City and County of Denver
Toole Design Group
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TECHNICAL SUPPLEMENT

Denver Vision Zero Action Plan

Technical Supplement

This technical supplement to the Denver Vision Zero Action Plan summarizes analyses conducted throughout the Plan development process. It contains a description of data sources, a summary of crash data analysis, documentation of the methods used to identify the High-Injury Network (HIN) and Communities of Concern, and analysis of speed survey data.

Data Sources

Introduction

The project team used several data sources in the development of the Denver Vision Zero Action Plan. These data sources included:

- Denver Public Works (DPW): vehicle, pedestrian, and bike crash data files and street centerline file
- Denver Police Department (DPD): fatality data file and speed survey data
- Colorado Department of Transportation (CDOT): Jefferson County crash data file and findings from Colorado Problem Identification Report[1]
- U.S. Census Bureau: American Community Survey, 2011-2015
- Other data sources

Each of these datasets is discussed in more detail below.

Denver Public Works crash data

DPW provided vehicle, pedestrian, and bicycle crash data to the project team. DPD originally collected this data while responding to crashes involving a motor vehicle. As such, the data does not include crashes involving a single bicyclist, multiple bicyclists without a motor vehicle, nor a bicyclist and a pedestrian without a motor vehicle. Crashes involving a train are also excluded from the dataset. These data limitations result in underreporting of pedestrian and bicyclist injuries; however, the extent of this underreporting in Denver (and in most cities) is unknown.

Another type of underreporting occurs when crashes involving motor vehicles are not reported to law enforcement. This underreporting affects all types of collisions regardless of mode. The extent of this type of underreporting is also unknown, but is thought to be more common among less severe crashes.

The project team used DPW crash data as the basis for identifying overall trends and in-depth analysis of crash contributing factors. The summary of findings from the DPW crash data are included in the next section of this supplement, 'Denver Crash Data Summary'.

Statistics and analysis based on DPW crash data also appear in the Action Plan as follows:

- Page 1, Crash severity infographic
- Page 8-9, High Injury Network map

[1] Colorado Department of Transportation. Fiscal Year 2016 Colorado Problem Identification Report.

Denver Police Department crash data

Some fatal crashes are not included in the DPW crash data. This may be due to time lags associated with fatal crash investigations or exclusion of some crashes in the DPW data. To ensure consistency of statistics reported in the Action Plan with other official DPD sources, and to supplement the DPW crash data, the project team obtained DPD fatal crash data. With the DPD fatal crash data, the project team summarized total fatalities by mode. DPD fatal crash data was also used to enhance the mapping of fatal crashes and in the development of the High Injury Network. Because the City does not have jurisdiction over interstates, fatal crashes on interstates were not included in the dataset used to develop the High Injury Network.

DPD fatal crash data was used in the Action Plan as follows:

- Page 2, Figures 1 and 2
- Page 8-9, High Injury Network map and fatality statistics

Colorado Department of Transportation (CDOT) crash data

To supplement the DPW and DPD crash data, the project team obtained additional crash data from CDOT. This data accounted for crashes along Sheridan Boulevard and other boundary roadways, as law enforcement officers from other jurisdictions respond to some crashes along those streets, resulting in incomplete data within the Denver crash datasets. CDOT crash data was used strictly for the development of the High-Injury Network.

CDOT’s Colorado Problem Identification Report served as another data source. This report includes county-level fatalities attributable to behavioral contributing factors. The report is also based on completed fatal crash investigations, as submitted to the National Highway Traffic Administration’s Fatality Analysis Reporting System, which is the official fatality data source for most national studies and reports.

CDOT fatal crash data was used in the Action Plan as follows:

- Page 5, percentage of fatalities involving speeding in 2015 (Colorado Problem Identification Report)
- Page 5, risky behaviors infographic (Colorado Problem Identification Report)
- Page 8-9, High Injury Network map (Jefferson County/Sheridan Blvd. crash data)

Denver Public Works street centerline file

To understand how crashes in Denver are distributed throughout the street network, the project team analyzed crashes by roadway type and other roadway variables. The DPW street centerline file served as the reference street network for this analysis. Functional class data within this file is known to have some errors or inconsistencies, but is nevertheless the best source for roadway information in Denver.

The DPW street centerline file was used in the Action Plan as follows:

- Page 4, Arterial roads infographic
- Page 6, High Injury Network statistics
- Page 8-9, High Injury Network map

Denver Police Department speed survey data

Speed is a crucial factor that influences the likelihood of a crash occurring and whether an injury or fatality occurs. Comprehensive vehicle operating speed data throughout the Denver street network was not available, but DPD collected speed data on a subset of streets. This data was collected using speed data collection devices mounted on traffic poles or other roadside objects. The project team analyzed the speed survey data to understand operating speeds relative to posted speed limits in Denver. The results of the analysis are described in the 'Speed Survey Data Analysis' section of this Technical Supplement.

The speed survey data is also used in the Action Plan as follows:

- Page 5, Discussion of drivers exceeding speed limits on Denver streets.

Other Data Sources

A few other data sources were used as references for the Action Plan, including NHTSA fatal crash rates and the U.S. Census Bureau's American Community Survey (ACS). The project team used NHTSA data to compare Denver's fatal crash rate per 100,000 population to peer cities (Action Plan, p. 2).[2] ACS commute mode share data for 2011 through 2015 was used to compare fatalities by mode with commute patterns (Action Plan, p.2, fig. 2).

Interpretations and Assumptions

The overall findings in this report are consistent with information as provided in the crash report. While the DPW, DPD and CDOT crash data used for this analysis are the most reliable source of crash information, the data does have limitations. By the time that the data is recorded in a crash record, it has undergone several rounds of interpretation (by the victim(s), then by the officer). While this should not diminish the value of the data provided in crash reports, it underscores the complexity of crashes and the crash reporting process, as well as the need to identify additional data sources to augment existing data. For more information about the Colorado Accident Report Form, see Denver's Bicycle Crash Analysis Report.

[2] National Highway Traffic Safety Administration. Traffic Safety Facts 2014. https://crashstats.nhtsa.dot.gov/Api/Public/Publication/812261

Denver Crash Data Summary

Introduction

This summary presents an overview of the results of the Denver Vision Zero crash analysis for crashes involving pedestrians, bicycles, motorcycles, or vehicles.[3] It serves as a high-level companion summary for the more in-depth analyses that informed the Denver Vision Zero Action Plan. The analysis covers the 76,290 crashes reported by the DPD from 2011 to 2015.[4] Pedestrian crashes refer to crashes involving at least one pedestrian and at least one motor vehicle; bicycle crashes refer to crashes involving at least one non-motorized bicycle and at least one motor vehicle; motorcycle crashes include crashes involving at least one motorcycle; and vehicle crashes include crashes involving at least one vehicle and that do not involve a pedestrian, bicyclist, or motorcyclist.[5] Crashes were analyzed by the most severe injury resulting from the crash (i.e., fatality, injury, or no injury).[6]

There are two data caveats that should be noted. First, given the limitations of the data provided for analysis, it was not possible to determine which person or person type (e.g., pedestrian, bicyclist, driver, passenger) was injured in a given crash. As a result, the analysis and reporting of injuries is typically done at the crash level (e.g., number of people injured or killed in pedestrian crashes). It is reasonable to expect that the most vulnerable person was the most likely to suffer the most severe injury, and the analysis proceeded as such, but there may have been exceptions. Second, it is important to note that detailed injury data was not available for analysis. Thus, minor injuries such as a scrape were analyzed in the same category as more serious injuries like broken bones and serious, life-threatening injuries such as head traumas . Fatalities were analyzed separately, but the lack of clarity about injury level may mask serious risk because we were not able to home in on more serious injuries for analysis. For the purposes of Vision Zero, analyzing serious injuries and fatalities together is something that Denver will explore in the future.

Distribution of Crashes by Mode

As might be expected given travel patterns, the majority of crashes included in this analysis were either single-vehicle or multiple-vehicle crashes, although nearly six percent of crashes involved at least one bicycle, pedestrian, or motorcycle (Figure 1). Figure 2 indicates that the risk of being involved in a fatal crash is substantially higher for pedestrians, bicyclists, and motorcyclists than it is for vehicle occupants. While pedestrian crashes represented 2.5 percent of all crashes, they represented 38 percent of fatal crashes.

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[3] In this document the term “Motorcycle” includes motorcycles and mopeds that can travel at least 30 mph.

[4] All bicycle data from 2011-2012 taken from prior Denver Bicycle Crash Analysis.

[5] Three bicycle crashes involved bicyclists and vehicles and may also have involved pedestrians –these three crashes were included in the bicycle dataset only. There were three crashes in the pedestrian crash dataset that involved bicycles, two were also included in the bicycle crash dataset; one of these crashes resulted in an injury and two of them also involved vehicles. There were three crashes that are in both the motorcycle crash dataset and the bicycle crash dataset.

[6] Fatal crashes include all crashes resulting in at least one fatality, regardless of whether or not there were non-fatal injuries sustained by either party.

Figure 1. Distribution of Crashes by Mode

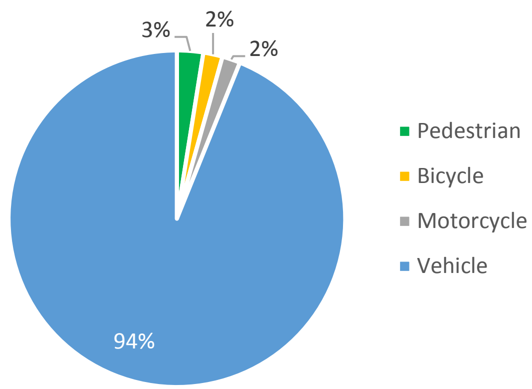
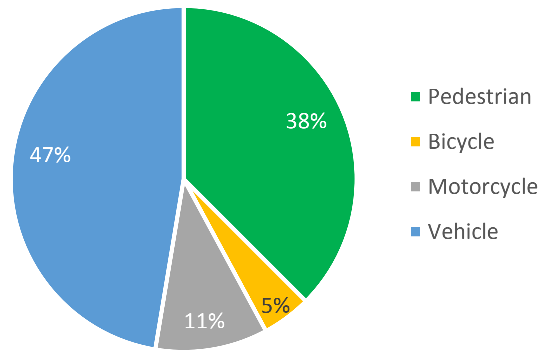


Figure 2. Distribution of Fatal Crashes by Mode



Annual Crash Trends

This section examines the distribution of crashes by mode and year. From 2011 to 2015, the total number of crashes increased by 28 percent. The number of pedestrian, bicycle, motorcycle, and vehicle crashes increased by 26, 19, 19, and 28 percent, respectively. In comparison, the total population of Denver increased by approximately 10 percent during that time.[7]

Table 1. Number of Crashes by Mode, 2011 to 2015

Year	Pedestrian	Bicycle	Motorcycle	Vehicle	Total
2011	330	249	222	12,409	13,210
2012	366	322	316	14,625	15,629
2013	415	271	259	13,825	14,770
2014	397	272	264	14,846	15,779
2015	416	297	265	15,924	16,902
Total	**1,924**	**1,411**	**1,326**	**71,629**	**76,290**

Annual Injuries and Fatalities

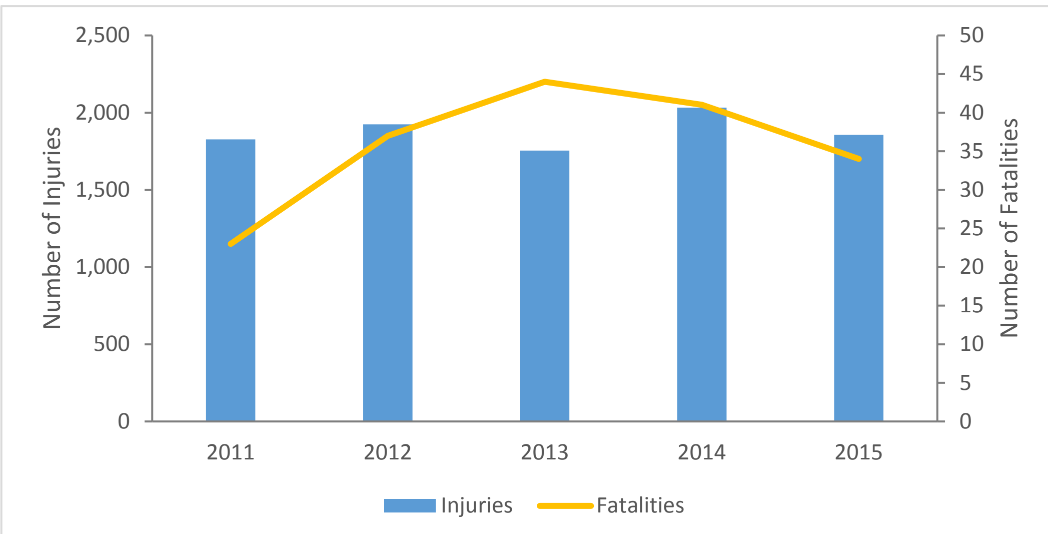
For the majority of this report, crash statistics are based on the number of crashes, which is an approach to discuss crash trends that allows for injury and non-injury crashes to be analzed together. However, it is important to acknowledge that some crashes lead to more than one injury or fatality, and that, ultimately, reducing the number of *people* injured or killed is more important than reducing the number of crashes

[7] American Commuter Survey 1-Year Estimates (2011-2015). Accessed October 2016. http://factfinder2.census.gov/

(although the two are related). To this end, this section presents an overview of the number of *people* injured or fatally wounded in crashes from 2011 to 2015.

Over the five-year analysis period, 9,394 people were injured and 179 were killed in traffic crashes. These victims represent five injuries per day and approximately one fatality every 10 days over the course of the study period and include pedestrians, bicyclists, motorcyclists, drivers, and other vehicle occupants. Figure 3 shows the number of total traffic-related injuries and fatalities by year. Overall, the number of people injured or fatally wounded in traffic crashes increased from 2011 to 2015, however the annual number of fatalities decreased from 2013 to 2015.

Figure 3. Traffic-Related Injuries and Fatalities in Denver, by Year



Tables 2 and 3 show the number of injuries and fatalities by mode and year. Except for vehicle crashes, all modes saw the number of people injured in traffic crashes increase from 2011 to 2015. Table 3 shows that the decline in total traffic-related fatalities from 2013 to 2015 shown in Figure 3 is not present across all modes. The overall decline from 2013 to 2015 is largely due to the decline in vehicle crash fatalities since the number of pedestrian and motorcycle fatalities increased from 2014 to 2015.

Table 2. Number of Injured People by Mode, 2011 to 2015

Year	Pedestrian	Bicycle	Motorcycle	Vehicle	Total
2011	242	141	126	1,317	1,826
2012	235	159	177	1,354	1,925
2013	257	112	128	1,258	1,755
2014	253	153	146	1,481	2,033
2015	250	159	153	1,293	1,855
Total	**1,237**	**724**	**730**	**6,703**	**9,394**

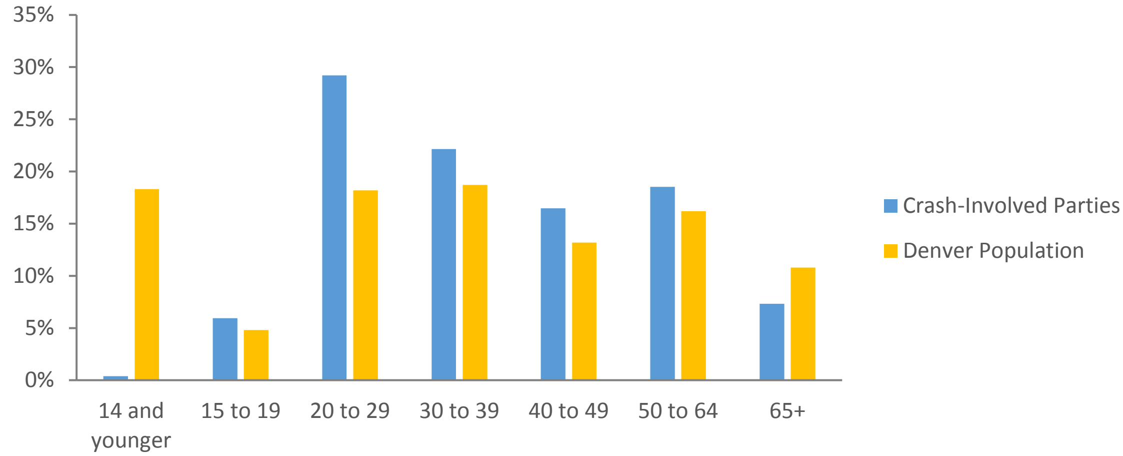
Table 3. Number of Fatalities by Mode, 2011 to 2015

Year	Pedestrian	Bicycle	Motorcycle	Vehicle	Total
2011	8	1	2	12	23
2012	18	2	2	15	37
2013	12	0	4	28	44
2014	9	4	4	24	41
2015	11	0	6	17	34
Total	**58**	**7**	**18**	**96**	**179**

Demographic Characteristics of Roadway Users Involved in Crashes

This section shows the distribution of crashes by mode and age for roadway users involved in crashes. Figure 4 shows the age distribution of crash-involved parties compared to the age distribution of Denver's population. These data suggest that people age 20 to 29 are heavily overrepresented in crashes in Denver.

Figure 4. Comparison of Age Distribution between Crash-Involved Parties and Denver's Population



Source: American Community Survey, 2011-2015, Five-year estimate

Table 4 shows the distribution of crashes by age of the roadway user. The distribution varies across modes in somewhat expected ways, given restrictions on driving and motorcycle riding for younger people, and a related greater volume of younger people walking. For each mode, people aged 20-29 were most likely to be involved in a crash. Again, this is likely somewhat related to exposure, although exposure alone does not likely fully explain the overrepresentation of this age group overall.

Table 4. Age Distribution of Roadway Users Involved in a Crash

Age	Pedestrian		Bicycle		Motorcycle		Vehicle*		Total	
	#	%	#	%	#	%	#	%	#	%
14 and Younger	172	14%	94	8.9%	3	0.4%	99	0.1%	368	0.2%
15 to 19	145	11%	85	9.9%	31	5.0%	6,918	8.9%	7,179	4.6%
20 to 29	384	17%	487	34%	368	31%	34,351	27%	35,590	23%
30 to 39	262	12%	275	14%	306	20%	26,092	17%	26,935	17%
40 to 49	263	17%	160	11%	197	14%	19,361	12%	19,981	13%
50 to 64	373	16%	186	12%	267	17%	21,635	13%	22,461	14%
65+	148	7.5%	38	2.8%	36	3.0%	8,645	23%	8,867	5.7%
Unknown	187	6.0%	92	7.1%	130	9.6%	33,144	0.3%	33,553	22%
Total	**1,934**	**100%**	**1,417**	**100%**	**1,338**	**100%**	**150,245**	**100%**	**154,934**	**100%**

Note: Some crashes involved more than one pedestrian, bicyclist, motorcyclist or driver.
*Only includes drivers involved in single- or multiple-vehicle crashes.

When considering only users involved in fatal crashes, the largest share of motorcyclists and drivers involved in fatal crashes were between the ages of 20 and 29 (50 percent and 28 percent, respectively), whereas the largest share of pedestrians involved in fatal crashes were between the ages of 50 and 64 (38 percent) (Table 5). A review of the age distribution of drivers involved in crashes with pedestrians or bicyclists indicates that driver age information is rarely recored for these types of crashes. Driver age data was missing for nearly 40 percent of crashes involving pedestrians or bicyclists.

There was no additional demographic information in the crash datasets. The availability of exposure data by mode, including demographic information, would allow for a deeper understanding of whether certain groups, like seniors, are over- or underrepresented in crashes. Ensuring that additional victim demographic information is retained in Denver crash analysis datasets would allow more detailed demographic analyses of crash victims.

Table 5. Age Distribution of Roadway Users Involved in a Fatal Crash

Age	Pedstrian		Bicycle		Motorcycle		Vehicle		Total	
	#	%	#	%	#	%	#	%	#	%
14 and Younger	3	5.2%	0	0%	0	0%	0	0%	3	1.3%
15 to 19	1	1.7%	0	0%	0	0%	12	8.6%	13	5.8%
20 to 29	7	12%	2	29%	9	50%	28	20%	46	21%
30 to 39	9	16%	1	14%	3	17%	27	19%	40	18%
40 to 49	8	14%	1	14%	4	22%	17	12%	30	13%
50 to 64	22	38%	2	29%	1	5.6%	16	11%	41	18%
65+	6	10%	1	14%	0	0%	20	14%	27	12%
Unknown	2	3.4%	0	0%	1	11%	20	14%	23	10%
Total	**58**	**100%**	**7**	**100%**	**18**	**100%**	**140**	100%	**223**	100%

The remainder of this data summary presents findings from analyses of the number of *crashes*. Examining crash patterns, rather than person patterns, provides a greater understanding of the prevalence of factors over which the City and County of Denver has some control, such as the need for engineering or behavioral interventions.

Temporal Crash Patterns

This section examines crashes by mode, month, day, and time of day for all crashes. Figure 5 shows the percentage of crashes by month for crashes involving pedestrians, bicycles, motorcycles, and vehicles. Each mode follows a slightly different distribution, however there are some similarities across modes. While the greatest percentage of pedestrian and vehicle crashes occur in October, December, and January, vehicles otherwise display a relatively flat trend. Bicycle and motorcycle crashes clearly spike in the summer months, between June and September. The spike for motorcycle and bicycle crashes is likely due to variations in exposure, given that those modes are more weather dependent and are particularly popular for summer travel and recreation. The same cannot be said of the pedestrian spike, however: pedestrian travel tends to decrease in the winter months, suggesting that other factors, such as darkness and poor visibility, are contributing to those increased numbers. A review of fatal crashes by mode and month presented relatively similar results to the trends shown in Figure 5, however the seasonal variation was slightly more pronounced (see Figure 6).

Figure 5. Percentage of Crashes by Mode and Month

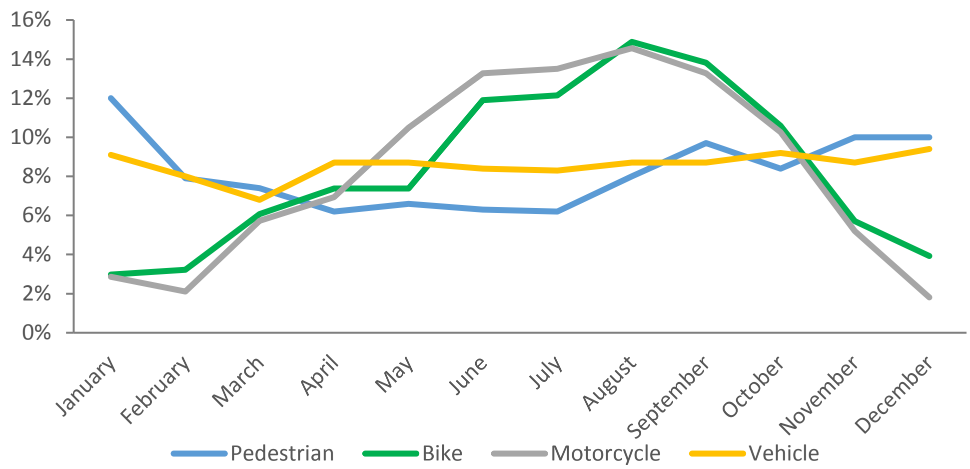


Figure 6. Percentage of Fatal Crashes by Mode and Month

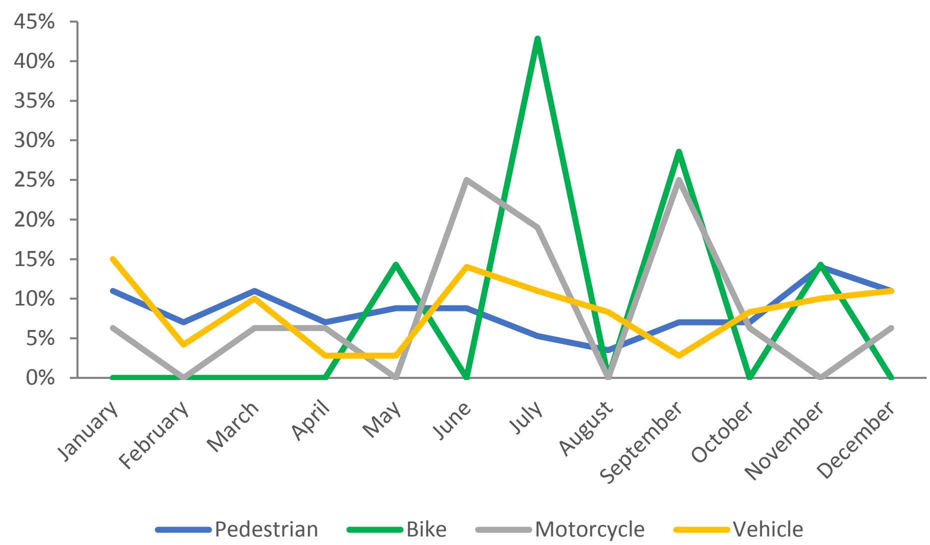


Figure 7 shows the percentage of all crashes by mode and day of the week (weekday vs weekend). The large majority (77 percent) of all crashes occur on a weekday, with 23 percent occuring on the weekend. There is little variation in this trend by mode, although slightly more bicycle crashes occur during the week and slightly more motorcycle crashes occur during the weekend in comparison to other modes. The trends among fatal crashes by day of the week and mode were similar to those presented in Figure 7 for vehicle crashes, but differed for all other modes. The distribution of fatal crashes involving pedestrians, bikes, and motorcycles was much more evenly distributed between weekdays and weekends.

Figure 7. Percentage of Weekday and Weekend Crashes by Mode

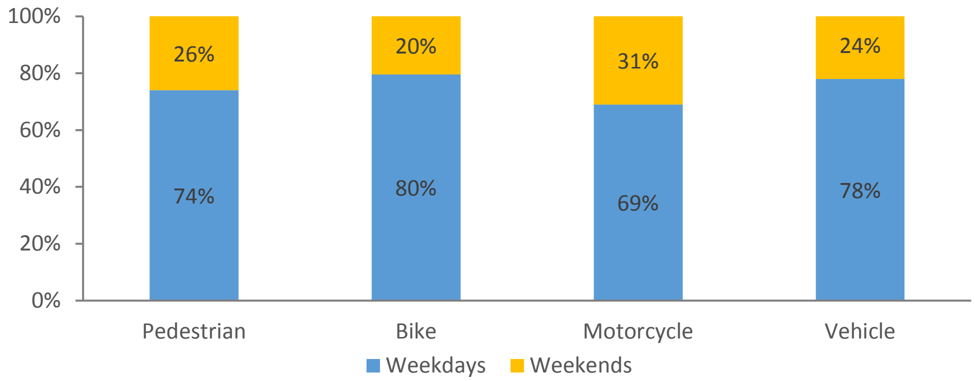
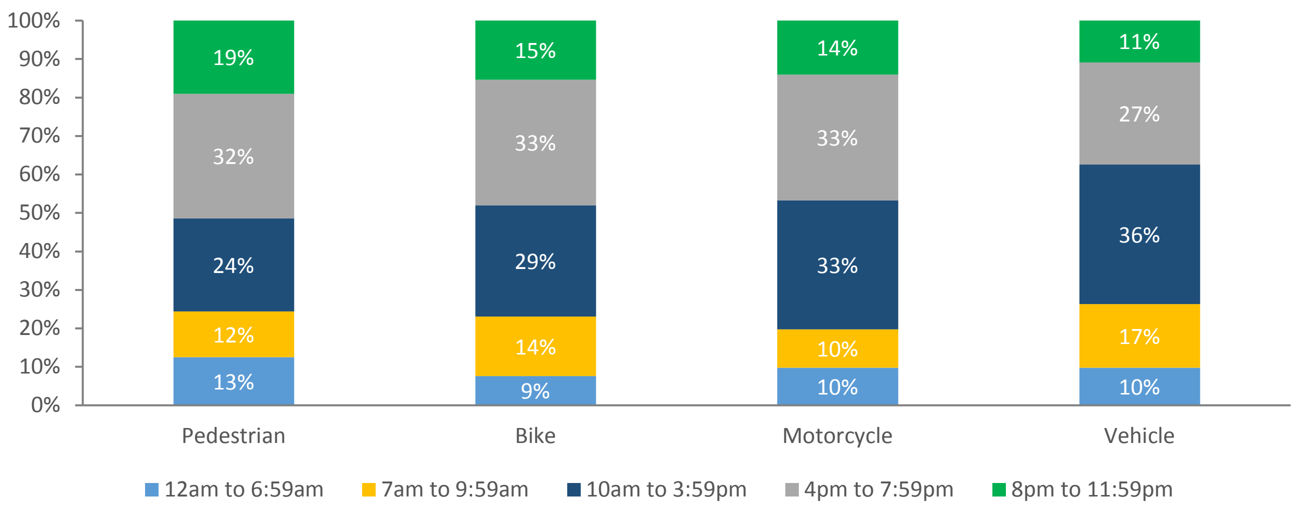


Figure 8 shows the percentage of crashes by mode and time of day. All four modes follow a relatively similar trend, with slight differences in peaks. The largest share of bicycle and pedestrian crashes occured between 4pm and 7:59pm, whereas the largest share of vehicle crashes occurs between 10am and 3:59pm. Peak motorcycle crashes were split between both of those time periods. Notably, pedestrian crashes had the greatest percentage of late night and early morning crashes (between 8pm and 6:59am).

Figure 8. Percentage of Crashes by Mode and Time of Day



The trends among fatal crashes by mode and time of day presented different results, and speak to factors that are more pernicious at night, including dramatically reduced visibility and the greater likelihood of alcohol usage. In comparison to the trends presented in Figure 8, a much greater percentage of fatal vehicle crashes occurred between midnight and 7am (10 percent versus 26 percent), and a greater percentage of fatal motorcycle crashes occurred between 4pm and midnight (47 percent versus 64 percent). Additionally, approximately twice as many fatal pedestrian crashes occurred between 8pm and midnight than total pedestrian crashes (19 percent versus 39 percent). The majority of the fatal bicycle crashes also occurred between midnight and 7am (9 percent versus 71 percent).

Environmental and Roadway Conditions

This section examines all crashes by environmental and roadway conditions. Figures 9 through 13 show the percentage of all crashes by road contour and grade, weather, and lighting conditions. In cases where trends are not the same across all modes, additional information is provided.

Road Contour

Nearly 70 percent of crashes occurred on straight roads with a grade, and 32 percent of crashes occurred on straight, level roads (Figure 9). The trends are similar among fatal crashes (Figure 10), with the exception of crashes occurring on a curve or hillcrest; a greater percentage of fatal crashes occurred on these roads than all crashes. Table 6 shows the distribution of crashes by mode and road contour. A similar percentage of all types of crashes occurred on straight, level roads and straight roads with a grade.

Figure 9. Distribution of Crashes by Road Contour and Grade

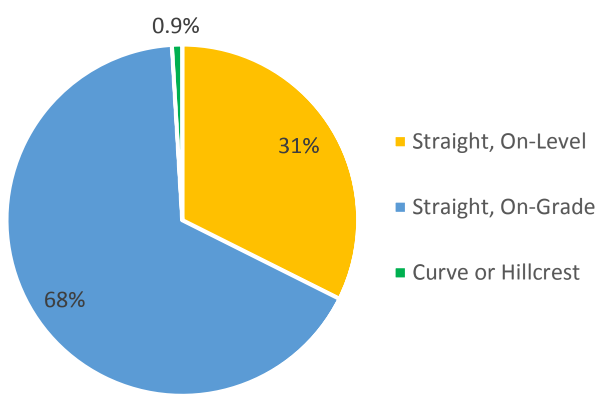


Figure 10. Distribution of Fatal Crashes by Road Contour and Grade

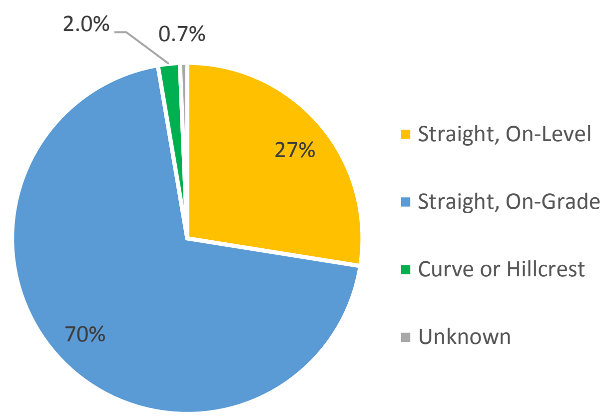


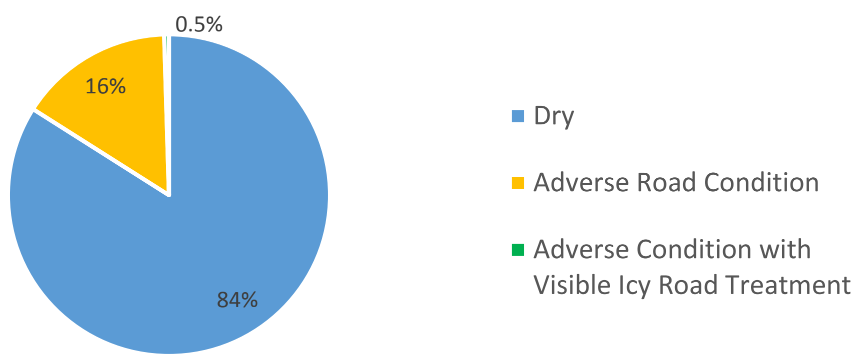
Table 6. Distribution of Crashes by Mode and Road Contour

Road Contour	Pedestrian		Bike		Motorcycle		Vehicle	
	#	%	#	%	#	%	#	%
Straight - On-Level	640	33%	449	32%	402	30%	22,316	31%
Straight - On-Grade	1,263	66%	943	67%	903	68%	48,417	68%
Curve - On-Level	2	0.1%	11	0.8%	14	1.0%	455	0.6%
Curve - On-Grade	7	0.4%	2	0.1%	2	0.1%	143	0.2%
Hillcrest	2	0.1%	3	0.2%	3	0.2%	74	0.1%
Unknown	12	0.6%	5	0.4%	2	0.1%	224	0.3%
Total	**1,924**	**100%**	**1,411**	**100%**	**1,326**	**100%**	**71,629**	**100%**

Adverse Road Condition

Figure 11 shows the distribution of crashes by presence of adverse road condition. Eighty-four percent of crashes occurred when no adverse weather was present. Similarly, 87 percent of fatal crashes occurred when no adverse weather conditions were present. Among the modes, pedestrians and motorists were more likely than bicyclists and motorcyclists to be involved in a collision in adverse weather (85 percent versus 95 percent, respectively).

Figure 11. Distribution of Crashes by Presence of Adverse Road Condition



Lighting

The majority of crashes occurred in daylight, although 23 percent of crashes occurred in dark, lit conditions (Figure 12). Table 7 shows the distribution of crashes by lighting condition and mode. Between 20 and 25 percent of bicycle, motorcycle, and vehicle crashes occurred in the dark, in comparison to nearly 40 percent of pedestrian crashes (Table 7). This trend is particularly alarming when considering pedestrian exposure, which tends to be much lower at night, and underscores the importance of lighting and visibility to pedestrian safety.

Table 7. Distribution of All Crashes by Mode and Lighting Condition

Lighting	Pedestrian		Bike		Motorcycle		Vehicle	
	#	%	#	%	#	%	#	%
Daylight	1,088	57%	1,032	73%	953	71%	50,073	70%
Dawn or Dusk	101	5.3%	61	4.3%	61	4.6%	2,934	4.1%
Dark - Lighted	655	34%	287	20%	299	22%	16,729	23%
Dark - Unlighted	73	3.8%	26	1.8%	22	1.6%	1,422	2.0%
Unknown	7	0.8%	5	0.4%	4	0.3%	471	0.7%
Total	**1,924**	**100%**	**1,411**	**100%**	**1,339**	**100%**	**71,629**	**100%**

The distribution of all crashes by lighting conditions differs substantially from that of fatal crashes (Figures 12 and 13, respectively), with nearly fifty percent of all fatal crashes occurring in dark conditions. In comparison to all crashes, fatal crashes are twice as likely to occur under dark conditions. This trend of greater fatalities under dark conditions was particularly pronounced for pedestrians and bicyclists, despite their much greater exposure to traffic during daylight (Table 8).

Figure 12. Distribution of Crashes by Lighting Condition

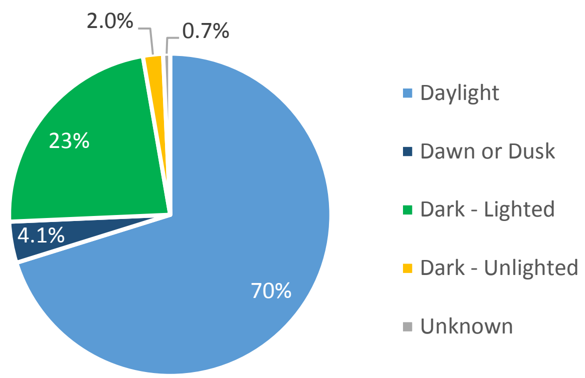


Figure 13. Distribution of Fatal Crashes by Lighting Condition

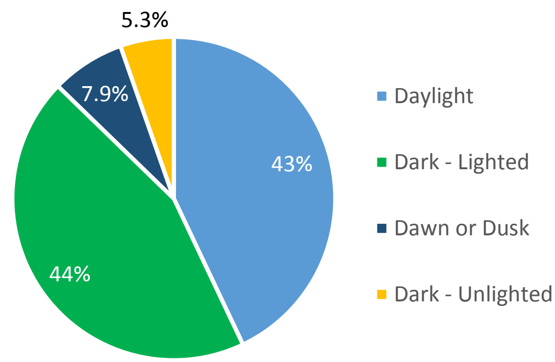


Table 8. Distribution of Fatal Crashes by Mode and Lighting Condition

Lighting	Pedestrian		Bike		Motorcycle		Vehicle	
	#	%	#	%	#	%	#	%
Daylight	17	30%	2	29%	9	56%	37	51%
Dawn or Dusk	5	8.8%	1	14%	1	6.3%	5	6.9%
Dark - Lighted	29	51%	4	57%	5	31%	29	40%
Dark - Unlighted	6	11%	0	0%	1	6.3%	1	1.4%
Total	**57**	**100%**	**7**	**100%**	**16**	**100%**	**72**	100%

Speed

This section examines the percentage of crashes by posted speed limit. Figure 14 shows that nearly 60 percent of all crashes occurred on roadways with posted speed limits of 25 and 30 mph. This is not surprising given that these roads represent the majority of Denver's roads. Thirty-five percent of crashes occurred on roads with speed limits of 35 and 40 mph, while less than three percent of crashes occurred on roadways with speed limits of 0 to 20 mph. The trends in the distribution of crashes by speed limit were relatively similar across all modes, however a smaller percentage of pedestrian and bicycle crashes occurred on roadways with speed limits of at least 35 mph compared to that of motorcycle and vehicle crashes (Table 9). This is to be expected given that the volumes of pedestrians and bicyclists are likely smaller on these higher-speed roads. It should also be noted that, while less than two percent of crashes overall do not list a speed, 25 percent of pedestrian crashes lack speed limit information—a lack of data that may hamper a more thorough understanding of pedestrian crash trends.

Figure 14. Distribution of Crashes and Roadway Miles by Posted Speed Limit

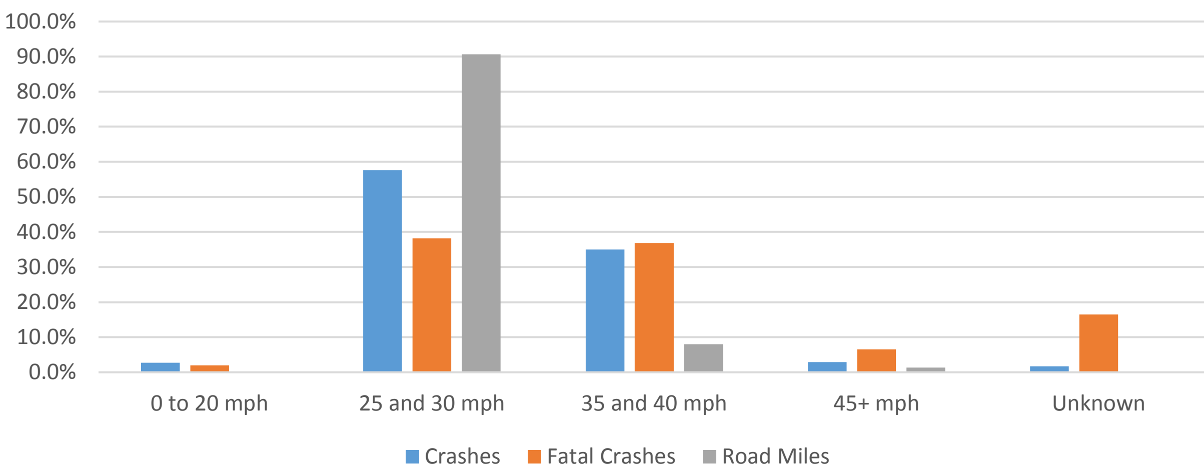


Table 9. Distribution of Crashes by Mode and Posted Speed Limit

Posted Speed Limit	Pedestrian		Bike		Motorcycle		Vehicle	
	#	%	#	%	#	%	#	%
0 to 20 mph	93	4.8%	72	5.1%	33	2.5%	1,903	2.7%
25 and 30 mph	953	50%	977	69%	801	60%	41,227	58%
35 and 40 mph	386	20%	255	18%	449	34%	25,623	36%
45+ mph	19	1.0%	15	1.1%	34	2.6%	2,116	3.0%
Unknown	473	25%	92	6.5%	0	0%	760	1.1%
Total	**1,924**	**100%**	**1,411**	**100%**	**1,326**	**100%**	**71,629**	**100%**

Table 10 shows the distribution of fatal crashes by mode and posted speed. Across all modes, fatalities were more likely to occur on higher-speed roadways. This is particularly alarming for pedestrians, for whom nearly forty percent of fatalities occurred on these roadways, despite their lower likelihood of exposure along those roads. Additionally, note that speed information is missing for approximately forty percent of fatal pedestrian and bicyclist crashes, a limitation that should be addressed to enable a deeper understanding of the role of vehicle speed and pedestrian and bicyclist deaths.

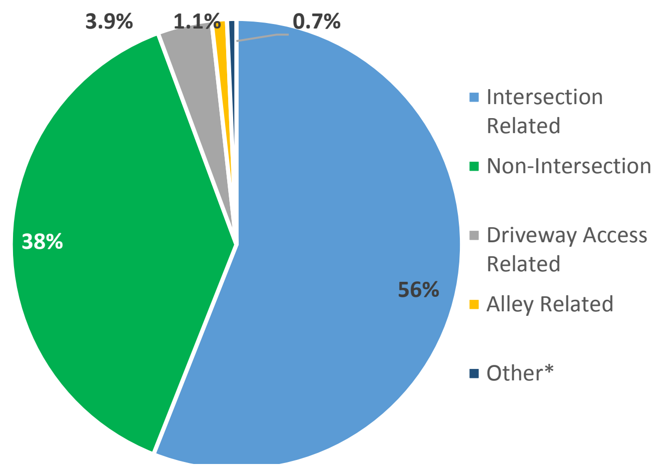
Table 10. Distribution of Fatal Crashes by Mode and Posted Speed Limit

Posted Speed Limit	Pedestrian		Bike		Motorcycle		Vehicle	
	#	%	#	%	#	%	#	%
0 to 20 mph	1	1.8%	0	0%	1	6.3%	1	1.4%
25 and 30 mph	13	23%	3	43%	7	44%	35	49%
35 and 40 mph	19	33%	1	14%	8	50%	28	39%
45+ mph	2	3.5%	0	0%	0	0%	8	11%
Unknown	22	39%	3	43%	0	0%	0	0%
Total	**57**	**100%**	**7**	**100%**	**16**	**100%**	**72**	**100%**

Crashes by Location

Fifty-six percent of crashes were intersection related, while 38 percent of crashes did not occur at or near an intersection (Figure 15). Less than seven percent of crashes occurred at a driveway, roundabout, parking lot, or highway interchange. These trends were similar across modes, although a smaller percentage of pedestrian crashes were driveway access or alley related compared to the other three modes (Table 11). Additionally, a much smaller percentage of bicycle crashes was not intersection related compared to the other three modes.

Figure 15. Distribution of Crashes by Location



*Includes parking lot, roundabout, and highway interchange

Table 11. Distribution of Crashes by Mode and Location

Road Description	Pedestrian		Bike		Motorcycle		Vehicle	
	#	%	#	%	#	%	#	%
Intersection Related	1,247	65%	1,039	74%	741	56%	39,722	56%
Non-Intersection	617	32%	222	16%	479	36%	27,736	39%
Alley Related	13	0.7%	53	3.8%	20	1.5%	760	1.1%
Driveway Access Related	37	1.9%	87	6.2%	75	5.6%	2,779	3.9%
Other*	7	0.4%	7	0.5%	11	0.9%	485	0.7%
Unknown	3	0.2%	3	0.2%	0	0%	147	0.2%
Total	**1,924**	**100%**	**1,411**	**100%**	**1,326**	**100%**	**71,629**	**100%**

*Includes parking lot, roundabout, and highway interchange

Table 12 shows the distribution of fatal crashes by mode and location. Excluding bicycle crashes, fatal crashes were more likely to occur at non-intersection locations. The largest difference in crash trends by location for total and fatal crashes is among pedestrian crashes. Whereas 32 percent of total pedestrian crashes occurred at non-intersection locations, 53 percent of fatal pedestrian crashes occurred at those locations.

Table 12. Distribution of Fatal Crashes by Mode and Location

Road Description	Pedestrian		Bike		Motorcycle		Vehicle	
	#	%	#	%	#	%	#	%
Intersection Related	25	44%	5	71%	5	31%	31	43%
Non-Intersection	30	53%	2	29%	7	44%	39	54%
Alley Related	0	0%	0	0%	0	0%	1	1.4%
Driveway Access Related	2	3.5%	0	0%	2	13%	1	1.4%
Other*	0	0%	0	0%	2	13%	0	0%
Total	**57**	**100%**	**7**	**100%**	**16**	**100%**	**72**	**100%**

*Includes parking lot, roundabout, and highway interchange

Crashes by User Actions and Contributing Factors

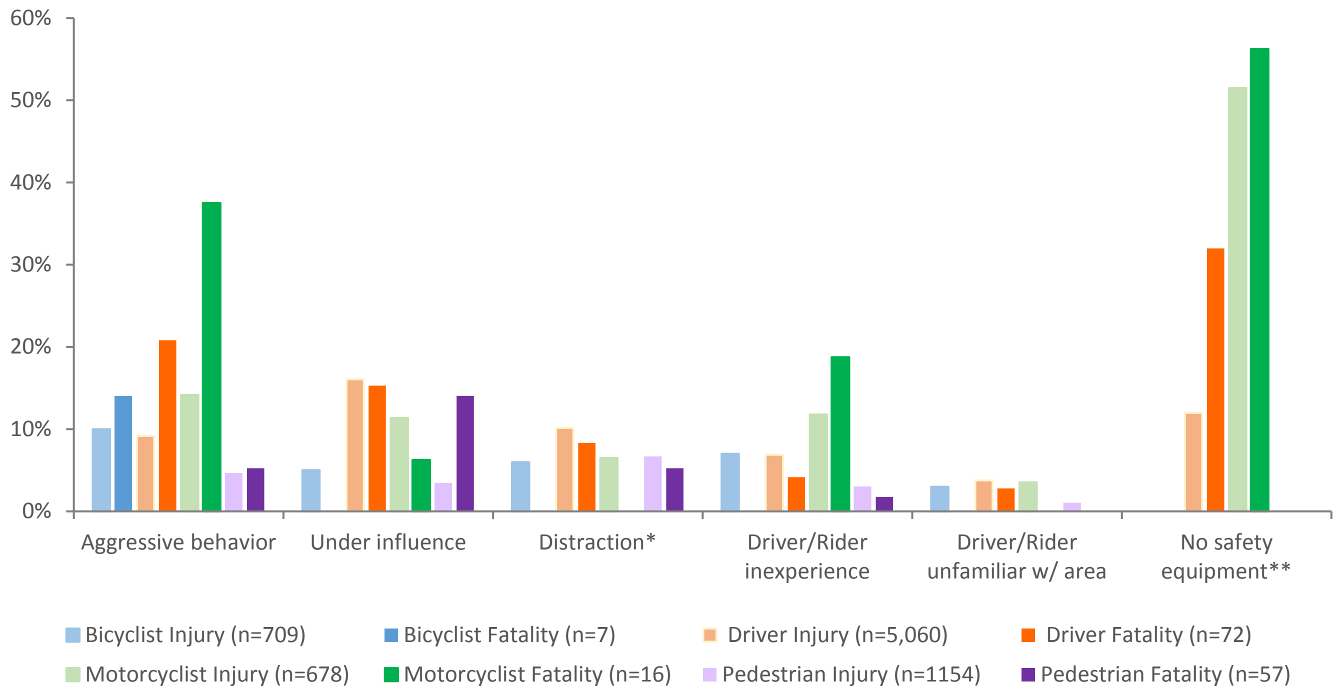
This section explores the contributing factors and pre-crash actions of the road users involved in traffic crashes. Contributing factors are those things that contribute to a crash, such as driving under the influence or being distracted, but do not equate to the pre-crash action, which includes things like "failure to yield right of way" and "disregarding traffic control device." Both of these variables help to further explain what happened to cause a crash to occur, providing important contextual information for other variables such as movements (e.g., left turns or going straight).

Figure 16 shows the distribution of contributing factors between injury and fatality crashes for all modes. Note the difference between the prevalence of certain factors among injury crashes versus fatal crashes, as well as how they differ by mode. For example, aggressive driving is much more prevalent among motorcycle crashes, and particularly so for fatal motorcycle crashes. Traveling under the influence was a factor in approximately 15 percent of driver injury and fatal crashes, and approximately the same percentage of pedestrian fatal crashes. Distraction also occurred for all modes, with the highest percentage among driver crashes. Recent research using large sets of cellphone data suggest that these percentages are likely underestimates of the true influence of distraction.[8]

A lack of safety equipment for drivers (seatbelts) and motorcyclists (helmets) was also prevalent among a relatively high percentage of driver and motorcycle fatal crashes, respectively. Note that there were also a substantial number of crashes for each mode that had "no apparent" contributing factor; these instances are combined with instances of unknown or missing information and shown in Figure 16.

[8] Cambridge Telematics, 2017. National Cell Phone Data Study

Figure 16. Contributing Factors for All Injury and Fatality Crashes

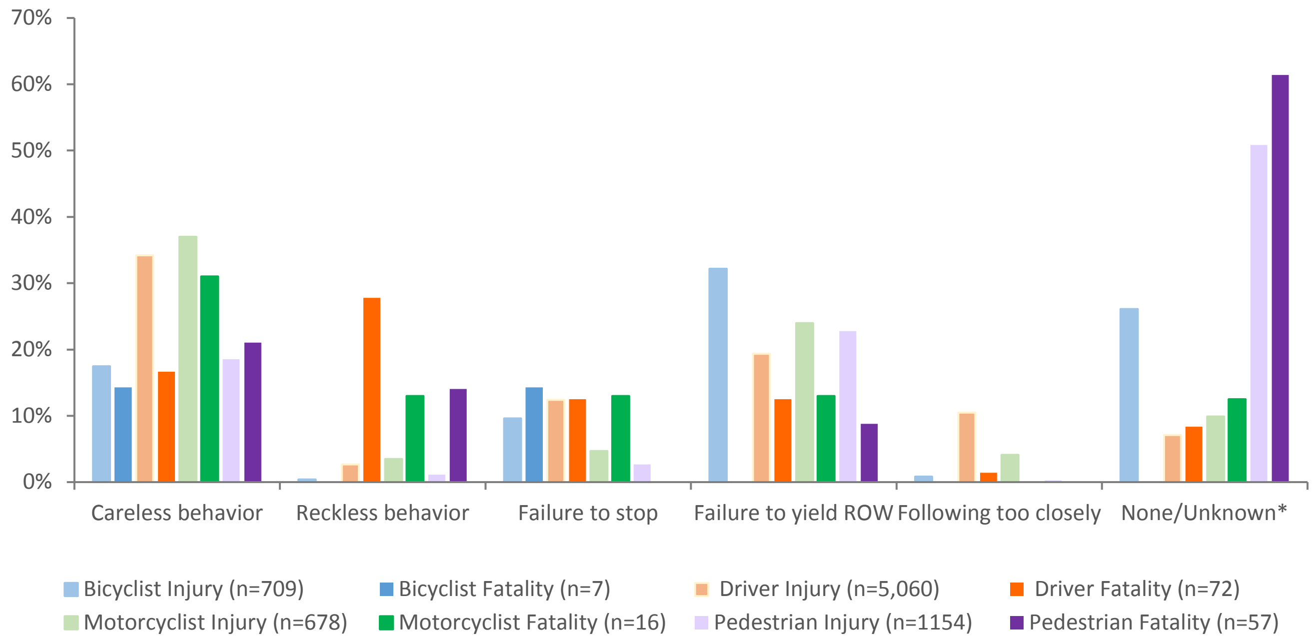


*Distractions related to use of cell phone, radio, other passengers, food, pets, or any other object.

**Safety equipment information reflects seatbelts for motorists and passengers, and helmet use for motorcyclists

Figure 17 shows the pre-crash actions for pedestrian, bicycle, motorcycle, and vehicle crashes. Note that the actions for pedestrian crashes in this figure refer to the actions of the motorists in the crashes. As was the case with contributing factors, the most common pre-crash actions for injury crashes are not necessarily the most common pre-crash actions for fatal crashes. This is particularly the case for reckless driving, which is much more likely to be involved in fatal crashes than injury crashes. Careless behavior, which is considered a less serious version of dangerous driving than reckless behavior, is the most commonly cited action, and is involved with both injury and fatal crashes. In contrast, following too closely is much more likely to be associated with just injury crashes. The last category in Figure 16 represents the percentage of crashes for each mode that are missing information about pre-crash actions and contributing factors. Note that over fifty percent of pedestrian crashes lack information about pre-crash actions and contributing factors; in contrast, just about ten percent of motorist and motorcyclist crashes lack this important explanatory information. While some of the missing information for pedestrian crashes is related to hit-and-run crashes, others simply lack this information, prohibiting a more thorough understanding of factors contributing to pedestrian risk.

Figure 17. Pre-Crash Actions for All Injury and Fatality Crashes



*None/Unknown crashes include crashes with neither a pre-crash action nor a contributing factor listed.

Conclusion

The data presented in this section of the Technical Supplement give a general comparison of crash patterns in Denver by severity, temporal factors, environmental and road conditions, speed, and actions for crashes involving pedestrians, bicyclists, motorcyclists, and drivers. This summary provides context for the summaries specific to each of the four transportation modes which present a deeper analysis of crash trends. This analysis indicates that there are different patterns in the locations and conditions under which the majority of pedestrian, bicycle, motorcycle, and vehicle crashes occur, which the modal-specific analyses explore more in depth. As for variables that are associated with crashes, there are similar trends in contributing factors and pre-crash actions across modes, although certain factors are more likely to be associated with some modes over others. For example, while failure to yield right of way is common across all modes, reckless driving and driving under the influence of drugs or alcohol are more likely to be associated with certain crashes over others.

Regardless of the differences between modes, this summary shows that there are likely many strategies which can benefit all modes, such as speed reduction, design that reinforces desired behavior, and educational campaigns. All of these have an important role in Denver’s Vision Zero program.

High-Injury Network Development & Methodology

Introduction

This section of the Technical Supplement describes the processes used to develop the High Injury Network (HIN) for the Denver Vision Zero Action Plan. It is divided into sections for each major component of the analysis: inputs, key assumptions, and process.

The HIN can be defined as a set of streets that account for a large percentage of traffic fatalities and injuries relative to the rest of the network. Knowing which streets fall into this category will allow Denver to not only focus its resources on these high-injury streets, but also to understand the road characteristics that contribute to crashes and worse injury outcomes.

Inputs

There were three sources of crash data included in the HIN analysis: City of Denver Public Works (DPW), Colorado Department of Transportation (CDOT), and Denver Police Department (DPD). The DPW datasets were the most important crash data used in the analysis. Crash data from CDOT was needed to account for crashes along Sheridan Boulevard. Data from DPD was then added to the analysis to account for some fatal crashes that had been omitted from the DPW datasets. These fatal crashes could have been omitted from the DPW data for various reasons such as if a crash investigation was ongoing at the time data was transferred.

Key Assumptions

Crashes in the Denver crash database were assigned to the nearest intersection node in the City's street centerline data. For the CDOT crash data, the nearest as-the-crow-flies intersection to the crash point was used. Poor placement of the crash point in the source data could have resulted in a crash being assigned to an incorrect intersection. However, the effect of this type of error is expected to be minimal and is assumed to have no effect on the outcome of the analysis.

Intersections were analyzed by mode to produce three distinct HINs: pedestrian, bicycle, and vehicle. Since the causes of—and mitigation strategies for—crashes related to each mode can be different, the project team evaluated each mode separately. As a result, some locations that were included in the pedestrian HIN may not be part of the vehicle HIN, and vice versa.

The project team assigned a weight representing the severity of the crash. Fatal crashes received a weight of three (3) and injury crashes were weighted at one (1). Non-injury crashes were not counted in the weighting, meaning they were excluded from consideration as part of the development of the HIN. Because the Denver crash data used in the analysis did not indicate the severity of injury, it was not possible to differentiate between serious injury, moderate injury, and minor injury crashes.

Finally, the project team excluded the area encompassing Downtown from the analysis. Because of its unique street usage characteristics and development intensity, including Downtown streets in the analysis would influence the identification of other HIN corridors. Rather than focusing on one particular street, the City is focused on needs in downtown as a network.

Analysis Process

The analysis followed five major steps:

1. Summarize crashes at each intersection
2. Create sliding corridor windows
3. Develop statistics for crashes within corridor windows
4. Filter for high crash locations
5. Finalize the HIN

Each step used input from the previous step. The result was a separate draft HIN for all three modes: pedestrian, bicycle, and vehicle.

Summarize Crashes at Each Intersection

With all source crashes assigned to an intersection, the project team summarized all crash data for each intersection. The result was a count of the number of fatal, injury, and non-injury crashes. The project team also produced counts of crashes by crash type (e.g. T-Bone, same direction, etc.) for crashes where such information was available.

Create Sliding Corridor Windows

To focus on high-risk corridors, the project team combined individual street segments into longer corridors. Corridors were created by joining all road segments that shared the same base name and formed a continuous line. Anomalies were minimized thanks largely to the City's rectilinear grid system and consistent naming scheme, however, it is possible that the HIN results could be affected by this process in locations where continuous roadways do not share a street name. These effects are assumed to be negligible.

After creating corridors, the project team developed a series of sliding windows across each corridor, with a shorter segment centered on each intersection. Each window spanned a one-mile section of the corridor (a half-mile in either direction from its central intersection), resulting in a series of windows that partially overlap across the entire corridor. This process allowed for an intersection to be considered for inclusion in the HIN based partly on crashes that occur along the same stretch of roadway but at nearby intersections, in addition to the statistics of the intersection itself. The intent was to ensure some smoothing of the HIN across an area greater than individual block segments, and to reflect the fact that problems at one intersection are likely symptomatic of design decisions and land use patterns that are present through an entire area.

Develop Statistics for Crashes within Corridor Windows

The project team summarized each window on a variety of metrics. These included basic summaries such as the weighted crash total of all intersections in the window and a count of the number of intersections meeting a minimum weight threshold.

More sophisticated analyses were also employed. One such measure was the weighted crash total of the window with the highest and lowest values eliminated—the high-low weighted crash total. The effect of this measure was to eliminate the impact of outliers in either direction and emphasize typical conditions within the window. For instance, a window consisting of 6 intersections with weighted crash totals of 2, 1, 9, 3, 0, and 2 would have a high-low weighted crash total of 8 (2+1+3+2 with 0 and 9 excluded).

Another window measure employed was the vicinity-adjusted crash index. This was calculated by adding all weighted crashes within the window and dividing by the sum of all weighted crashes within a half mile network distance of the intersection. This measure represents the share of crashes near an intersection that occur along the corridor in question. For example, a one-mile stretch of roadway with 20 weighted crashes on the roadway and 5 weighted crashes on nearby roadways would have an index score of 0.8 (20 corridor crashes divided by 25 total crashes). In other words, a high index score indicates that a given stretch of roadway represents a disproportionate share of crashes for its location in the network.

Filter for High Crash Locations

The window statistics were used to filter the road network to locations exhibiting high crash levels and warranting consideration in the HIN. After examining the network and crash distributions, locations were filtered for the bicycle and pedestrian HINs by selecting windows meeting either of the following criteria:

- High-low weighted crash total of at least 4 AND at least two intersections with weighted crash totals higher than 2

--OR--

- Four or more intersections with weighted crash totals higher than 0 AND a vicinity-adjusted crash index score of at least 0.8

Locations were filtered for the vehicle HIN with the following criteria:

- High-low weighted crash total of at least 14 AND at least two intersections with weighted crash totals higher than 2

Finalize the HIN

The result of the window filtering was a loose network of corridors. While the process minimized gaps and isolated segments, some manual intervention was needed to create a fully coherent network. To this end, and after discussions with the City, short gaps in corridors were filled and some small isolated areas were removed. This resulted in the final HIN included in the Action Plan.

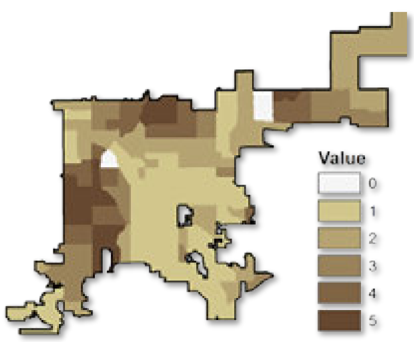
Communities of Concern Methodology

The Vision Zero Communities of Concern utilized a weighted overlay process to create an average Community of Concern score for each High Injury Network (HIN) segment. The GIS processes used to develop the Community of Concern score are described here. Some of the process steps require the ArcGIS Spatial Analyst Extension. This model builds on a model created for Denver Environmental Health by Matrix Design.

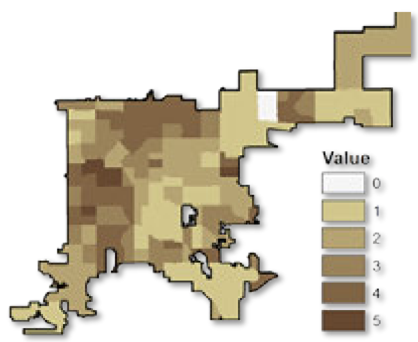
The Communities of Concern includes seven sub-models.

1. Socio-economic: Census tract information from the American Community Survey (2010-2014) was used for a) Education (percent of those over age 25 without a high school diploma or the equivalent by census tract *(Source: ACS 2010-2014))* and b) Poverty (percent of poverty). Each tract was ranked a score of 1 to 5 based on lowest education to highest education and 1 to 5 based on lowest poverty to highest poverty. Each layer was converted to a 250x250 foot grid.

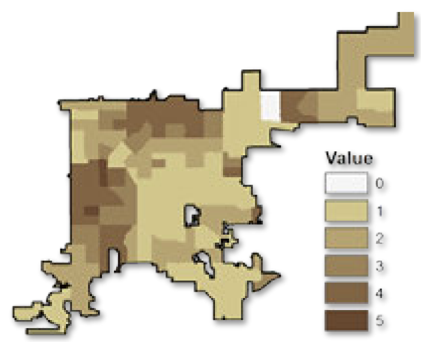
   The average of the two rasters created one **socio-economic raster** for use in the final model. The following illustrates the overlay process used throughout the Community of Concern analysis.



Ranking for Percent with Less than a HS Diploma (SE_EDU_250.tif)



Ranking for Percent in Poverty (SE_POV_250.tif)



Average of Inputs (SE_250.tif)

2. Traffic safety is the second sub-model. This includes the count of all car crashes, including bike and pedestrian related crashes (Source: Denver Police Department, 2012-2015, x/y coordinates table). Traffic crashes involving a pedestrian or bicycle were weighted 1.5 times motor vehicle crashes. Traffic crashes were overlaid with the average speed limit, weighted by road distance (Source: City and County of Denver GIS, 2016, street data, updated by DEH and Matrix Design to exclude interstates and highway ramps). The two safety indicator layers to create one **Safety** raster layer for use in the final model.

3. Key Destinations and Children is the third sub-model. This sub-model includes: a) the density of facilities, including public and private schools and recreation centers (Source: City and County of Denver, Technology Services GIS, 2016). GIS generated a 250' x 250' grid using the Kernal Density tool to determine the density of sites. The sub-model also includes: b) the proximity of children within 1 mile of the school that they attend (elementary and middle schools only; source: Denver Public Schools, 2016). Census blocks were ranked using Jenks and assigned values of 1 to 5, from lowest to highest children density, respectively. The final Key Destinations and Population layer averages the two rasters to create the Key Destinations and Children 250x250 foot raster layer for use in the final model.

4. Health is the fourth sub-model. This model includes: a) Adult obesity (percent of adults identified as obese by census tract) and b) Childhood obesity (percent of children identified as obese by census tract). Source: Colorado BMI Monitoring System, 2012-2014). Each layer was converted to a 250x250 foot raster and ranked from 1 to 5, with one being the lowest obesity and 5 the highest. The Health layer averages the two rasters to create the Health 250x250 foot raster layer for use in the final model.

5. Older Adults is the fifth sub-model. This model includes the percent of population that are aged 70 and above by census block group *(Source: ACS 2010-2014).* Using Jenks each census block group is ranked from 1 to 5, with 1 being the lowest percent of older adults and 5 the highest. The layer was then converted to a 250x250 foot raster.

6. No vehicle ownership is the sixth sub-model. This model includes the percent of households with no vehicle access by census tract (Source: ACS 2010-2014). Using Jenks, each census tract is ranked from 1 to 5, with one being the highest vehicle ownership and 5 being the lowest. The layer was then converted to a 250x250 foot raster.

7. Disabilities is the seventh sub-model. This model includes the percent of population with a disability by census tract *(Source: ACS 2011-2015).* Using Jenks, each census tract is ranked from 1 to 5, with one being the lowest percent of people with disabilities and 5 being the highest. The layer was then converted to a 250x250 foot raster.

Final Weighted Model

Weighted Model – The final Community of Concern model weights the sub-models to generate a final Community of Concern raster dataset. For the Community of Concern, weighting gives consideration to the detail of the input data sets. For instance, datasets with a finer spatial resolution were weighted higher than those at a census tract level. Additionally, safety was rated slightly less because the model was developed to inform the high injury network, which was created with safety as the main consideration. The sub-model weights are shown in Table 13.

Table 13. Communities of Concern Sub-model Weights

Sub-Model	Weight
Socio-economic	2
Safety	1
Key Destinations and Kids	3
Health	1
Older Adults	2
No Vehicle Ownership	2
Disabilities	2

Process to Assign Community of Concern weighted raster to the High Injury Network.

The High Injury Network features (lines) were buffered by 500 feet to cover a larger area. The average raster values underlying each buffered segment were assigned as a COC score to each segment in the output table. A custom Zonal Statistics tool from ESRI must be used due to the fact that one raster square may contribute to more than one buffered segment (i.e. the buffered segments overlap).

In addition to creating a weighted Community of Concern index, the HIN was also attributed with each independent sub-model (e.g. high socio-economic concern = weight of 5, holding all other inputs at weight = 0; etc.). The output tables were added into a single table using Access. These results were joined to the original buffered HIN layer and added to the HIN as a field attribute.

Speed Survey Data Analysis – Key Findings

Introduction

The City and County of Denver collects speed data using data collection devices installed in areas suspected of having a speeding problem. This section of the technical supplement covers key findings from analysis of the speed data and their potential impact on Denver's effort to eliminate serious and fatal injuries from traffic collisions.

Analysis

Posted speeds where data was collected ranged from 15 to 45 mph. Because fewer than five observations were available for each of the 15, 20, 40, and 45 mph locations, this section focuses on findings from locations signed at 25, 30, and 35 mph. Table 14 shows statistics for average and 85th percentile speeds at these locations.

Table 14. Variation in Measured Speeds at Locations Signed at 25, 30, and 35 MPH

Posted Speed (mph)	Sample Size	Average Speed (mph)	Average 85th Percentile Speed (mph)	High 85th Percentile Speed (mph)	Diff between High 85th and Posted (mph)	% of locations 5+ mph over posted
25	128	21.6	25.4	34.1	9.1	25%
30	133	27.9	32.8	43.8	13.8	38%
35	41	33.0	38.8	45.4	10.4	54%

This data revealed several trends. First, average speeds were slightly below and average 85th percentile speeds were only slightly above posted speeds for all speed categories examined. Looking closer at the 85th percentile speeds, however, the data showed that as posted speed increased, so did the percentage of locations where 85th percentile speed was at least 5 mph over the posted speed. The result was that only 25% of 25 mph locations showed an 85th percentile speed of at least 5 mph over (30 mph), whereas over half (54%) of 35 mph locations showed an 85th percentile speed of at least 5 mph over (40 mph).

Additionally, the "high" 85th percentile speed for all speed categories (that is, the highest 85th percentile speed recorded among the range of locations for each posted speed limit) approached or exceeded 10 mph over the posted speed. This is alarming for several reasons. First, certain land uses tend to be associated with certain behaviors (e.g., residential areas are generally posted as and considered to be slower speed areas), and conflict or injury may result if behavioral expectations associated with posted speeds are violated. Second, drivers traveling at higher speeds see less at any given time and need more space and time to stop, thereby increasing the chances of a collision (see Figure 16). Third, if a collision does occur at an increased speed, the chances of severe injury or death increase non-linearly, such that the average pedestrian struck at 20 mph only has a 13% chance of severe injury or death, whereas being hit at 35 mph results in a 55% chance of severe injury or death.

Figure 16. Risk of Fatal or Severe Pedestrian Injury by Vehicle Impact

Data source: Tefft, 2013. "Impact speed and a pedestrian's risk of severe injury or death." *Accident Analysis & Prevention*

Furthermore, the risk was not equally distributed throughout the population: research has found that older pedestrians have a significantly higher risk of severe injury or death than younger pedestrians. According to Tefft (2013), the average adjusted, standardized risk of severe injury or death for a 70-year-old pedestrian is approximately the same as the risk faced by a 30-year-old pedestrian struck by a vehicle going 11-12 mph faster—regardless of the base speed. In other words, a 70-year-old struck by a driver traveling at 25 mph results in approximately the same injury as would befall a 30-year-old struck by a driver traveling 36 mph. This data on the increased risk of speed, particularly as it concerns older pedestrians, underscores the need to reevaluate locations signed at speeds unsafe for human life, as well as those where drivers routinely drive faster than the posted speed limit and pose additional danger to pedestrians.

Some of the roadways with 85th percentile speeds substantially above the posted speed limit also appear in Denver's High Injury Network. However, it should be noted that the data from the data collection devices is not a comprehensive set of all locations with speeding problems.

Conclusions

The speed data provided insights into the relationship between prevailing and posted speeds, as well as where speeding may be particularly problematic. The data revealed that areas with lower posted speeds were less likely to be associated with drivers traveling at least 5 mph over the speed limit, but still had a few locations were drivers traveled at speeds nearly or above 10 mph over the speed limit. Although many of the problematic areas are known through their appearance in the High Injury Network, a more formal process to randomly measure speed throughout the City could lead to greater insights and potentially identify areas with even greater issues than the current data could reveal.