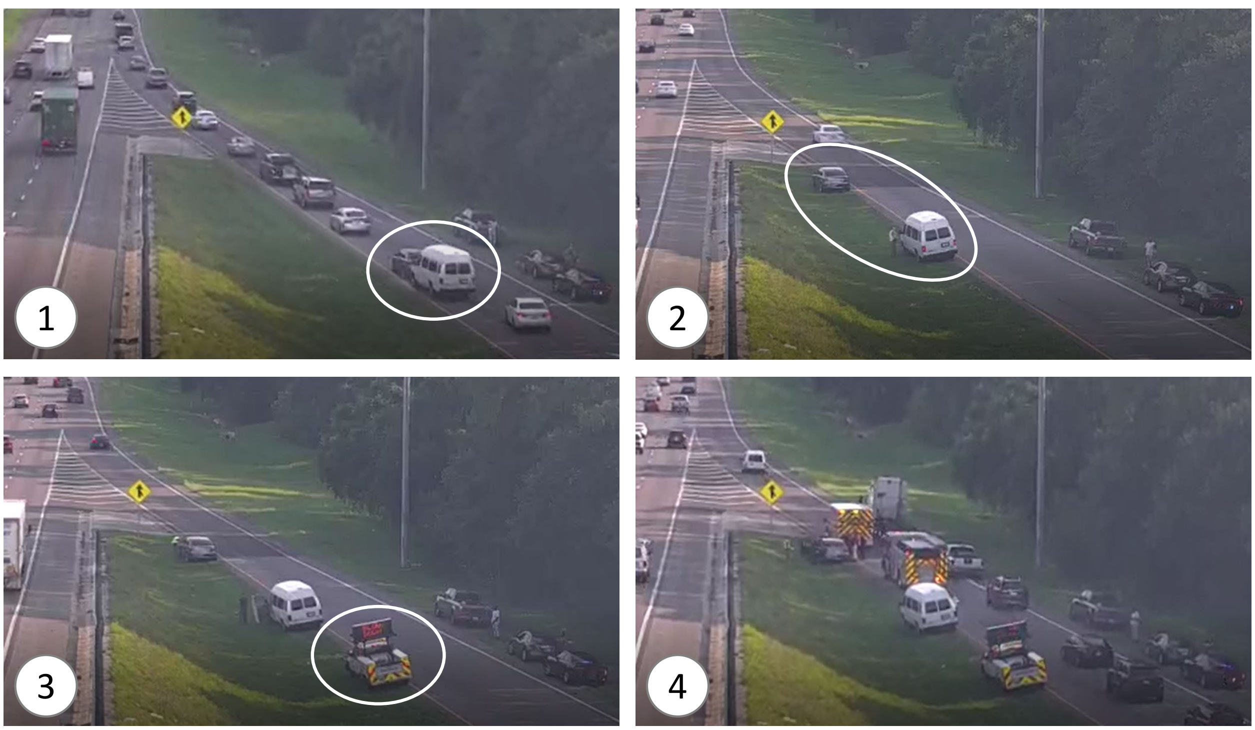
Figure 21. Photograph. Images from Florida Department of Transportation camera—primary crash.

Description of Secondary Crash

This secondary crash is classified as a **Type 1: Rear-End Vehicle Adjacent to/ Upstream of Prior Crash**

Due to the activity associated with the primary crash on the right shoulder, passing drivers slowed on the on-ramp. Around 8:41 a.m., just minutes after the arrival of law enforcement on the scene of the primary crash, the driver of a white Ford van was traveling at approximately 15 miles per hour while passing the primary crash activity. The driver failed to see a Chrysler sedan slowing ahead and rear-ended the Chrysler (figure 22, image 1). The two vehicles involved in the secondary crash pulled off the on-ramp onto the grassy area on the left side of the on-ramp, and the officer working the primary incident checked on the drivers (figure 22, image 2). There were no injuries, and both vehicles incurred about $2,250 of functional damage.

Around 8:48 a.m., a safety service patrol (SSP) vehicle arrived on the scene, established a protective block for the vehicles involved in the secondary crash, and provided advance warning to approaching vehicles (figure 22, image 3). Around 8:50 a.m., fire rescue and fire department arrived on the scene and positioned toward the left side of the on-ramp (figure 22, image 4). Traffic continued to pass between the SSP vehicle and the primary crash scene and then to the right around the secondary crash scene and responder vehicles.



All images source: Florida Department of Transportation.

Figure 22. Photograph. Images from Florida Department of Transportation camera—secondary crash type 1.

Discussion

The primary crash was present on the shoulder of the interstate on-ramp for approximately 50 minutes before the arrival of response personnel. During this time, drivers navigated safely past the crash scene without incident. However, within 5 minutes of the arrival of law enforcement, there was a secondary crash despite the officer's instructing the driver of the Tundra to move the vehicle to the right shoulder so that traffic did not have to split the primary crash vehicles. In this secondary crash, the driver of the Ford van was cited for careless driving. From the video of the incident (figure 22, image 1), it appears that the van was adjacent to the primary crash scene at the time of the secondary crash, suggesting that the driver was looking at the crash scene instead of the roadway and vehicles ahead. While the presence of emergency responders at roadside incidents (and the incidents themselves) can create a distraction for passing drivers, drivers are responsible for maintaining attention to safe vehicle operation.

CASE STUDY INVOLVING SECONDARY CRASH TYPE 1: REAR-END IN QUEUE UPSTREAM OF PRIOR CRASH AND TYPE 2: CRASH WITH VEHICLE INVOLVED IN PRIOR CRASH

This case study focuses on a primary crash that led to two secondary crashes: a type 1 secondary crash and a type 2 secondary crash in the forms of a rear-end crash in queue upstream of prior crash and crash with vehicle involved in prior crash, respectively. Possible factors contributing to these secondary crashes include nighttime conditions (e.g., dark but lighted), driver inattention or distraction, and driving too fast for prevailing conditions.

Description of Primary Incident

At approximately 12:15 a.m. on September 4, 2021, an Infinity FX35, traveling on an urban Interstate Highway, changed lanes and sideswiped a BMW 340i, causing both vehicles to spin out of control. The BMW veered to the right and came to a stop on an entrance ramp to the freeway. The Infinity slid left across several lanes and came to a stop facing in the opposite direction of travel in the left lane of two freeway express lanes. Figure 23, image 1, shows the BMW on the entrance ramp and the Infinity in the left express lane; both vehicles were obstructing the flow of traffic. A vehicle entering the highway also can be seen in the gore area of the entrance ramp, attempting to negotiate around the BMW. While dark, the freeway was well lighted.

Description of Secondary Crashes

Secondary Crash No. 1 is classified as a **Type 1: Rear-End in Queue Upstream of Prior Crash**

Secondary Crash No. 2 is classified as a **Type 2: Crash With Vehicle Involved in Prior Crash**

Approximately 2 minutes after the primary crash, a Ford pickup truck and a Chevrolet Equinox were stopped for the disabled Infinity, side by side, in the two express lanes (figure 23, image 2). Another vehicle stopped on the inside shoulder next to the pickup truck. A Land Rover Range Rover, visible in image 2 with brake lights, failed to slow down and struck the Equinox in the right express lane. This secondary crash sent the Equinox into the general-purpose lanes, while the Range Rover continued forward, striking the disabled Infinity (another secondary crash) involved in the primary crash (figure 23, image 3). These vehicles came to a final rest in the express lane and the inside general-purpose lane, causing approaching traffic to slow and stop (figure 23, image 4).

All images source: Florida Department of Transportation.

Figure 23. Photograph. Images from Florida Department of Transportation camera—secondary crash types 1 and 2.

Discussion

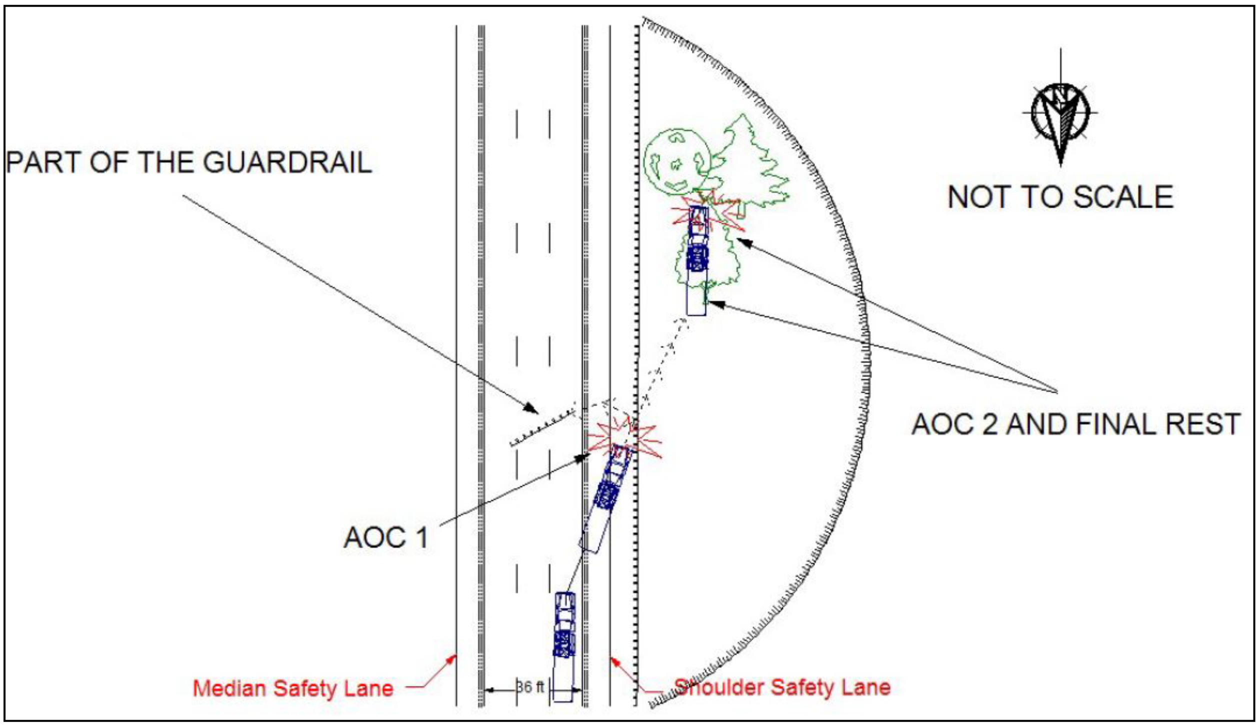
The primary crash created hazardous conditions on a well-lighted Interstate Highway during nighttime free flowing conditions. The fact that multiple drivers perceived the hazard and safely avoided the crash scene shows safety can prevail if drivers are attentive. In this case, when the secondary crashes occurred, no responders were present on the scene, and thus no TIM strategies had been applied to reduce the potential for secondary crashes. This series of events, where drivers crash into a prior crash soon after the crash has occurred (and often before the arrival of responders), illustrates a common type of secondary crash. State laws that require drivers to immediately remove crashed vehicles from travel lanes can help reduce the frequency of secondary crashes, though not every State has such laws, and many drivers are still not aware that these laws exist.

CASE STUDY INVOLVING SECONDARY CRASH TYPE 4: COLLISION WITH DEBRIS FROM PRIOR CRASH

This case study focuses on a primary crash that led to a type 4 secondary crash: collision with debris from prior crash. Possible factors contributing to the secondary crash include low-lighting conditions, a high-speed roadway, and driver inattention.

Description of Primary Incident

On November 11, 2019, in the early evening hours on a dry and clear day, the driver of a tractor trailer truck hit fixed objects while traveling south on I-75 near Gainesville, FL. For an unknown reason, the driver drifted onto the right shoulder and struck a guardrail and light pole; a portion of the guardrail was propelled into the travel lanes of I-75. The tractor trailer continued onto the grassy shoulder and down an embankment into some trees. The driver sustained injuries and was transported to an area hospital by ambulance. The diagram from the crash report of the primary crash is shown in figure 24.



Source: Florida Traffic Crash Report 88238491.

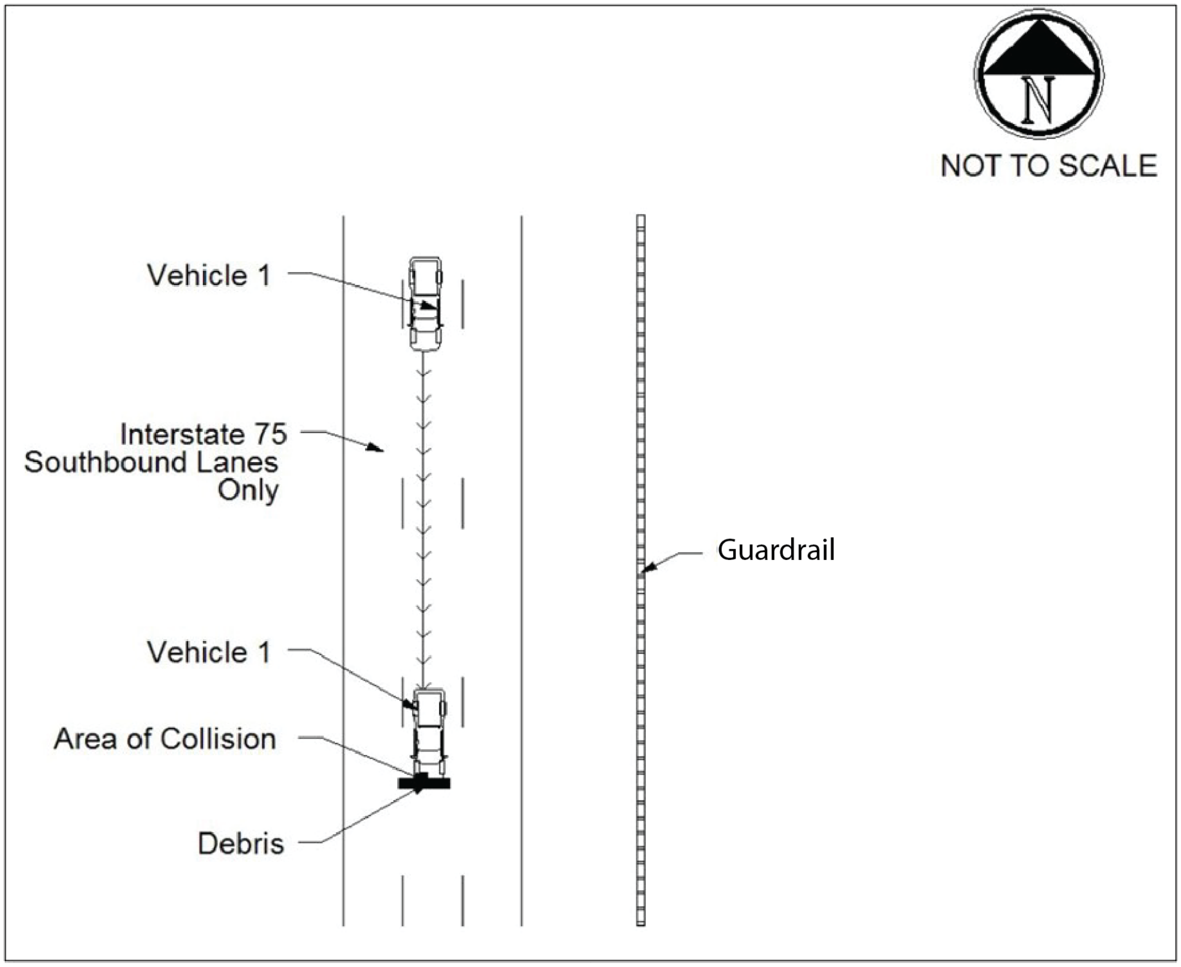
AOC = Area of Collision.

Figure 24. Diagram. Florida Traffic Crash Report diagram from primary crash, November 11, 2019, along I-75 in Alachua County, FL.

Description of Secondary Crash

This secondary crash is classified as a **Type 4: Collision With Debris From Prior Crash**

Approximately 10 minutes after the initial crash, the driver of a Nissan Frontier pickup truck came upon the scene in the center of three lanes. Due to the absence of lighting on the rural highway (among other potential factors), the driver did not see the guardrail debris in the roadway. The driver struck the debris with the pickup truck, causing disabling damage to the vehicle. The diagram from the crash report of the primary crash is shown in figure 25.



Source: Florida Traffic Crash Report 88153008 © 2019.

Figure 25. Diagram. Florida Traffic Crash Report diagram from secondary crash, November 11, 2019, along I-75 in Alachua County, FL.

Discussion

When debris from a crash is in the roadway and is struck by an approaching vehicle, it is classified as a traffic crash. Most debris from prior crashes does not cause severe damage, yet occasionally, the size or nature of the debris, coupled with the speed of the vehicle, can cause significant, even disabling, damage, like what happened in this secondary crash.

When on scene, responders should remove debris or position a blocking vehicle or temporary traffic control device ahead of the debris to decrease the chances of a secondary crash. In this case, responders had not yet arrived on the scene. Given that the primary crash occurred in the evening along a rural Interstate Highway, the high speeds and low-lighting conditions may have contributed to the driver's not seeing the debris in the roadway in enough time to stop or avoid striking it.

CASE STUDY INVOLVING SECONDARY CRASH TYPE 5: LANE CHANGE SIDESWIPE NEAR PRIOR INCIDENT

This case study focuses on a primary crash that led to a type 5 secondary crash: lane change sideswipe near prior incident. Possible factors contributing to the secondary crash include heavy traffic and driver inattention or distraction.

Description of Primary Incident

On August 16, 2019, a cloudy yet dry afternoon, a Chevrolet Impala was traveling in the right lane on I-95 in light traffic. For an unknown reason, the driver of the Impala drifted to the right, crossed the shoulder, and left the roadway, traveling onto the grassy right-of-way. The vehicle dipped into a ditch filled with standing water, damaging its undercarriage.

Law enforcement and county fire and rescue responded to the scene; the driver was pronounced dead. It was later determined that the driver, age 59, had suffered a cardiac emergency while driving.

The death of a driver in a motor vehicle requires a separate criminal investigation, so two different law enforcement officers responded to the traffic crash. Florida Department of Transportation (FDOT) SSP responded to the scene to provide advance warning and temporary traffic control around the scene.

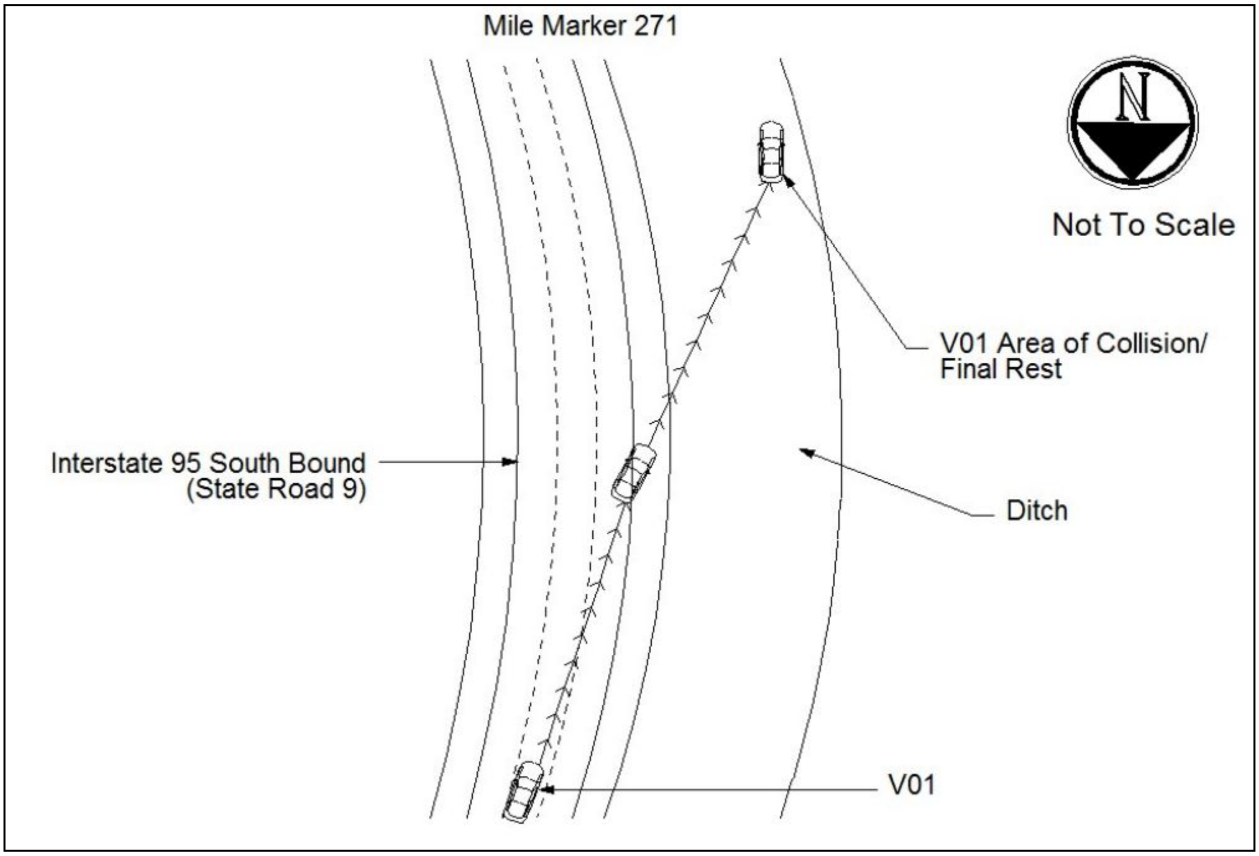
The responders closed the right travel lane because of a horizontal curve where the crash occurred. All responder vehicles were on the shoulder, yet the lane closure provided additional lateral space while they worked on the shoulder, near their vehicles and in the right-of-way. Approximately two dozen traffic cones were set up for the transition and closure. A vehicle-mounted arrow board on the SSP truck provided warning and direction to approaching motorists. Traffic slowed significantly because of the lane closure and roadside activity. The diagram from the primary crash report is shown in figure 26.

Description of Secondary Crash

About 2 hours into the investigation of the primary crash, a Dodge Ram pickup truck and a Hyundai Sonata approached the primary crash scene. The driver of the Sonata, traveling in the right lane, needed to change lanes due to the lane closure and sideswiped the Ram pickup truck while doing so.

This secondary crash is classified as a **Type 5: Lane Change Sideswipe Near Prior Crash**

The drivers' statements conflicted, but the evidence showed that the right front of the Ram pickup truck made impact with the driver's door of the Sonata. There were no injuries, and the vehicles sustained about $2,200 in estimated damages. The diagram from the crash report for the secondary crash is shown in figure 27.



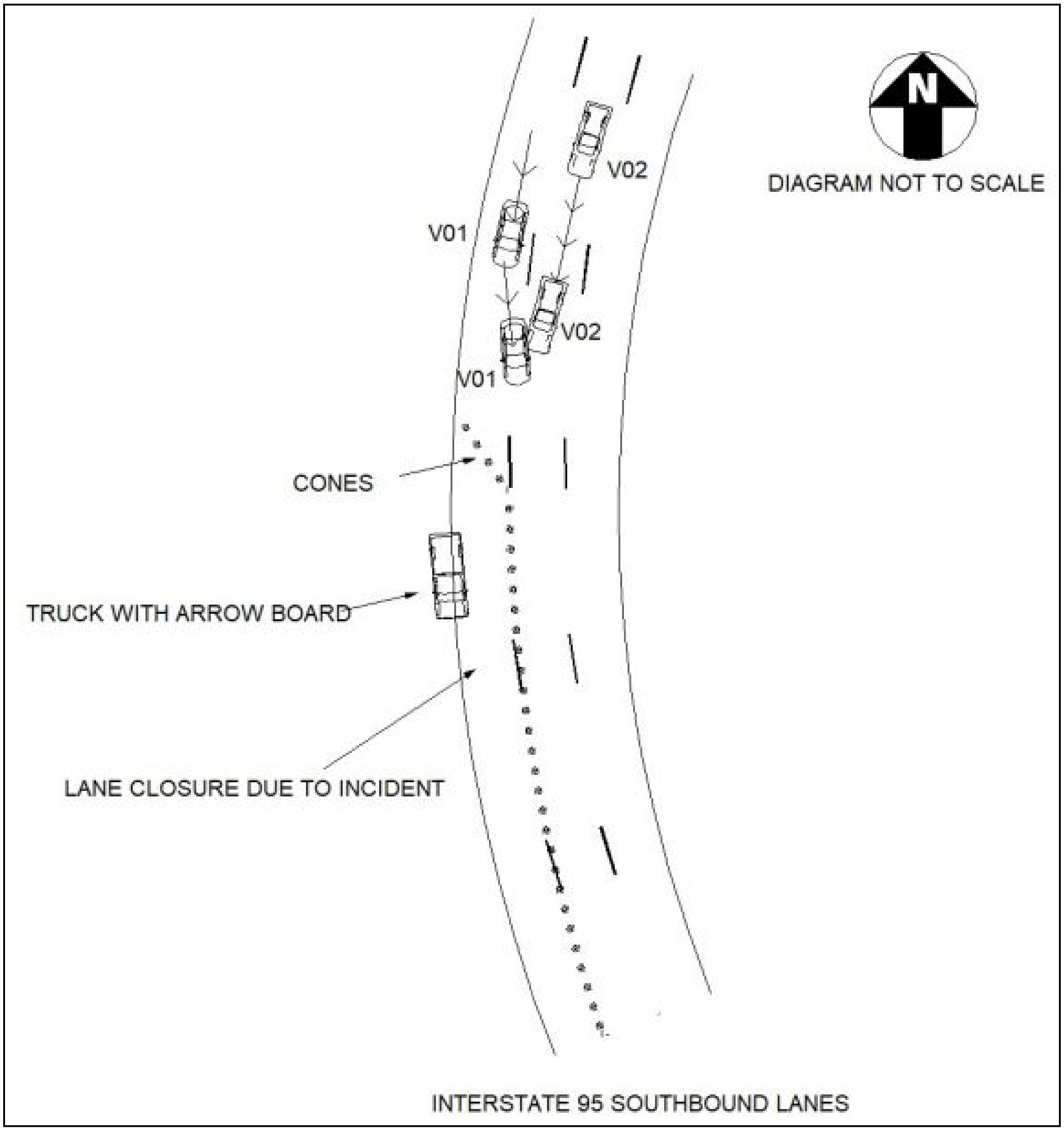
Source: Florida Traffic Crash Report 88187897.

Figure 26. Diagram. Florida Traffic Crash Report diagram—primary crash, August 16, 2019, on I-95 in Volusia County, FL.

Discussion

Motor vehicle crashes involving deaths require a specially trained investigator in addition to an officer who investigates the traffic crash itself. Fatal traffic crashes are always considered “major” incidents and can last 2 hours or longer, as was the case in this secondary crash due to the time required for the in-depth investigation and the arrival of a medical examiner.

A TIM strategy known as “lane plus one” blocking involves blocking the involved lane (in this case the right shoulder) plus one additional lane (in this case the outside right lane) to provide additional lateral space for responders. In this case, due to the roadway curvature and the extended time on scene, this extra measure of safety was prudent. Providing advance warning of and directions for the lane closure should be sufficient. Given that the primary crash occurred on an afternoon along I-95, that a travel lane had been closed by responders, and that the investigation had been ongoing for 2 hours, traffic was likely moving very slowly when the secondary crash occurred. The secondary crash likely occurred due to driver inattention or error where two lanes merged into one due to the lane closure.



Source: Florida Traffic Crash Report 87190323.

Figure 27. Diagram. Florida Traffic Crash Report diagram—secondary crash, August 16, 2019, on I-95 in Volusia County, FL.

CASE STUDY INVOLVING SECONDARY CRASH TYPES 1, 4, AND 6: COLLISION WITH RESPONDER AT PRIOR INCIDENT

This case study focuses on a primary crash that led to three secondary crashes. The secondary crashes included types 1, 4, and 6: rear-end crash in slowing traffic adjacent to prior crash, collision with debris from prior crash, and collision with a responder at prior incident, respectively. Possible factors contributing to these secondary crashes include driver inattention or distraction and driving too fast for the prevailing conditions.

Description of Primary Incident

In the early morning hours of December 3, 2018, a GMC pickup truck was pulling a trailer in the center lane of three lanes on I-95. The conditions were dry, but there was some smoke/fog in the area. The driver of a large truck approaching from behind did not perceive the GMC and took evasive action but struck the rear of the trailer. The GMC and trailer were forced to the right shoulder, where they struck a light pole, went down an embankment, and hit a fence.

No one was injured in the crash. The light pole was knocked down onto the I-95 travel lanes, and the GMC and trailer necessitated incident support. At that time, morning rush hour was impending.

Description of Secondary Crashes

Secondary Crash No. 1 is classified as a **Type 4: Collision With Debris From Prior Crash**

Within seconds of the light pole's falling onto the I-95 travel lanes, a secondary crash occurred. The driver of a Toyota Prius was unable to avoid the obstruction and struck the light pole in the center lane (secondary crash No. 1). The driver was uninjured; the undercarriage of the vehicle was functionally damaged.

In the following 2 hours, several responders were on scene to handle the two crashes, a downed utility pole, and a complicated vehicle recovery in the fence line of the highway.

This section of I-95 has paved shoulders on either side of three travel lanes. FDOT and two FHP troopers were on the scene. The outside lane was blocked by FDOT to provide lateral space for the investigators, whose vehicles were parked on the shoulder. Two FDOT pickup trucks with arrow boards were positioned in the outside lane with arrow indicators, and one additional FDOT pickup truck was on the shoulder displaying a caution mode. More than two dozen traffic cones were used to transition traffic and parallel the closed lane.

Secondary Crash No. 2 is classified as a **Type 1: Rear-End in Slowing Traffic Adjacent to Prior Crash**

While an FHP trooper on the scene was talking with a party involved in the primary crash, a white Chevrolet van and a black Audi sedan were traveling at highway speed in the left lane (figure 28, image 1). As the Audi slowed while passing the primary crash scene, the driver of the Chevrolet van did not use appropriate care and rear-ended the Audi (secondary crash No. 2, figure 28, image 2), propelling it across the center lane (figure 28, image 3) and outside lanes (figure 28, image 4) and into the primary crash scene. The pedestrian trooper successfully pushed the primary crash victim out of the way before being struck by the Audi (secondary crash No. 3, figure 28, image 5). The diagram from the crash report of the secondary crash is shown in figure 29.

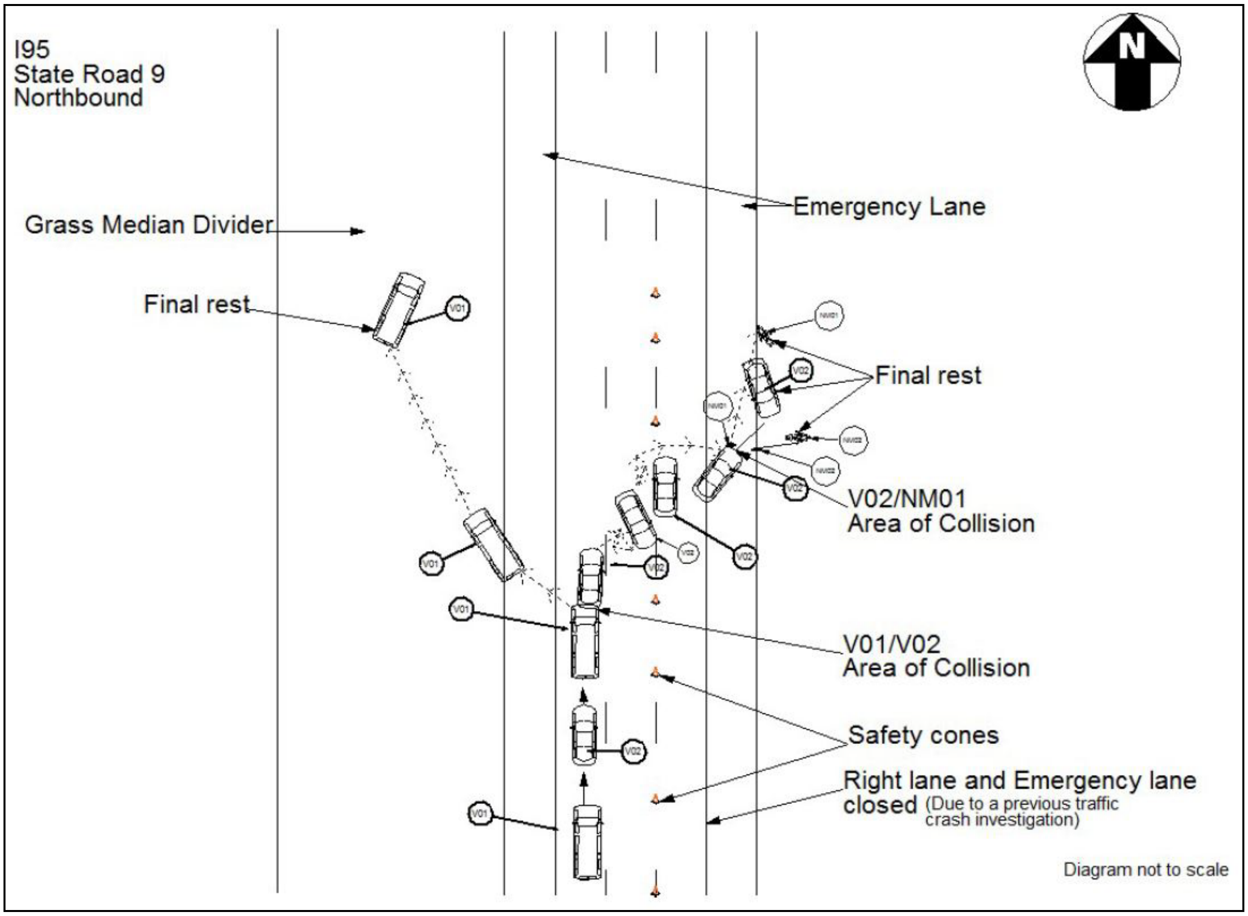
Secondary Crash No. 3 is classified as a **Type 6: Collision With Responder at Prior Incident (i.e., responder struck-by crash)**

All images source: Florida Highway Patrol.

Figure 28. Photograph. Images from Florida Department of Transportation camera—secondary crash types 1 and 6.

Discussion

At the time of the second secondary crash (Chevrolet van rear-ending the black Audi), the primary crash was off the roadway and the fallen light pole had been moved to the shoulder. Appropriate advance warning, a protective block, and temporary traffic control devices were in place. Despite all appropriate TIM measures, inattentive drivers can cause secondary crashes at primary crash scenes or, as in this case, two secondary crashes, one of which involved a pedestrian responder. Given the nature of the primary crash and the first secondary crash, the response had taken more than 2 hours at the time of the secondary and third secondary crashes. The longer it takes responders to clear the scene, the higher the likelihood that a secondary crash will occur. Responders should always maintain situational awareness, including facing traffic and having an escape route.



Source: Florida Traffic Crash Report 85539416.

Figure 29. Diagram. Florida Traffic Crash Report diagram from secondary crash, December 3, 2018, on I-95 in Martin County, FL.

CASE STUDY INVOLVING SECONDARY CRASH TYPES 1, 2, 5, 6 AND TYPE 3: SINGLE VEHICLE VERSUS FIXED OBJECT

This case study focuses on a primary crash that led to four subsequent secondary crashes. The secondary crashes included types 1, 2, 3, 5, and 6: rear-end crash with slowing traffic adjacent to prior crash, crash with a vehicle involved in the prior crash, crash with a fixed object, lane change sideswipe near prior crash, and collision with responder at prior incident, respectively. Possible factors contributing to one or more of the crashes in this case study included weather (i.e., rain), roadway geometry (i.e., horizontal curve), driver inattention and distraction (i.e., cell phone), and driving too fast for the prevailing conditions.

Description of Primary Incident

On a rainy morning near downtown Orlando, FL, I-4 became the scene of a crash that led to four secondary crashes. Westbound I-4 contains curves that drivers have difficulty negotiating when the road is wet. Around 7:45 a.m., a Lexus sedan traveling in the rightmost lane lost control, went into a spin, and struck the concrete barrier adjacent to the right shoulder. The Lexus came to a stop on the shoulder, facing in the opposite direction of travel. The driver was not injured, and the vehicle incurred about $3,000 in disabling damage.

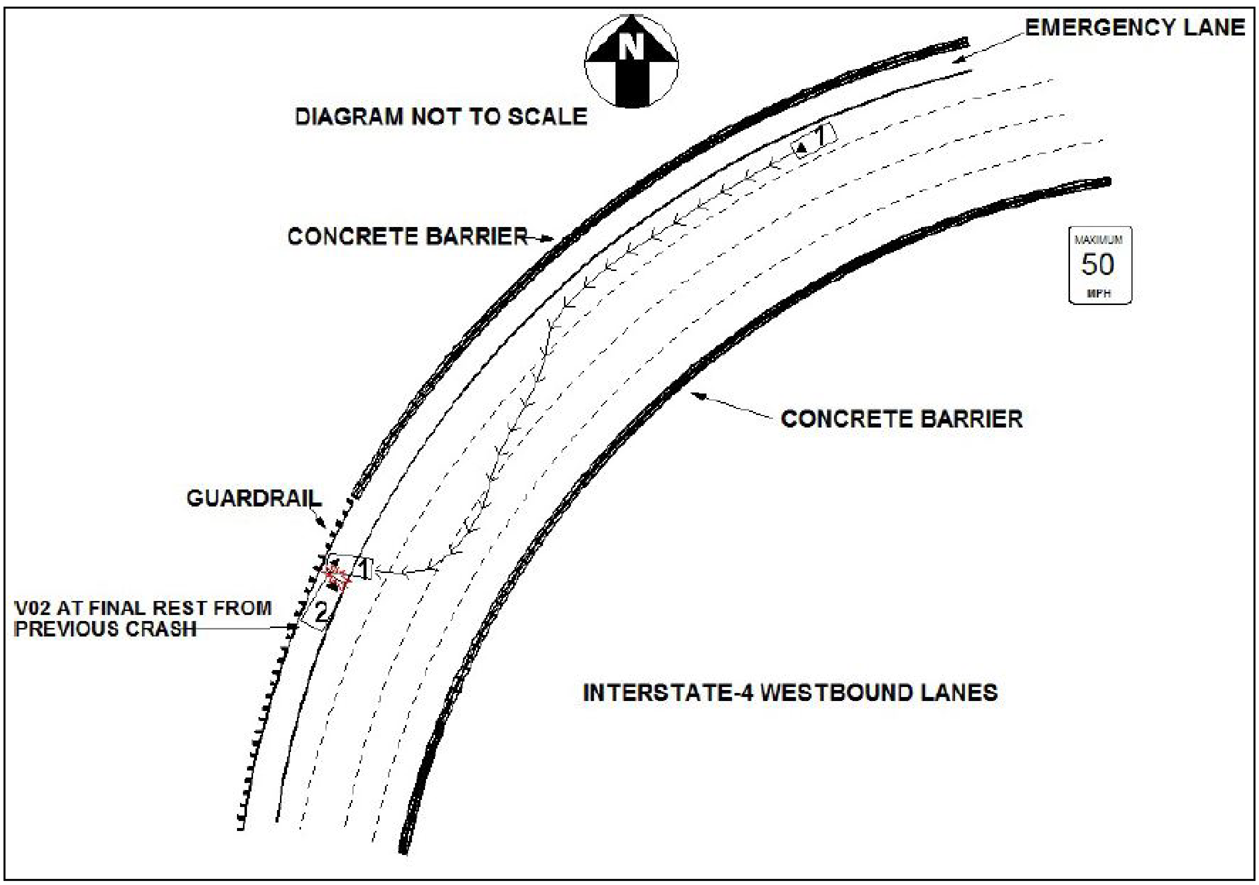
Description of Secondary Crashes

Four secondary crashes resulted from this primary crash. In this section, each secondary crash is described in chronological order, and the type of secondary crash is noted.

Secondary Crash No. 1

Secondary Crash No. 1 is classified as a both a **Type 3: Single Vehicle Versus Fixed Object** and a **Type 2: Crash With Vehicle Involved in Prior Crash**

Within minutes of the primary crash, a 21-year-old driver in a 4-door Saturn, driving too fast for the conditions, lost control along the curved, wet roadway. The front of the vehicle struck the metal guardrail, and the vehicle's momentum led to the left side of the Saturn's striking the front of the Lexus involved in the primary crash (i.e., side to front). The driver was not injured. The Saturn incurred about $4,000 in disabling damage (figure 30).



Source: Florida Traffic Crash Report 85591443.

Figure 30. Diagram. Florida Traffic Crash Report diagram from secondary crash No. 1, November 23, 2017, on I-4 in Orange County, FL.

Florida Road Rangers (i.e., SSP) and law enforcement arrived on the scene and set up temporary traffic control, an arrow board, and a protective block for the outside two lanes of the four-lane Interstate Highway (figure 31).

All images source: Florida Department of Transportation.

Figure 31. Photograph. Image from Florida Department of Transportation camera—primary and secondary crash No. 1.

Secondary Crash No. 2

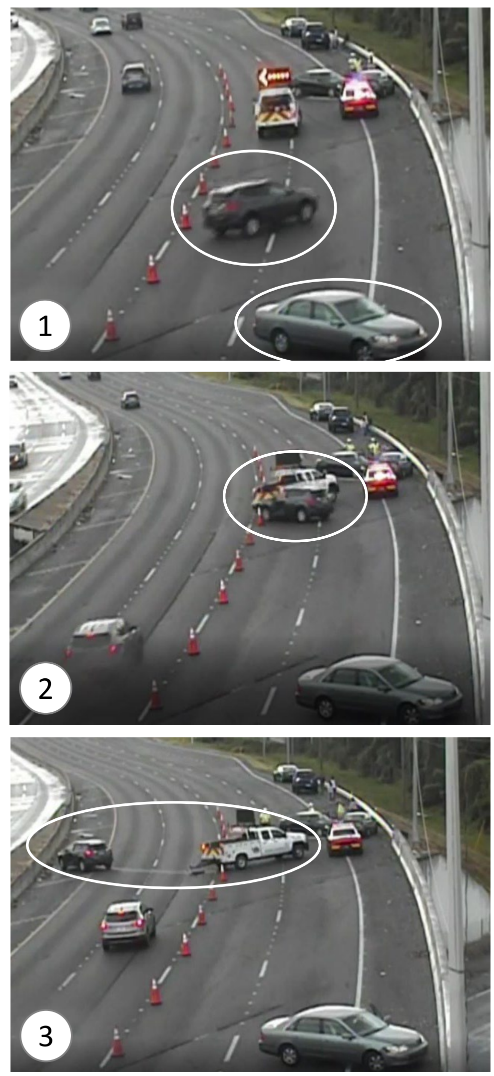
A Toyota Avalon and a Toyota Rav 4 were driving next to each other just below the speed limit as they approached the crash scene and lane closure (figure 31). The driver of the Avalon slowed abruptly, lost control, and struck the side of the Rav 4. The Rav 4 then spun out of control into the cones and lane closure (figure 32, image 1). The Avalon came to rest in the rightmost travel lane and right shoulder facing the opposite direction of travel (figure 32, image 1).

As the Rav 4 driver tried to regain control, the vehicle struck the concrete barrier wall on the right shoulder and ricocheted back across all lanes, struck the Florida Road Ranger truck in the process (figure 32, image 2), and came to rest on the left shoulder (figure 32, image 3).

The driver of the Avalon was not injured. The driver of the Rav 4 required transport to an area hospital by ambulance. Figure 33 shows the diagram of the crash from the crash report.

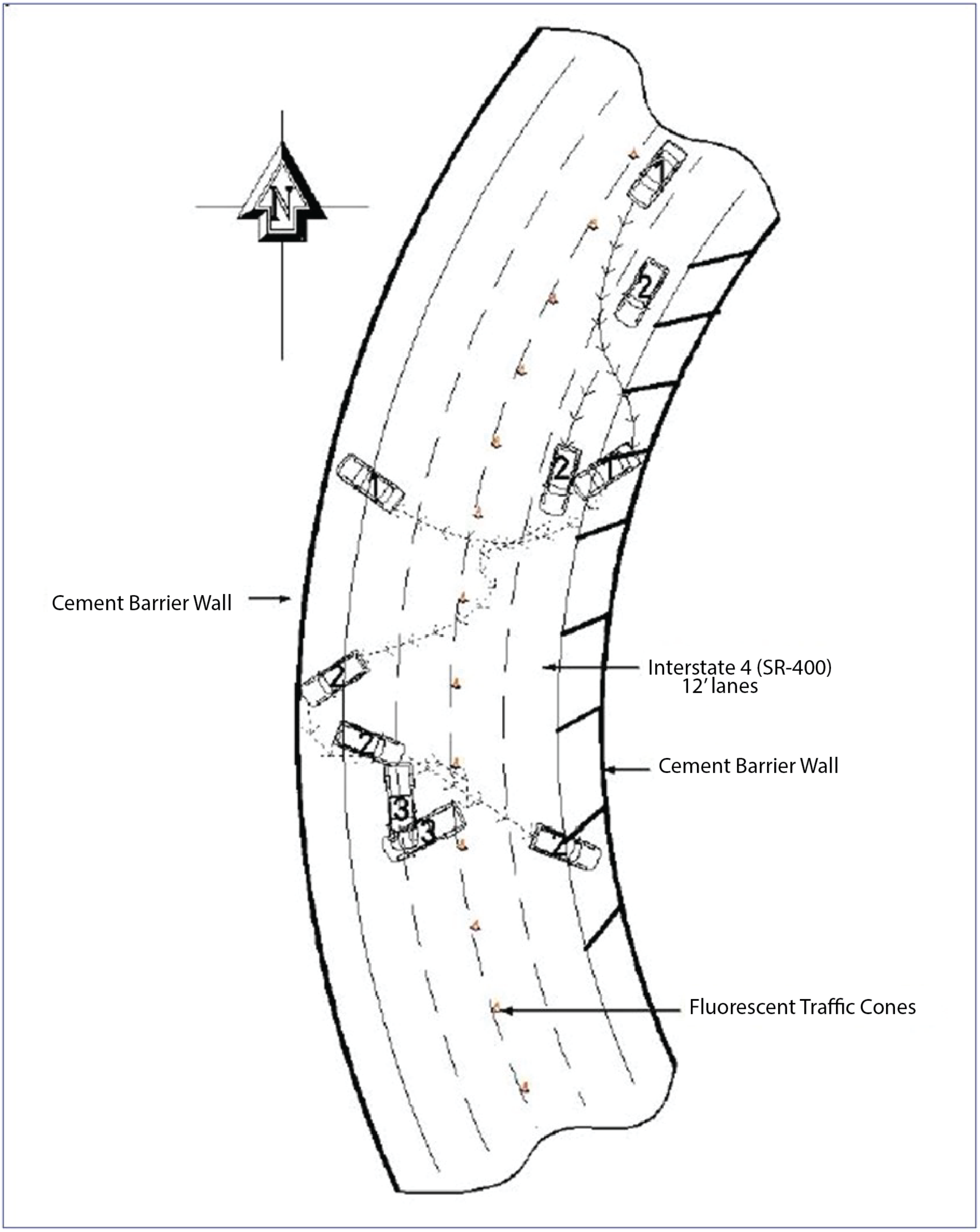
Secondary Crash No. 2 is classified as all the following:

- **Type 5: Lane Change Sideswipe Near Prior Incident**
- **Type 3: Single Vehicle Versus Fixed Object**
- **Type 6: Collision With Responder at Prior Incident**



All images source: Florida Department of Transportation.

Figure 32. Photograph. Images from Florida Department of Transportation camera—secondary crash No. 2 (types 3, 5, and 6).



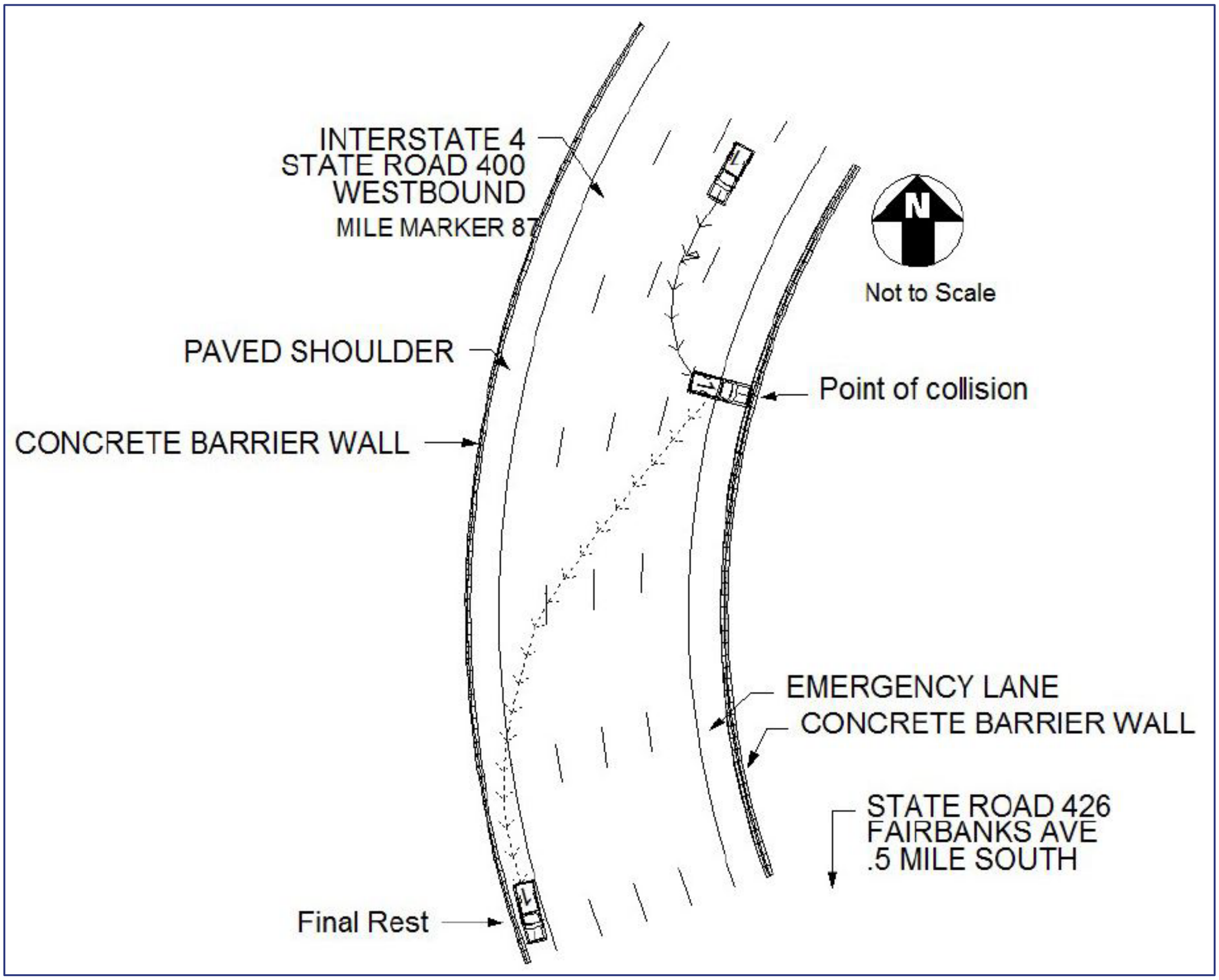
Source: Florida Traffic Crash Report 85460415.

Figure 33. Diagram. Florida Traffic Crash Report diagram from secondary crash No. 2, November 23, 2017, on I-4 in Orange County, FL.

Secondary Crash No. 3

Secondary Crash No. 3 is classified as a **Type 3: Single Vehicle Versus Fixed Object**

About 30 minutes after the crashes previously described, another, single-vehicle crash occurred upstream in a manner comparable to the original crash. A Ford Ranger pickup truck in the second-to-inside lane lost control, veered across the inside lane, and struck the concrete median barrier. The truck ricocheted off the barrier and slid across all lanes to the right shoulder, where it came to a stop. Once again, the driver was going too fast for conditions. While the driver was not injured, the pickup truck had extensive damage that required towing (figure 34).



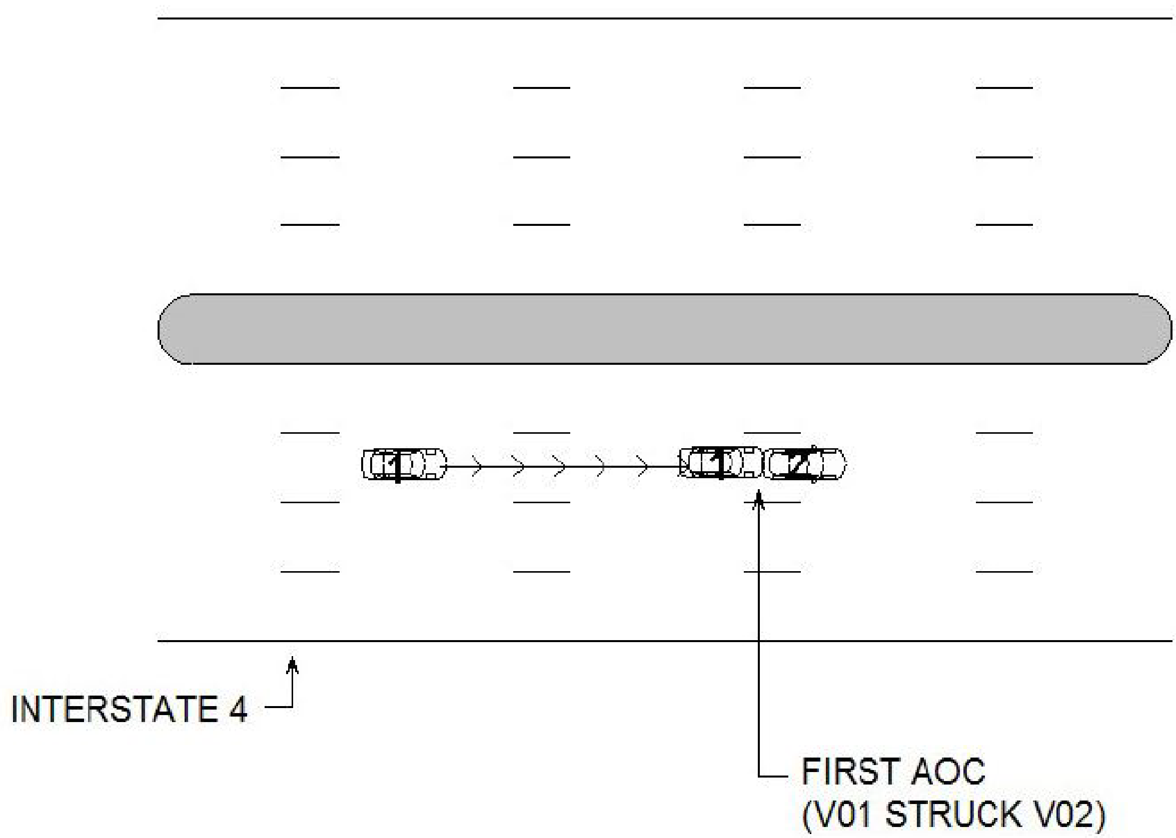
Source: Florida Traffic Crash Report 85604953.

Figure 34. Diagram. Florida Traffic Crash Report diagram from secondary crash No. 3, November 23, 2017, on I-4 in Orange County, FL.

Secondary Crash No. 4

Secondary Crash No. 4 is classified as a **Type 1: Rear-end in Queue Upstream of Prior Crash**

Within minutes of the pickup truck crash, approaching drivers slowed to navigate the scene. A Honda Civic approached a stopped Chevrolet Malibu upstream of the pickup truck crash. The driver of the Civic, distracted by using a cell phone, did not stop in time and struck the rear of the Malibu. The driver of the Malibu was transported by ambulance due to non-incapacitating injuries. Figure 35 shows the diagram from the police crash report for this crash.



Source: Florida Traffic Crash Report 87119290.

AOC = Area of Collision.

Figure 35. Diagram. Florida Traffic Crash Report diagram from secondary crash No. 4, November 23, 2017, on I-4 in Orange County, FL.

Discussion

This case study involved four secondary crashes, two of which involved multiple collisions (i.e., first hitting a concrete barrier and then striking a crashed vehicle; first hitting another vehicle, propelling that vehicle into a fixed object and another vehicle). These four secondary crashes involved five of the six defined secondary crash types (all but type 4: crash with debris from prior crash).

The first secondary crash occurred within minutes of the primary crash. Responders were able to establish a protective block, temporary traffic control devices, and a directional arrow to protect the primary and secondary crash scenes and provide warning and direction to oncoming drivers. Not long after the scene was protected, the second secondary crash occurred just upstream of the scene. Then, 30 minutes later, the third secondary crash occurred, and just minutes later was followed by the fourth secondary crash. The sequence of events in this case study illustrates 2 types of secondary crashes: one that occurs very quickly following a primary crash—or, in this case, one of the secondary crashes—and another that occurs a while after the primary or previous secondary crash, including after the arrival of responders and the implementation of TIM strategies.

This case study involved seven drivers; five were not injured and two were transported to the hospital. In both cases, the drivers transported to the hospital were struck by other vehicles (in secondary crash No. 2, the injured driver struck was propelled into a concrete barrier and then into an SSP vehicle; in secondary crash No. 4, the injured driver was rear-ended).

In this case study, wet roads, moderate traffic, and the presence of a horizontal curve contributed to the primary crash and the four subsequent secondary crashes. While responders established temporary traffic control, advance warning, and a protective block, driver actions (e.g., distraction or inattention or driving too fast for prevailing conditions) continued to be the primary factors that led to most of the secondary crashes.

CHAPTER 5. CONCLUSIONS AND POSSIBLE NEXT STEPS

This report describes the research and associated tasks to bring together, uniformize, and analyze disparate crash data from 10 States; identify the most common types of secondary crashes; and provide a deeper dive into secondary crashes in Florida through the development of secondary crash case studies. This last chapter provides conclusions and possible next steps based on the research findings.

CONCLUSIONS

From the descriptive statistics and the cluster analysis, the following general conclusions were made regarding the occurrence of secondary crashes:

- Most secondary crashes occurred on Interstate Highways or other principal arterials (freeways, U.S. highways); in urban areas; and during daylight, clear or otherwise non-inclement weather conditions.
- Most secondary crashes involved no injuries.
- About two-thirds of secondary crashes were classified as "front to rear" (secondary crash types 1 and 2).
- About 10 percent of secondary crashes were classified as "sideswipe same direction" (secondary crash type 5).
- Just under 10 percent of secondary crashes were classified as "not a collision between two motor vehicles" (secondary crash types 3, 4, and 6).
- Most secondary crashes occurred close in time and space to the primary crash location:
    - More than half of the linked primary and secondary crashes had the same latitudes and longitudes, and about 84 percent of secondary crashes reportedly occurred within a half kilometer of the primary crashes.
    - About 30 percent of the secondary crashes reportedly occurred at the same time as the primary crashes, and about half occurred within 20 minutes of the primary crashes. Certain data collection biases are associated with time of occurrence of the secondary crashes—namely, rounding to the nearest 5 minutes, 60 minutes, and 120 minutes.
    - Secondary crashes that occur at nearly the same times and locations as primary crashes are difficult to mitigate, as responders are not yet on the scene to implement TIM strategies to mitigate their occurrence.
- Secondary crashes followed an expected temporal distribution across the day, similar to that of the volume of traffic. While they were distributed across all days of the week and weeks of the month, there were more secondary crashes on Fridays and during autumn and winter.
- For most (71 percent) of the secondary crashes, contributing circumstances were "unknown," "null," or "none." Where contributing circumstances were noted, the most commonly reported contributing circumstances were:
    - "Stopped/parked vehicle" (14.3 percent)
    - "Failing to reduce speed to avoid crash" (12.2 percent)

- “Following too closely” (10.6 percent)
- “Weather” (6.0 percent)

- When the contributing factors were aggregated across the States:
  - Forty-one percent were related to “driver skills” (e.g., driver experience, failure to reduce speed, failure to yield right-of-way, following too closely, or improper lane usage).
  - Twenty-eight percent were related to a “road hazard” (e.g., object, vehicle, animal, or nonmotorist in the roadway).
  - 24.1 percent were associated with a roadway/traffic condition (e.g., prior crash, moving vehicle, road surface condition, or weather).
  - These findings were echoed in the case studies of secondary crashes in Florida, with driver inattention or distraction or error being the primary contributor to the secondary crashes.

Another finding was that more than two-thirds of the secondary crashes in the original State data did not have identifiable primary crash candidates within 2 hours and 2 kilometers in the data. While the team’s spatial–temporal analysis approach to verifying the secondary crashes has been used by other researchers, a different approach to secondary crash verification may yield different results. Nonetheless, this finding suggests multiple potential issues, including misunderstanding or misuse of the definition of secondary crashes at the time of data collection, geospatial errors in the locations of the primary and secondary crashes, and reporting anomalies (e.g., primary crash not a reportable crash). This finding also suggests that a portion of secondary crashes are caused by noncrash incidents, which are harder to verify. As previously mentioned, verification of any of the crashes marked as secondary in the original data can require a review of the crash report narratives, which could be resource intensive. This qualitative approach, used in the development of the case studies, clarified why and how secondary crashes occurred and may be an approach for future research efforts to expand this understanding.

FUTURE RESEARCH

The following are suggestions for potential next steps or future research based on the findings from this project:

- Verifying secondary crashes in the data was a challenge, and the approach significantly reduced the number of secondary crashes that were verified for analysis purposes. Furthermore, the review of 275 secondary crash report narratives from Florida found that nearly 20 percent of the narratives did not cite a primary event to the secondary crash; therefore, even after a review of the narratives, the team was unable to verify that these crashes were secondary in nature. The following are suggestions to overcome this challenge:
  - **Consider and compare other methods of verifying the data (both quantitative and qualitative).** Other quantitative methods to identify or verify secondary crashes are present in the literature (e.g., queuing model approaches, speed contour plot approaches, and shockwave approaches). The team used a spatial–temporal approach in this research, which resulted in the verification of only 30 percent of the crashes marked as secondary in the original datasets. However, this outcome was not uniform across the States (as was shown in table 2). For example, this approach verified 67 percent of the 1,264 secondary crashes in Florida, 39 percent of the 7,425 secondary crashes in Tennessee, and only

10 percent of the 18,110 secondary crashes in Illinois. This finding may have to do with the definition used, training, or other factors. A potential next step might involve reviewing a sample of crash report narratives from both the original and verified secondary crash datasets for each State (e.g., 100 original plus 100 verified times 10 States equals 2,000 crash reports). The outcome could identify the percentage of the verified secondary crashes from each sample and could point to potential problem areas, such as with data collection or definitions. This exercise also could result in a dataset of verified secondary crashes for each State that could be used for further analysis.

  - **Create linkages between primary crashes/incidents and secondary crashes within the crash data.** These linkages could be created in multiple ways but could be most helpful if the primary crash report ID were noted on the secondary crash report and vice versa. This approach could create a direct, easily identifiable linkage in the data. A less direct way could be for law enforcement officers to make notes as to the primary incident in the crash report narratives. This approach could require additional data mining to identify these notes and make the linkages; however, this approach may be necessary if the primary incident is not a crash. Another approach could be to consider modifications to the MMUCC C2. Crash Classification, S3. Secondary Crash (yes or no) data element and attribute by adding an additional attribute associated with the type of primary incident (e.g., "What was primary incident?" "Prior Crash," "Stalled/Disabled Vehicle," "Traffic Stop," or "Debris in Roadway").

- While there is value in combining data across States, in future research it may be prudent to **focus the analysis of secondary crashes regionally or even within individual States:**
  - The team experienced difficulties in merging the disparate crash data due to the use of different data elements and attributes. Furthermore, developing a uniform data schema across the States resulted in missing values for some data attributes for some States. Focusing on individual States could eliminate these challenges.
  - The results showed a lot of variability in certain factors, which complicates the interpretation of the results. For example, while the findings show that more secondary crashes occur in autumn and winter, few secondary crashes occur in inclement winter weather conditions, such as snow. Focusing on individual States or even regionally (e.g., northern versus southern States) could help reduce some of this variability and further clarify some of the findings.
  - The considerable number of unknown or null values for multiple data elements and attributes affected the analysis and reduced the conclusions that could be made. The cluster analysis was particularly susceptible to the missing or unknown values. Focusing the analysis at the State or regional level could likely affect the outcomes of the analysis and provide clarification to the findings.
- **Work to improve the quality and completeness of the crash data.** Throughout the process of reviewing, merging, and analyzing the data, the team found multiple issues with the quality and completeness of the crash data that if corrected could increase the utility of the data.
- **Standardize crash data collection across States.** This could improve the ability to integrate crash data across States, as well as increase the utility of the data for statistical analyses and to further understand crash trends.

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5. Support for the Dark Sky Application Programming Interface (API) ended on March 31, 2023, and has been replaced by Apple's WeatherKit API.

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