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FACTORS ASSOCIATED WITH CRASHES OF URBAN DRIVERS

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16. Abstract

This report focuses on the nature of crashes that occur in urban areas. The report first discusses the differences between the urban and rural crash pictures. We then take a closer look at a variety of urban crash configurations, separated into intersection crashes, non-intersection crashes, pedicyclist crashes, rear-end crashes, and lane-change crashes. Although fault and cause are not identified in databases, we address the array of causes by identifying violations charged to drivers, rates of drunkenness, and other factors associated with each crash type.

To supplement the crash data analysis, we present analysis of spatial road data from a selection of U.S. cities. The road data indicate the kinds of road conditions that drivers encounter in typical urban driving. The combination of road exposure and crash risk leads to the full picture of crashes in urban areas.

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Introduction

The urban environment presents many challenges to drivers. There is greater complexity in the environment, more choice points, and greater traffic volume. Buildings block views, and pedestrians and cyclists are more numerous than in rural areas. Audi has undertaken the challenging task of trying to build an Urban Driving Assistant to help drivers cope with many of the complex aspects of urban driving.

This report focuses on the nature of crashes that occur in urban areas. The report first discusses the differences between the urban and rural crash pictures. We then take a closer look at a variety of urban crash configurations, separated into intersection crashes, non-intersection crashes, pedicyclist crashes, rear-end crashes, and lane-change crashes. Although fault and cause are not identified in databases, we address the array of causes by identifying violations charged to drivers, rates of drunkenness, and other factors associated with each crash type.

To supplement the crash data analysis, we present analysis of spatial road data from a selection of U.S. cities. The road data indicate the kinds of road conditions that drivers encounter in typical urban driving. The combination of road exposure and crash risk leads to the full picture of crashes in urban areas.

Background

A literature was performed to identify past studies examining factors important for urban drivers. Broad categories of studies related to this topic include:

- urban vs. rural pedestrian crashes
- driver factors relating to urban and rural crashes
- factors affecting fatality/injury rates in urban rural crashes

Pedestrian crashes in urban and rural environments

Zhu et al. (2008) studied patterns of pedestrian collisions in New York state for years 2001-2002. Analysis considered miles walked. Rates of pedestrian crashes, fatalities, and injuries in small and mid-sized urban areas are twice that in rural areas. Highest rates of pedestrian injury were in large urban areas, likely because those residents walk twice as much as rural residents. Rates of fatal pedestrian accidents per miles walked were similar in large urban and rural environments.

Paulozzi (2006) studied regional variations in pedestrian fatalities for the years 1993-2003. They noted highest rates of fatalities in the South because of urban sprawl, urban traffic, and pedestrians under the influence of alcohol.

Paulozzi (2005) studied pedestrian fatality rate by vehicle type. Passenger cars and light trucks caused most of pedestrian fatalities, but buses, motorcycles, and light trucks had greater risk causing a pedestrian crash. Considering vehicle miles traveled, risk of pedestrian fatality is 1.57 times higher in urban environments compared to rural environments.

Miles-Doan and Kelly (1995) studied pedestrian crashes in Florida for 1988-90. Analyses indicated that both road environment and rural/urban mix contributed to differences in mortality and morbidity. The analysis was not able to separate the effects of urban/rural environment from the influence of medical care.

Mueller et al. (1988) compared pedestrian mortality and morbidity for urban and rural environments in Washington State from 1981-83. Rates of pedestrian injury were higher for urban environments, while fatality rate was higher in rural environments. The rate of dying once injured in a pedestrian crash was 2.3 times higher in rural compared to urban environments. Rural pedestrians sustaining injury died more frequently before receiving treatment at a medical facility and within the first hour after injury, suggesting that access to timely care is less prevalent in rural regions.

Driver factors relating to urban and rural crashes

Several researchers have studied crash patterns of younger drivers related to location in an effort to identify interventions that may vary with rural and urban drivers. Peek-Asa et al. (2010) studied crash pattern of teen drivers (aged less than 18) in urban, suburban, rural, and remote rural locations For drivers aged 15 and lower, crash rates were highest in more rural areas, while they were lower for teen drivers aged 16-18. Risk of serious or fatal injury was five times higher in rural compared to urban environments. Teen drivers involved in rural crashes more often were in single-vehicle crashes, crossing the centerline, occur at night, and involve a failure to yield the right-of-way.

Chen et al. (2010) studied crash patterns of younger drivers aged 17-25 in Australia. Crashes were sorted by urban, regional, or rural locations and drivers were classified by socio-economic status (SES). Over the 1997-2007 time period studied, fatality rate decreased only for urban drivers. Fatality risk is higher for rural vs. urban drivers, and for lower SES vs. higher SES. Characteristics most often seen in rural crashes were higher speed limits, intoxicated drivers, unbelted drivers, and driver fatigue. High speed limits, fatigue, and older vehicles were more often seen in crashes involving lower SES compared to higher SES.

Elshani et al. (2010) studied driving patterns of teen drivers in the state of Michigan to estimate exposure and behavior patterns. One of their finding indicates that those from urban areas drove more frequently than those from rural areas.

Clarke et al. (2010) studied fatal crashes in the United Kingdom using police reports from 1994-2005. Younger drivers were most often involved in fatal crashes at night in rural areas and/or while driving recreationally. High speed, alcohol involvement, and recklessness were common contributing factors. Older drivers most often had fatal accidents during the daytime on rural roads that involved misjudgment and errors in identifying right-of-way.

Rakauskas et al. (2009) studied attitudes towards risk between rural and urban drivers. Rural drivers are less likely to wear seatbelts because they have lower perceptions of the risks of being unrestrained compared to urban drivers. Pickup trucks are more often driven by rural drivers, and drivers likely to choose this vehicle type also have lower rates of seatbelt use and higher rates of driving while intoxicated. Rural drivers believe government-sponsored traffic safety programs are less useful than urban drivers.

Clarke (2001) compared motor-vehicle fatality rates in elderly (>65 years old) and other drivers. Fatality rates were higher for elderly drivers. Rural fatality rates were higher than urban rates. Elderly drivers who died in crashes were more often female, restrained, unintoxicated, and speeding than younger drivers. Fatal intersection crashes were more likely among elderly drivers, especially in urban environments.

Overall differences between urban and rural crashes

Goldstein et al. (2011) studied patterns of mortality from motor-vehicle crashes in the United States. Rural crashes are more often likely to result in death than urban crashes. The number of injuries sustained in each crash was greater in southern regions compared to northern regions, after controlling for urban/rural differences. The authors hypothesize that the greater number of deaths per injury is a result of challenges faced by first responders in rural area. They believe the greater number of injuries per crash in the south results from differences in vehicle, road, or driving conditions.

Brown et al. (2006) studied FARS data from 1977 through 1996 to evaluate differences in rural and urban mortality. Rural MVC mortality rates continue to be higher than urban mortality rates though both decreased over the time period studied. Rates of dead-at scene are increasing, with the rural rate higher than the urban rate.

Gonzalez et al. (2006) studied police crash reports and medical records in Alabama for a 20-month period from 2001-2003. Approximately 2/3 of injured occupants were involved in crashes in rural locations. Twice as many fatalities occurred in rural rather than urban locations, and 70% of rural fatalities were dead on scene compared to 57% of urban fatalities. Mean response time in crashes with survivors was 6.8 minutes for urban and 13.9 minutes for rural crashes. Distance to scene and time at scene were also larger for rural crashes and associated with mortality rate. In a similar study using the same counties and a subset of the time period, Gonzalez et al. (2007) found high speed to be a factor in 19% of rural crashes and 9% of urban crash. Among those speeding, mortality rates were similar in rural and urban environments, but rural mortality rate was higher among occupants traveling within the posted speed limit.

Clark and Cushing (2004) looked at how population density contributes to mortality from motor-vehicle crashes in rural and urban areas using data from 1998-2000. Vehicle miles traveled (VMT) per capita, population density, and southern location were all independent predictors of the rural mortality rate from MVC. Urban mortality rates were unaffected by population density but were also higher in the south. The presence of a state trauma system did not affect mortality rate.

Nilsson (1981) developed a model showing how the rates of fatal and injuries are related to traffic speed. These models have been used to predict how injury incidence might change if speed limits were lowered. Cameron and Elvik (2010) applied Nilsson's model to different types of roadways, and found that it was reasonable to use on freeways and rural highways, but was not applicable to urban arterial roadways.

Crash Database Analysis

Methods

Two different databases were used to conduct the analysis. The National Automotive Sampling System—General Estimates System (GES) is a sample of 50,000 crashes per year. Police reports from these crashes are coded into a large number of variables, but crashes are not directly investigated.

The GES sample is taken from a large number of primary sampling units (PSU) across the country. PSUs are selected from four regions (northeast, south, midwest, west) and within these regions, PSUs fall into three categories: central city (urban), area around a central city (suburban), and all others (rural). We identified a set of urban PSUs and analyzed data from these to look at urban crashes.

The other database is one including all crashes in California. Here, we selected crashes from three cities: San Diego, San Francisco, and Los Angeles. Details in the California database are limited, but we look at the nature of urban crashes in those cities to supplement the national analysis.

Overview of urban crash characteristics

The first step in analysis was to classify the crash types for urban and rural environments. The Volpe/DOT definitions of crash types were used in this analysis. Table 1 shows the distribution of crash types for urban and rural environments, as well as the ratio between the percentages. The top ten crash types for rural and urban environments are highlighted in green and yellow, respectively. The ten largest ratios, which indicate the largest differences between urban and rural crash types, are highlighted in orange.

Overall, nine crash types are among the top ten for both urban and rural: change lanes, control loss with no vehicle action, rear impact with lead vehicle moving, rear impact with lead vehicle stopped, opposite direction, road departure without maneuvers, running red light, turning/same direction, and intersection crashes without signals. The other main types of rural crashes involve animals, while the other main type of urban crashes is intersection crashes with signals.

When reviewing the differences between urban and rural crashes using the ratios, the ten crash types that are most often more likely to occur in urban environments are parking, pedestrian, rear impacts following vehicle maneuvers, drifting, changing lanes, other, running red light, rear impacts with lead vehicle moving, avoidance, intersections with signals, and cyclist.

Using both the most frequent types of urban crashes, plus the ratios between urban and rural, identify changing lanes, rear impacts with the lead vehicle moving, running red lights, and intersection crashes with signals as the leading types of urban crashes. Although pedestrian and parking crashes make up a relatively small proportion of the number of crashes, they are also considered significant among urban crashes because they are over twice as likely to happen in urban environments compared to rural ones.

Table 1. Distribution of rural and urban crash types plus their ratios.

Crash Type (Volpe/DOT definition)	Rural	Urban	Ratio (Urban/Rural)
Animal	9.81%	0.90%	0.09
Avoidance	0.28%	0.41%	1.46
Backing	2.23%	2.28%	1.02
Change lanes	4.23%	7.16%	1.69
Ctl Loss/No veh action	11.03%	6.45%	0.58
Ctl Loss/Veh action	1.89%	1.45%	0.76
Cyclist	0.76%	0.99%	1.31
Drifting	1.36%	2.63%	1.94
Low N	0.12%	0.11%	0.93
Non-collision	0.52%	0.17%	0.33
Object	1.62%	1.92%	1.19
Opp direction	2.50%	2.67%	1.07
Other	1.31%	2.12%	1.62
Parking	0.55%	1.23%	2.25
Pedestrian	0.88%	1.81%	2.07
RE: Following veh maneuver	0.86%	1.69%	1.96
RE: Lead vehicle moving	8.29%	12.15%	1.47
RE: Lead vehicle stopped	13.62%	13.75%	1.01
Road Depart/Backing	1.00%	1.11%	1.11
Road Depart/Man	1.20%	1.42%	1.18
Road Depart/No man	7.57%	6.11%	0.81
Rollover	0.06%	0.06%	0.95
Run red light	3.51%	5.34%	1.52
Run stop sign	0.99%	0.57%	0.57
Turning/same dir	3.44%	4.35%	1.27
Veh Failure	1.11%	0.79%	0.72
XPaths@Non-Signal	15.86%	15.45%	0.97
XPaths@Signal	3.43%	4.93%	1.44

Intersection crashes

Across the U.S. 43% of urban crashes occur away from any intersection, 3% occur on entrance/exit ramps, and the remainder occur at or near intersections. Thus, intersections pose a major problem in urban driving.

The distribution of all crash types that occur at urban intersections is shown in Figure 1. Rear impacts predominate, accounting for over one-quarter of all intersection crashes. The next most common type of intersection is turning into path at almost 12%. The least common types are head-on and backing crashes.

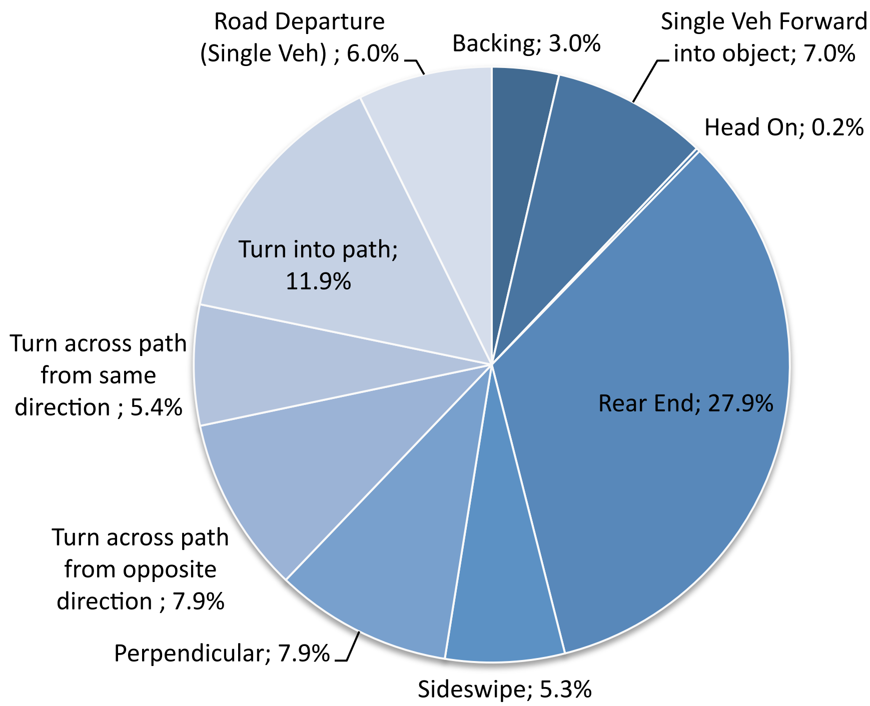


Figure 1. Distribution of intersection crashes by type.

NASS-GES cases involving intersections were reviewed to identify common factors contributing to some types of intersection crashes. Because NASS investigators are not allowed to assign blame when describing the crash circumstances, inferences were made based on the citations listed when available, as well as driver condition records.

Overall, intersections in urban areas occurred at which crashes occurred were signalized in 43% of cases, marked by stop sign in 19% of cases, and had no controls in 32% of cases. Many of these latter intersections are driveways and alleys, which are easy to ignore but present potential hazards in the lack of traffic controls.

Diagrams of each of these intersection crash configurations are shown in Figure 2. In this figure, the vehicle is in red and the struck vehicle in blue. In most cases, citations were given to the red vehicle if anyone was cited. Table 2 contains the percentage of each crash type broken down into more specific types (e.g., sideswipe right and sideswipe left). Highlights of causes and typical traffic control are noted. The full breakdown of all crash types, citations, and intersection controls are given in Appendix A.

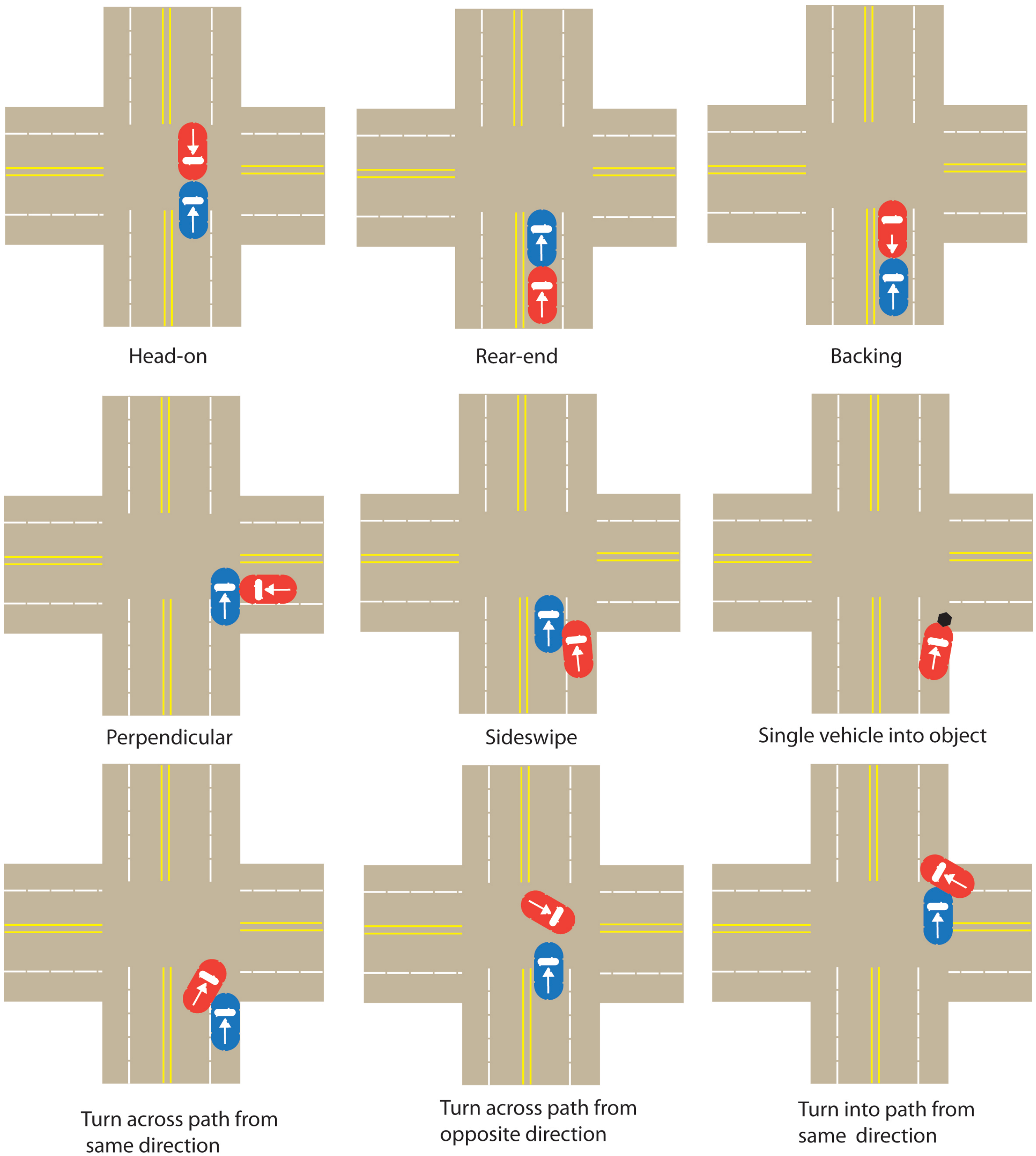


Figure 2. Diagrams of intersection crash types.

Table 2. Causes of different types of intersection crashes.

Type	Percentage	Common causes
Rear end into stopped	17.9%	59% cited for violation Speed-related 70% at traffic signal Driver distraction
Turn across path (initial opposite)	13.9%	57% cited for violation Failure to yield Reckless driving 60% at traffic signal 33% no traffic control
Perpendicular into right side	9.7%	61% cited for violation Failure to obey traffic signal Failure to yield Reckless driving 44% Stop sign 41% Traffic signal
Perpendicular into left side	9.3%	62% cited for violation Failure to obey traffic signal Failure to yield Reckless driving 46% Stop sign 40% Traffic signal
Turn into path in opposite dir (left side hit)	8.3%	61% cited for violation Failure to obey traffic signal Failure to yield Reckless driving 41% Stop sign 37% No traffic control
Forward into object	8.0%	34% cited for violation Drunk driver Distraction Speed-related 36% No traffic control
Rear end into decelerating	5.5%	53% cited for violation 48% No traffic control
Turn into path, same dir (right side hit)	3.7%	62% cited for violation 52% Traffic signal 34% No traffic control
Backing into vehicle	3.5%	62% cited for violation Failure to yield Reckless 29% Stop sign 43% No traffic control
Turn into path, same dir (left side hit)	3.5%	58% cited for violation Drunk driver 37% No traffic control

		35% Stop sign
Turn across path initial same (from right)	2.8%	50% cited for violation Drunk driver No traffic control
Road depart right	2.7%	50% cited for violation Drunk driver Speed related No traffic control
Rear end into slower	2.4%	52% cited for violation Speed related Distracted driver 54% Traffic signal
Turn across path initial same (from left)	2.4%	42% cited for violation Failure to yield Distracted driver 53% No traffic control
Road depart left	1.8%	54% cited for violation Drunk driver Speed related 59% No traffic control
Sideswipe same dir	1.2%	36% cited for violation Drunk driver Distracted driver 61% Traffic signal
Sideswipe cut-in from right	1.1%	43% cited for violation Distracted driver 45% No traffic control

Table 3 lists the different categories of intersection crashes and the percentage of each crash category where a factor contributed. Greatest percentages for each factor are highlighted in red. Drivers were cited for violations most frequently in perpendicular crashes, turning into path in opposite direction, turning into opposite direction, and sideswipe opposite direction. A drunk driver was a contributing factor most often in crashes where the vehicle departs the roadway or hits a forward object. Speed is the contributing factor most often when the vehicle departs the roadway. Failure to obey traffic control primarily contributes to perpendicular crashes. Failure to yield contributes to turn across path and turn into path crashes. Reckless driving most often affects perpendicular and turn into path crashes. Traffic lights contribute primarily to rear end into stopped, turn across path, and sideswipe same direction, while stop signs contribute to perpendicular, and turn into path opposite direction crashes. No control of vehicle is a factor when backing into a vehicle, turn across path initial same direction, and road departure. Driver distraction most often results in striking a forward object, rear end into slower, and sideswipe same direction.

Table 3. Contributing factors in different categories of intersection crashes.

Crash Type	Percent of All Crashes	Cited for Violation	Driver Drunk	Speed-Related	Failed to Obey Traffic Control	Fail to Yield	Reckless	Traffic Light	Stop Sign	No Control	Driver Distracted
Rear end into stopped	18	59	7	6			13	70	7	17	23
Turn across path (initial opposite)	14	57	5	1	1	10	28	60	4	34	12
Perpendicular into right side	10	61	7	1	8	7	28	41	44	7	19
Perpendicular into left side	9	62	7	1	6	7	32	40	47	7	16
Turn into path in opposite dir (left side hit)	8	61	4	1	3	10	31	19	41	37	13
Forward into object	8	34	11	6		1	8	38	20	37	43
Rear end into decelerating	6	53	4	4			7	41	5	48	19
Turn into path, same dir (right side hit)	4	62	5	1	2	9	28	24	29	43	22
Backing into vehicle	4	52	8	1		1	4	28	14	52	18
Turn into path, same dir (left side hit)	3	58	6		3	8	24	22	35	37	16
Turn across path initial same (from right)	3	50	7	1	1	2	5	30	1	62	19
Road depart right	3	50	19	36		1	16	27	13	54	19
Rear end into slower	2	52	7	4			8	54	6	35	44
Turn across path initial same (from left)	2	44	3	2		4	5	42	2	53	24
Road depart left	2	54	19	45			18	19	13	59	13
Sideswipe same dir	1	35	7	3			1	61	2	31	41
Sideswipe cut-in from right	1	43	5			3	4	44	1	45	22
Sideswipe cut-in from left	1	44	5				4	51	1	39	18
Turn into opposite dir (head on)	1	62						N/A	N/A	N/A	27
Sideswipe opposite dir		65						N/A	N/A	N/A	20
Head on		28						N/A	N/A	N/A	13
All Crashes		52	7	4	2	4	18	45	30	19	21

Non-intersection crashes

Non-intersection crashes were isolated in GES and analyzed in the same manner as intersection crashes. Figure 3 shows the relative distribution of crash types that occur away from intersections. Road departure and rear-end into vehicle or object (forward into object) make up the majority of these crashes. Table 3 describes the key factors associated with each crash type.

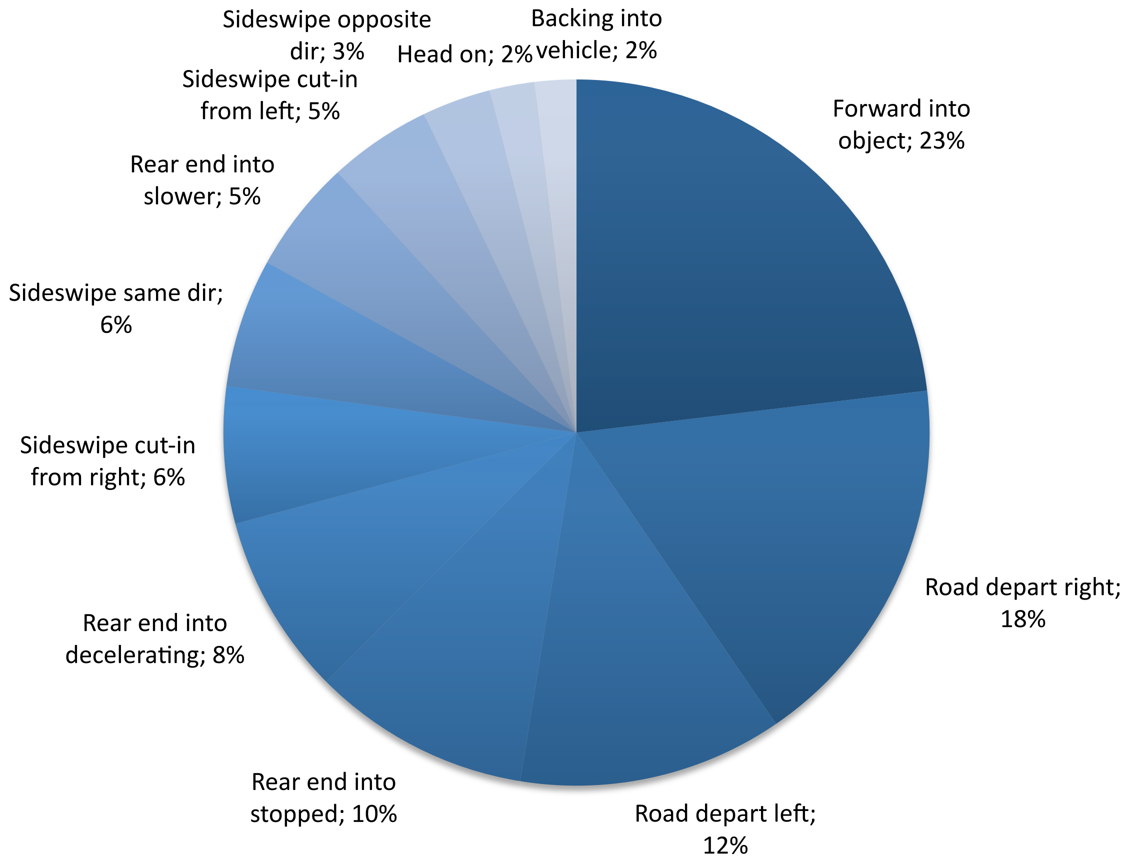


Figure 3. Distribution of crash types away from intersections.

Table 4. Causes of different types of non-intersection crashes.

Type	Percentage	Common causes
Forward into object	23.1%	46% cited for violation Drunk driver Distracted driver
Road depart right	17.3%	38% cited for violation Drunk driver Distracted driver Speeding Recklessness
Road depart left	12.1%	41% cited for violation Drunk driver Distracted driver Speeding Recklessness
Rear end into stopped	10.0%	49% cited for violation Recklessness
Rear end into decelerating	8.3%	48% cited for violation
Sideswipe cut-in from right	6.2%	43% cited for violation Lane violations
Sideswipe same dir	5.9%	38% cited for violation Lane violations
Rear end into slower	5.2%	53% cited for violation Drunk driver Recklessness
Sideswipe cut-in from left	4.7%	52% cited for violation Lane violation
Sideswipe opposite dir	3.2%	39% cited for violation Recklessness
Head on	2.0%	40% cited for violation Drunk driver Lane violation
Backing into vehicle	1.9%	27% cited for violation

Trends among factors contributing to non-intersection crashes, shown in Table 5, are similar to those seen in intersection crashes of the same category. Drivers are cited for violation most often in rear end into slower and sideswipe cut-in from left crashes. Road departure crashes frequently involve drunk, speeding, reckless drivers. Drunk drivers are also frequently involved in forward crashes into an object, as are distracted drivers.

Table 5. Contributing factors in different categories of intersection crashes.

Crash Type	Percent of All Crashes	Cited for Violation	Driver Drunk	Speed-Related	Reckless	Driver Distracted	Lane Violation
Forward into object	23%	46%	16%	11%	7%	59%	
Road depart right	17%	38%	17%	27%	13%	36%	1%
Road depart left	12%	41%	20%	30%	14%	33%	
Rear end into stopped	10%	49%	4%	7%	10%	16%	
Rear end into decelerating	8%	48%	3%	5%	7%	14%	
Sideswipe cut-in from right	6%	43%	3%	1%	4%	17%	6%
Sideswipe same dir	6%	38%	8%	2%	4%	24%	2%
Rear end into slower	5%	53%	14%	7%	11%	21%	
Sideswipe cut-in from left	5%	52%	8%		4%	19%	6%
Sideswipe opposite dir	3%	38%	11%	2%	9%	5%	
Head on	2%	40%	15%	3%	8%	10%	1%
Backing into vehicle	2%	27%	3%		3%	24%	
Grand Total	100%	43%	12%	13%	9%	32%	1%

Pedestrian/Cyclist crashes

Although pedestrians and cyclists make up a relatively small percentage of all crashes, they make up a larger percentage of fatal crashes. In addition, 65% of pedestrian events in GES occur in urban areas.

Of pedestrian crashes in urban areas, 64% occur at or near intersections, including driveways and alleys (which are 3 % of the total). Where it is possible to tell from the GES description, 27% of pedestrians are at fault and 45% of vehicles are at fault. The remainder is ambiguous. Pedestrians are hit about twice as often as cyclists in urban areas. Of pedestrians hit at intersections, 58% are hit at traffic signals, 12% at stop signs, and 25% at intersections with no traffic control.

Light plays a crucial role in pedestrian crashes. Of those occurring in urban areas, 25% occur in the dark under streetlight and 7% occur in dark, unlighted conditions. Alcohol is involved in 11% of pedestrian crashes, though it may be the pedestrian or the driver who is drunk. Drivers are cited in 33% of cases, most often for reckless driving. However, 25% of pedestrian crashes are hit and run, so more drivers might be cited if they were found.

For crashes with cyclists in urban areas, the cyclist is at fault 33% of the time and the vehicle at fault 41% of the time. The remainder is ambiguous based on GES codes. Cyclists are most often crossing the path of a vehicle when hit. This occurs 61% of the time vs. 32% of the time on parallel paths. The remainder is unknown or unusual configurations.

In urban areas, 77% of cyclist crashes occur during daylight and 18% occur at night in lighted areas. Alcohol is involved in 10% of these crashes. 80% of these crashes occur at or near intersections, including driveways and alleys. The latter group makes up 13% of cyclist crashes, which is substantial. At intersections, 40% of cyclist crashes occur with a traffic signal present, 25% are controlled by stop signs, and 30% of intersections are not controlled.

Rear end crashes

Rear-end crashes are more limited in variety. Rear-end crashes in urban areas from GES were analyzed. The basic distribution of rear-end crash configurations are shows in Figure 4. Rear-end into stopped vehicle is the most common type. Table 6 describes the characteristics of each of these types. In general, the striking vehicle (in the rear) is considered at fault.

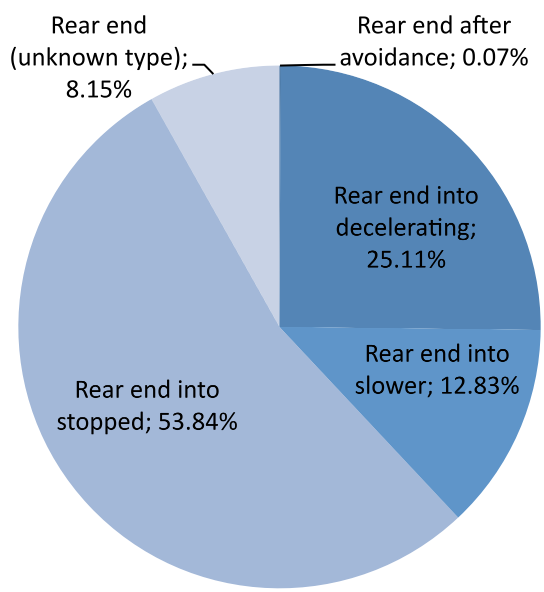


Figure 4. Distribution of types of rear-end crashes

Table 6. Causes of different types of rear-end crashes.

Type	Percentage	Common causes
Rear end into stopped	58.6%	57% cited for violation Recklessness 59% at intersection 41% No traffic control
Rear end into decelerating	27.3%	49% cited for violation 35% at intersection 72% No traffic control
Rear end into slower	14.0%	53% cited for violation Drunk driver 30% at intersection 73% No traffic control
Rear end after avoidance	0.1%	78% cited for violation Recklessness 14% at intersection 75% No traffic control

Most rear-end crashes of all types occur in daylight. Only rear-end into stopped vehicles is common at intersections. Other types more typically occur away from intersections and with no traffic controls present. Drunkenness is only commonly associated with rear-ends into slower-moving vehicles (11%). Speeding is rarely a cited violation in rear-ends.

California State Crash Data

Methods

We analyzed the California state crash database for 2008. This database contains all police-reported crashes in California, and includes city and county codes that allowed us to identify crashes in specific urban cities. In addition, the database contains a population code for the crash location, with the highest value indicating areas with population over 250,000. For some analyses, we used this code to select all urban areas in California.

Results

In 2008, there were 65,535 police-reported crashes in California. Of these, 25% occurred in areas with populations of 250,000 or more. San Diego, Los Angeles, and San Francisco were responsible for 14.5%, or 9513 crashes alone.

Among crashes in populous areas (250K+), 24% occurred at intersections, 5.7% involved a pedestrian, 2.3% involved a bicyclist, and 10% involved alcohol. The intersection crashes in urban California. Compared to national averages, the alcohol involvement rate is about the same, but pedestrians and bicyclists involved in crashes about twice as often. This is most likely due to higher pedestrian and cyclist exposure compared to other states. Unfortunately, it is difficult to get good estimates of exposure for pedicyclists. Interestingly, urban crashes in California occur about half as often at intersections, compared to national rates.

Among intersection crashes, 93% involved a violation. Of these, 33% failed to give right of way, 25% were related to signals or signs, and 11% were traveling at an unsafe speed. Away from intersections, 41% were driving at an unsafe speed, 15% were turning improperly, 11% made an unsafe lane change, and 8% were under the influence of alcohol or drugs.

Paradoxically, 37% of pedestrian crashes were coded as occurring at an intersection, but 50% of pedestrian action was coded as crossing in a crosswalk at an intersection. Another 24% of pedestrians were coded as crossing not at a crosswalk. Another 14% were in the road including the shoulder.

For cyclist crashes, 23% were cited for being on the wrong side of the road. Although the data does not clearly indicated who was cited, it seems likely that the cyclist was most often on the wrong side of the road, rather than the vehicle driver. Right of way violations accounted for another 20% of cyclist crashes and improper turning and traffic signal/sign violations accounted for 10% each.

Analysis of Spatial Roadway Data

To characterize experience of drivers in the urban environment, spatial road data were acquired for six urban areas. These data were obtained via web download and/or by contacting local government agencies. Two of the Highway Performance Monitoring System (HPMS) database fields were used to aid in standardizing the road data for the project, specifically climate zone and functional class (road type). HPMS is the nationwide database that describes the operating characteristics of the national public road infrastructure. The datasets gathered represent two of the four climate zones stipulated by HPMS when collecting system data, namely Wet-Freeze and Dry No Freeze. Analyzing the urban infrastructure for these two climate zones captures, in part, the variance in weather and road design criteria. For example, it is permissible to bank (super-elevate) horizontal curves on California roads at a greater rate than in an ice-and-snow state such as Michigan. This is because higher rates of banking (.06 - .08) may result in a large or slow-moving vehicle to slide down the curve due to snow or ice. This is just one of the examples that help to illustrate that road design, maintenance and construction practices can vary across the country. Table 7 lists the urban data sets categorized by climate zone.

Table 7. Climate Zone for each site

West Freeze	Dry No Freeze
Southeast Michigan	San Diego, California
New York City, New York	San Francisco, California
Chicago, Illinois	Houston, Texas

Functional Class (Road Type)
Roads are categorized by functional class or road type based on the hierarchical model of travel. This model recognizes that roads are part of a network and individually do not serve all traffic. This model drives transportation planning, highway funding and is reflected in the HPMS functional class definitions for roads. Road data categories varied slightly among the sites. However, to compare sites nationally, the road types were bundled with confidence in a subset of HPMS functional class categories to represent a national presentation of urban road types. For purposes of this report, road type will be used to describe road function.

Road characteristic data were gathered throughout the project and shown in Table 8. Using these data identified the percent distribution of road miles and intersections by road type (functional class) for five of the six sites. Additional road attributes such as pavement width and number of lanes were not available for all sites and thus were not incorporated into the analysis to date.

Table 8. Road characteristic data gathered for each site

City, State	Street Centerlines	Road Type	Number of Lanes	One/Two Street Designation	Intersection Nodes	Pavement Width Edges Curblines
Southeast Michigan	X	X	X		X	
San Diego, California	X	X	X	X	X*	X
New York City, New York	X	X			X*	X
San Francisco, California	X	X			X*	
Chicago, Illinois	X	X			X*	X
Houston, Texas	X				X*	X

City, State	Posted Speeds	Traffic Signals	Traffic Volume	Bike Route	Pedway	Building Footprints	Elev	County City Limits	Ortho-Corrected Aerial Photos	Lidar
Southeast Michigan	X	X	X			X	X	X	X	X
San Diego, California	X	X	X	X	X	X		X	X	
New York City, New York			X			X	X			
San Francisco, California	X	X								
Chicago, Illinois				X	X	X		X		
Houston, Texas						X			X	

*Indicates intesection nodes were created and/or data attributes were joined to complete analysis.

As indicated in Table 8, it was necessary to either create or expand upon the intersection data originally gathered to determine the percent of intersections by road type. This was achieved by applying a variety of GIS analysis tools to the data. In addition to road data, building footprints were acquired for five of the six sites. Building footprint was gathered to undertake, possibly in the future, intersection approach studies where the buildings may obscure the driver's line of sight and/or on-board safety feature functionality. Graphs presenting the percent distribution of road miles and intersections by type and aerial photos for San Francisco and Chicago are provided as Appendix B. Centerline, intersection and building footprint data were obtained for Houston. However, lack of documentation prevented conducting further analyses.

For Southeast Michigan, San Diego, and New York City, more data were available. The additional data obtained are shown in Table 8 and includes posted speeds, traffic volume, and, for Michigan only, geo-located crash data. The road type terminology varies slightly between the sites. However, it could be bundled with confidence to illustrate each site’s unique distribution of roads and intersections. A composite graph of the percent miles by the five major road types is presented below as Figure 5. Clearly New York City is the most "urban" with the highest percentage of higher volume and capacity road types and the lowest percentage of local roads. The distribution of miles by road type between San Diego and SE

Michigan vary only between 2-3% with the exception of the arterial category. Here SE Michigan surpasses San Diego with 7% more miles categorized as arterials.

A composite graph was also created for urban intersections by road type as shown in Figure 6. Overall the graphs are similar. However, New York City has more intersection access to the freeway/expressway road type category when compared to SE Michigan and San Diego. The percent of intersections at freeway/expressways for New York is 18% with Michigan and San Diego values of 2.9% and 4% respectively. This suggests more access to high-speed volume roads is available on the New York City road network.

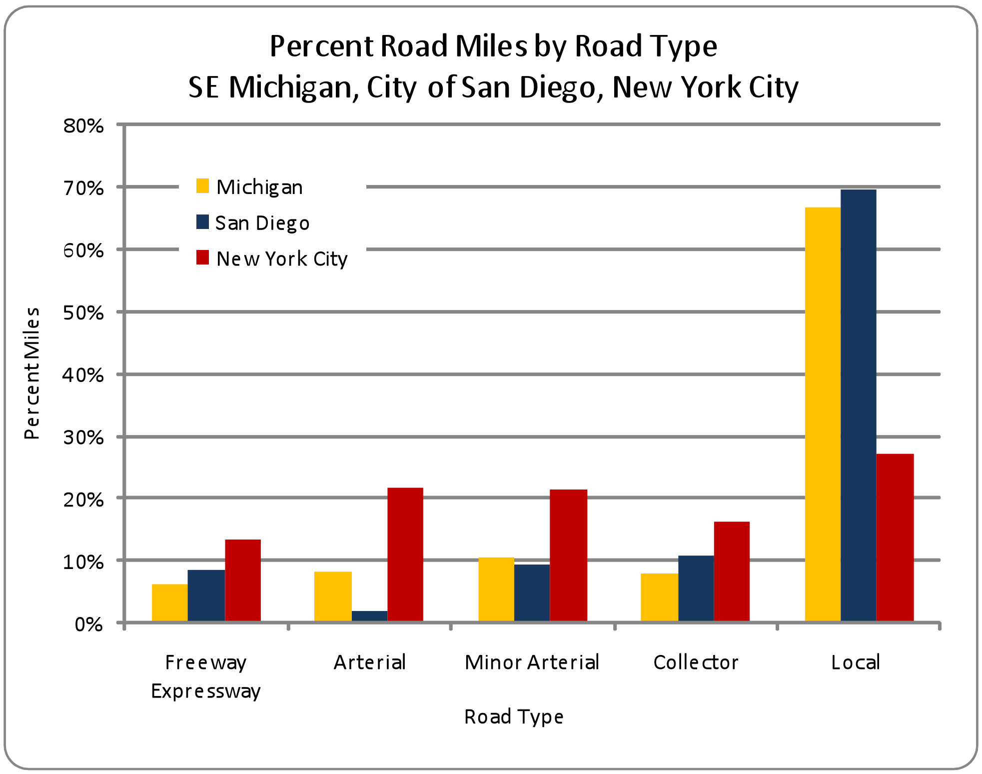


Figure 5. Percentage of road miles by road type for SE Michigan, San Diego, and New York.

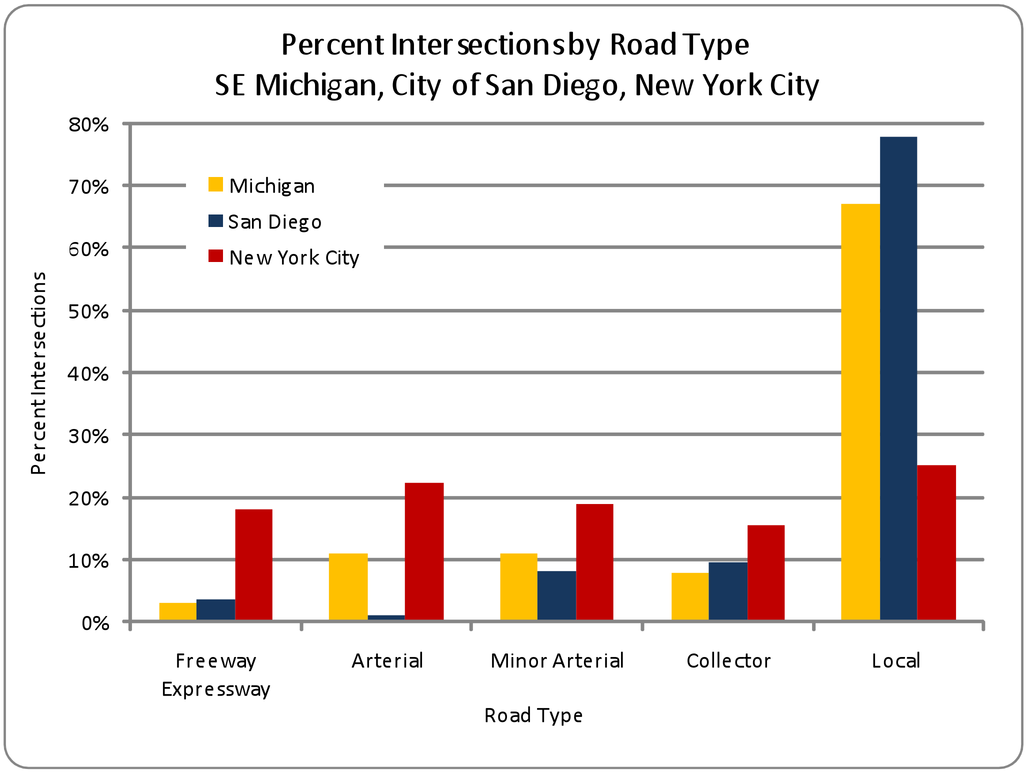


Figure 6. Composite graph of percent intersections by road type for SE Michigan, San Diego, and New York City.

Urban Area Sites

The urban areas of SE Michigan, New York City and San Diego are summarized below. The graphs presenting the analysis of the road data acquired follow.

Climate Zone Wet Freeze: SE Michigan

UMTRI has built a rich dataset of crash and road data for SE Michigan. These data were used to convey the urban character of SE Michigan which includes cites such as Detroit, Troy, Dearborn, Ann Arbor, and the Metro Airport complex. In total, the seven-county region has 28,137 road miles. Along this network are some 493,461 intersections for which 76% are classified as urban. Some 376,731 crashes were then spatially joined or “mapped” to the road on which the event occurred. Of these crashes, 202,983 were mapped within a 100 foot buffer of the urban intersections in this region. Figure 7 shows 100 foot buffers drawn on ortho corrected aerial imagery. Figure 8 is an aerial view of the Renaissance Center in Detroit and street view captured from Google maps. For SE Michigan a 6161 mile subset of roads was created using two roadway infrastructure data sets; the Michigan public road framework and the Michigan Highway Performance Monitoring System (HPMS) data to complete the analysis presented below.

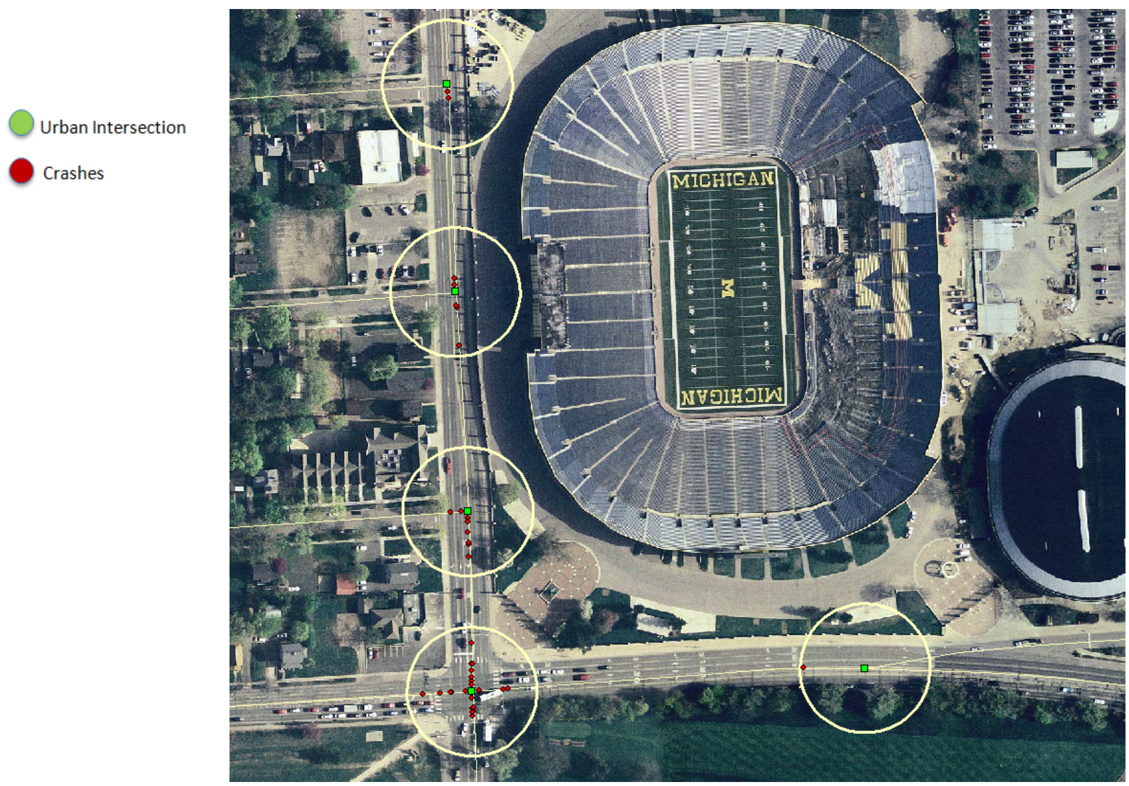


Figure 7. University of Michigan Stadium and surrounding intersections.

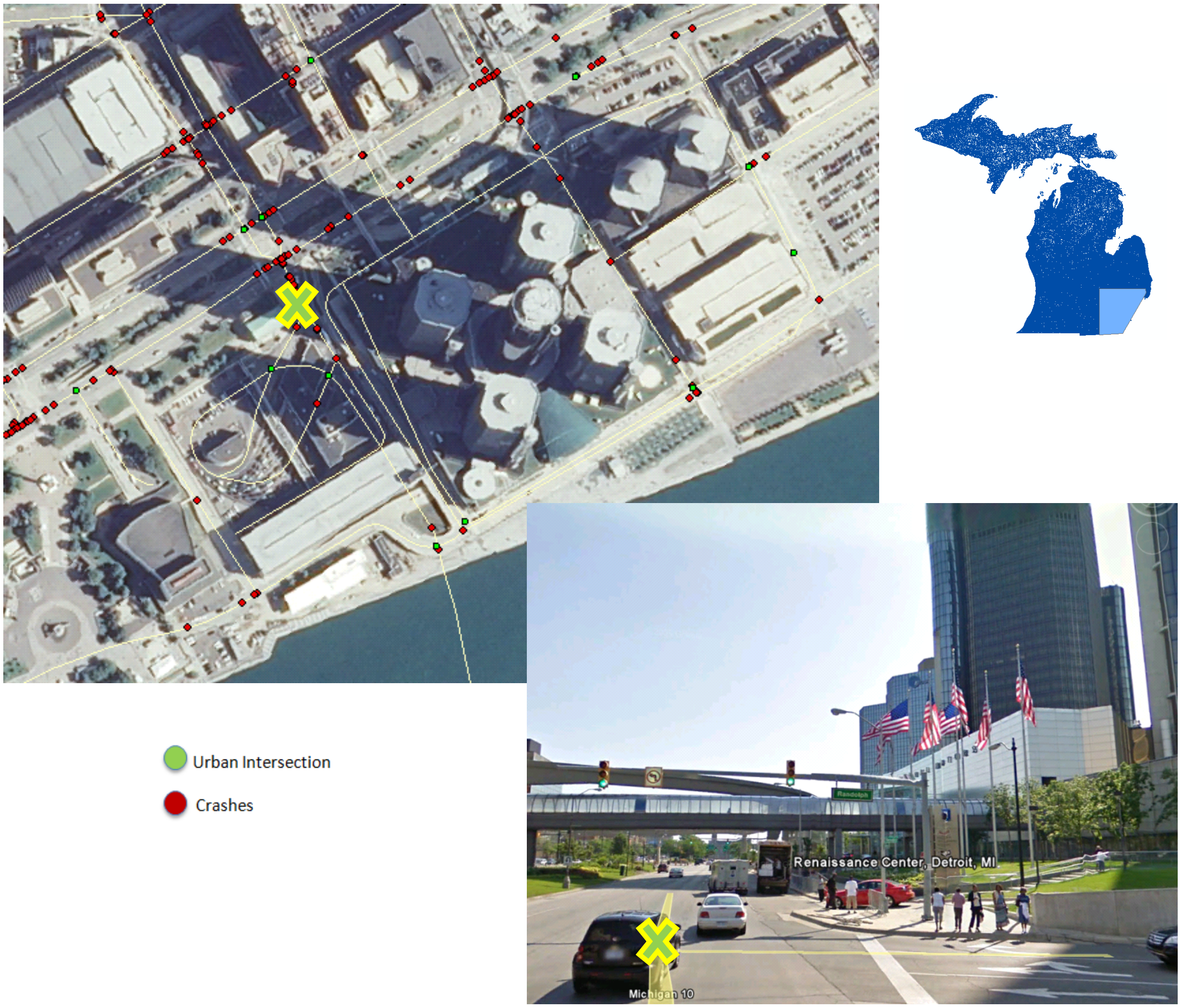


Figure 8. Aerial photo and street view of the Renaissance Center in downtown Detroit.

Figure 9 through Figure 13 depict data portraying the urban road system in SE Michigan. They include percent miles by road type, percent intersections by road type, average speed by road type, average traffic volume by road type, and percent of urban crashes with 100 feet of intersections. Note that crashes tend to occur on roads with less volume, indicating that those roads are more dangerous per mile than high-speed, high-volume roads in urban areas. Arterials, minor arterials, and local roads are most subject to this pattern (i.e., these roads have highest risk per mile).

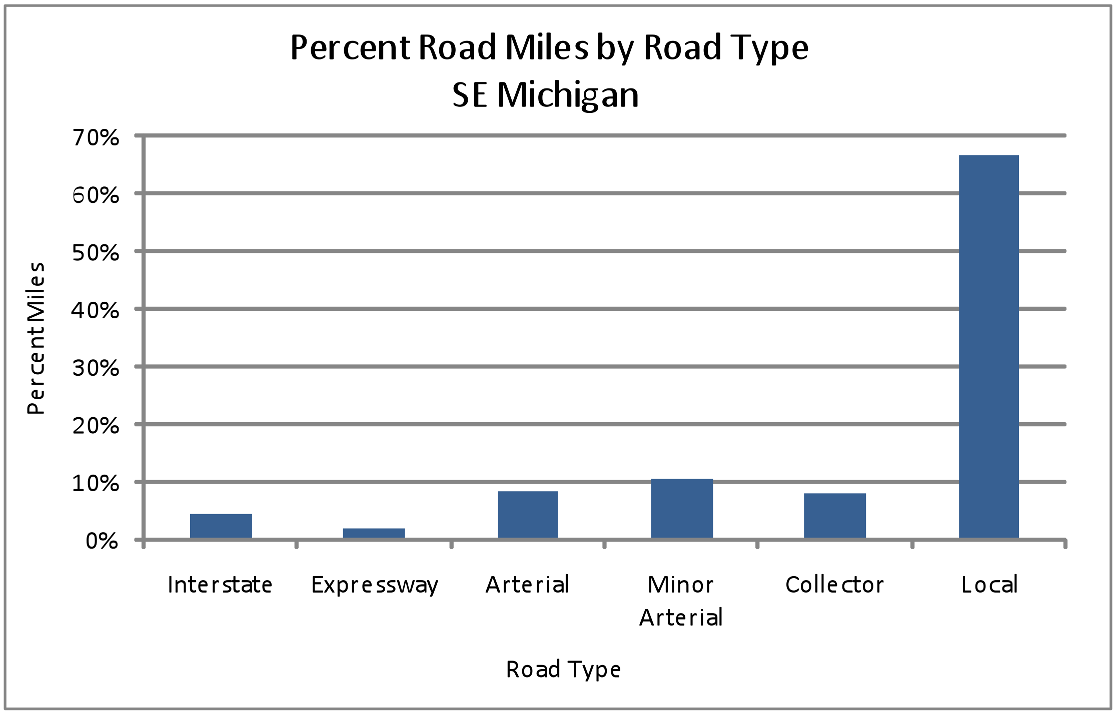


Figure 9. Percent road miles by road type in SE Michigan.

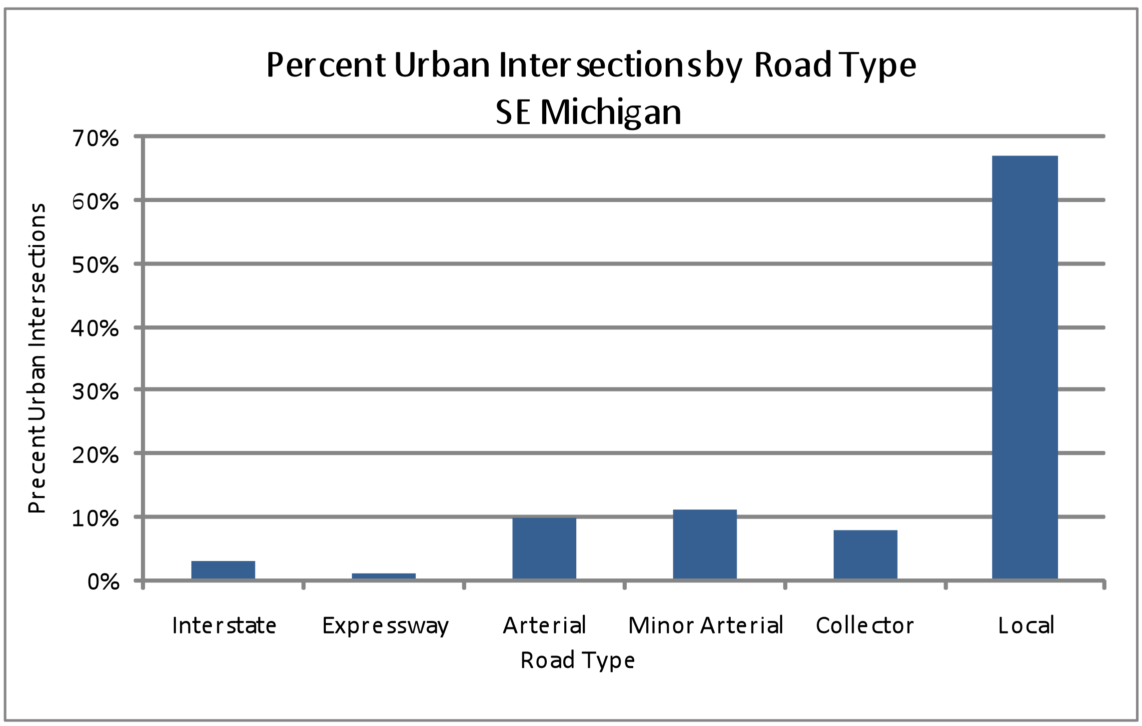


Figure 10. Percent urban intersections by road type in SE Michigan.

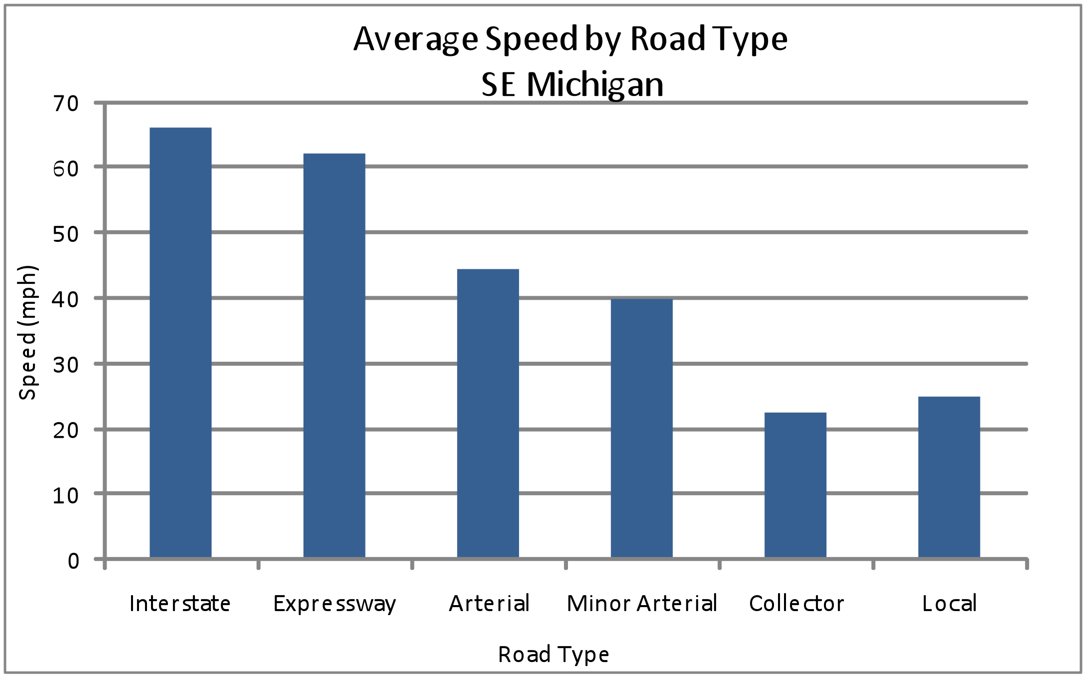


Figure 11. Average speed by road type in SE Michigan.

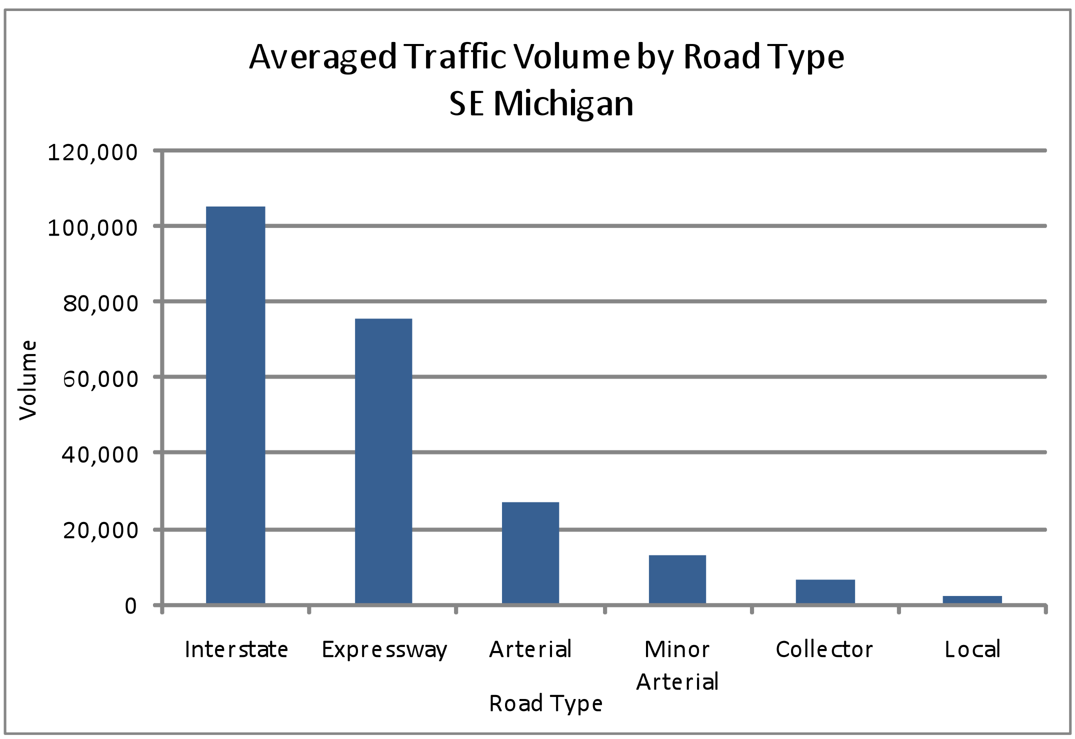


Figure 12. Average traffic volume by road type in SE Michigan.

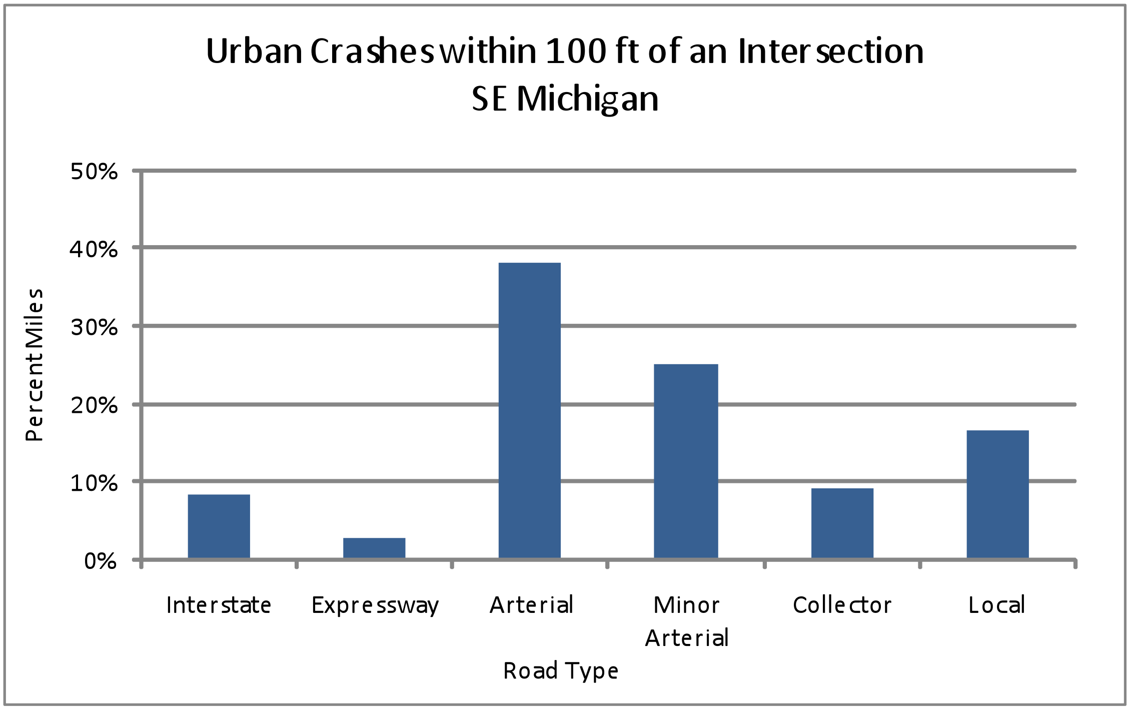
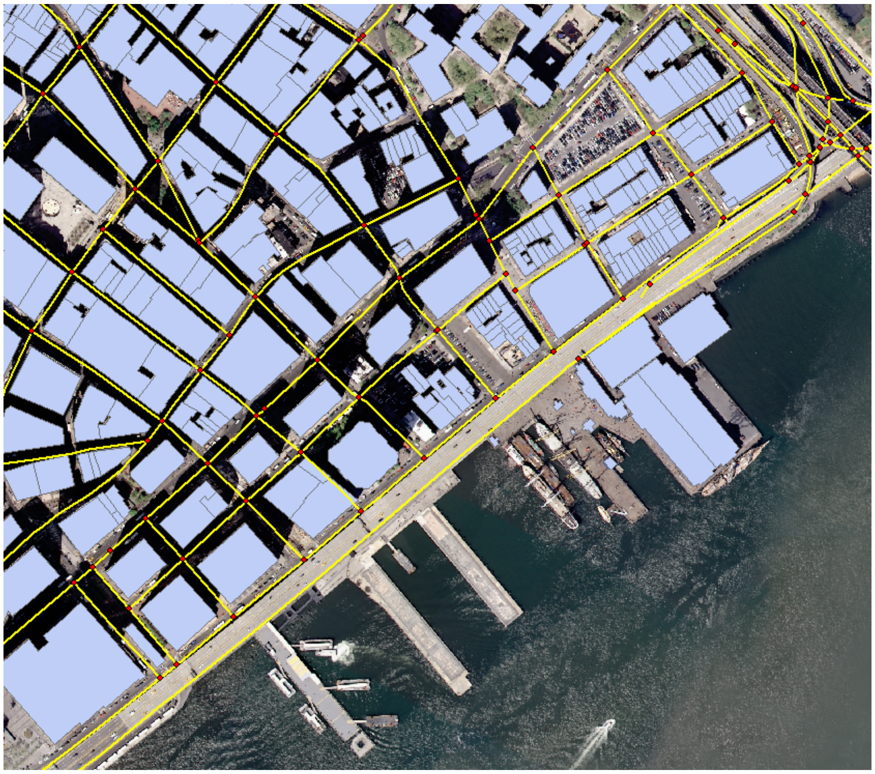


Figure 13. Urban crashes within 100 ft of an intersection in SE Michigan.

Climate Zone Wet Freeze: New York City

New York is the largest city in the US and has an extensive roadway system with approximately 6000 road miles. A subset of 3443 miles was developed for analysis using HPMS data provided by the New York department of transportation and New York City data sources. Crash data was not available because New York does not readily distribute this data. An example illustration of the available road and building data is shown in Figure 14.



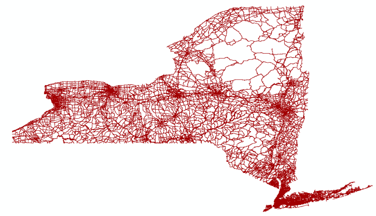


Figure 14. Example illustration of New York City road and building data.

Figure 15 through Figure 18 depict the characteristics of the New York City road system. Graphs include percent miles by road type, percent intersections by road type, average speed by road type, and average traffic volume by road type.

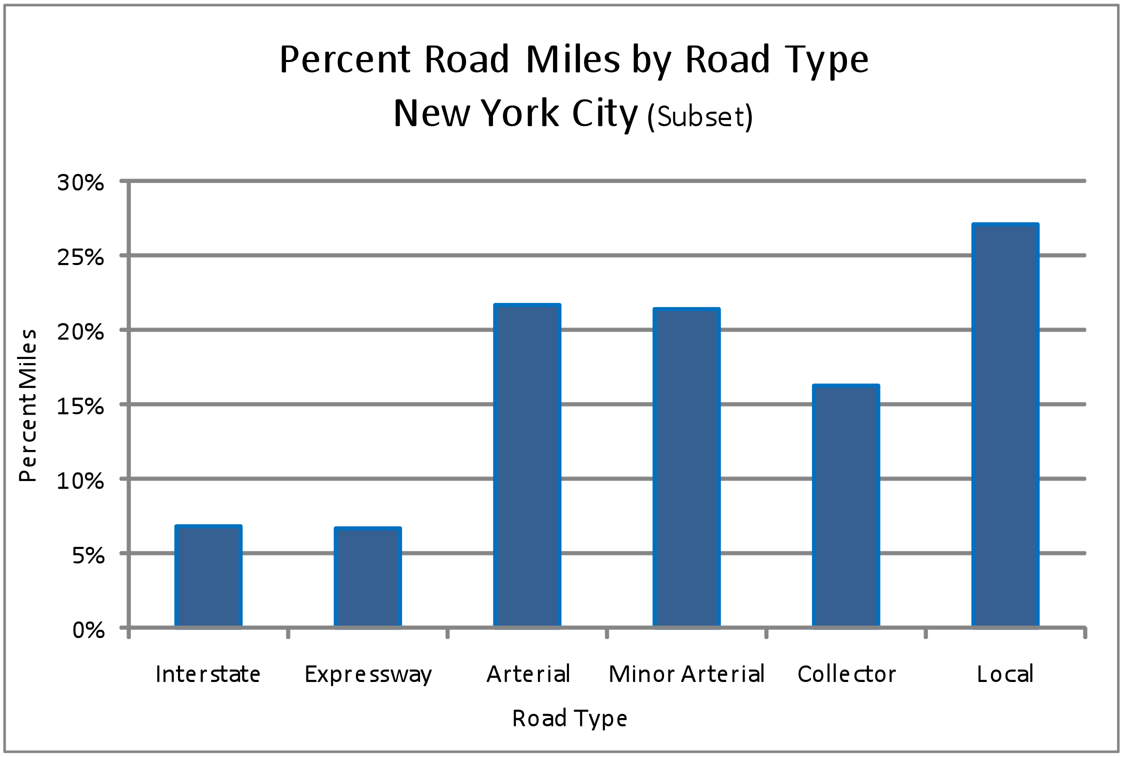


Figure 15. Percent road miles by road type in New York City.

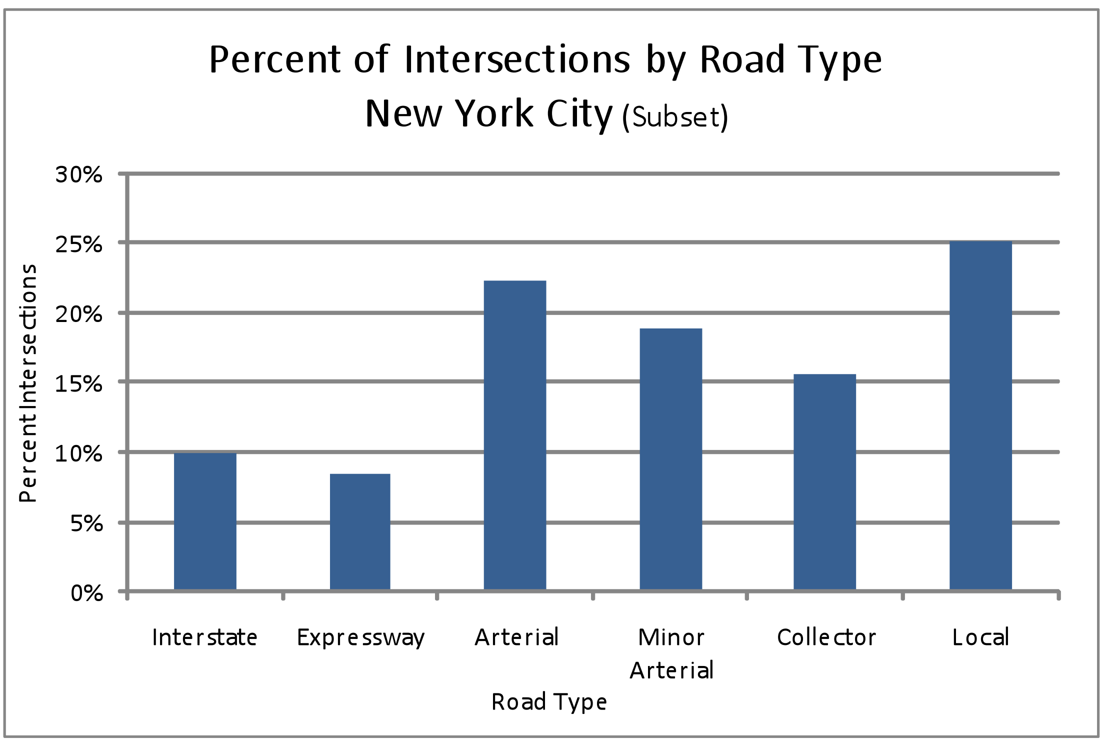


Figure 16. Percent of intersections by road type in New York City.

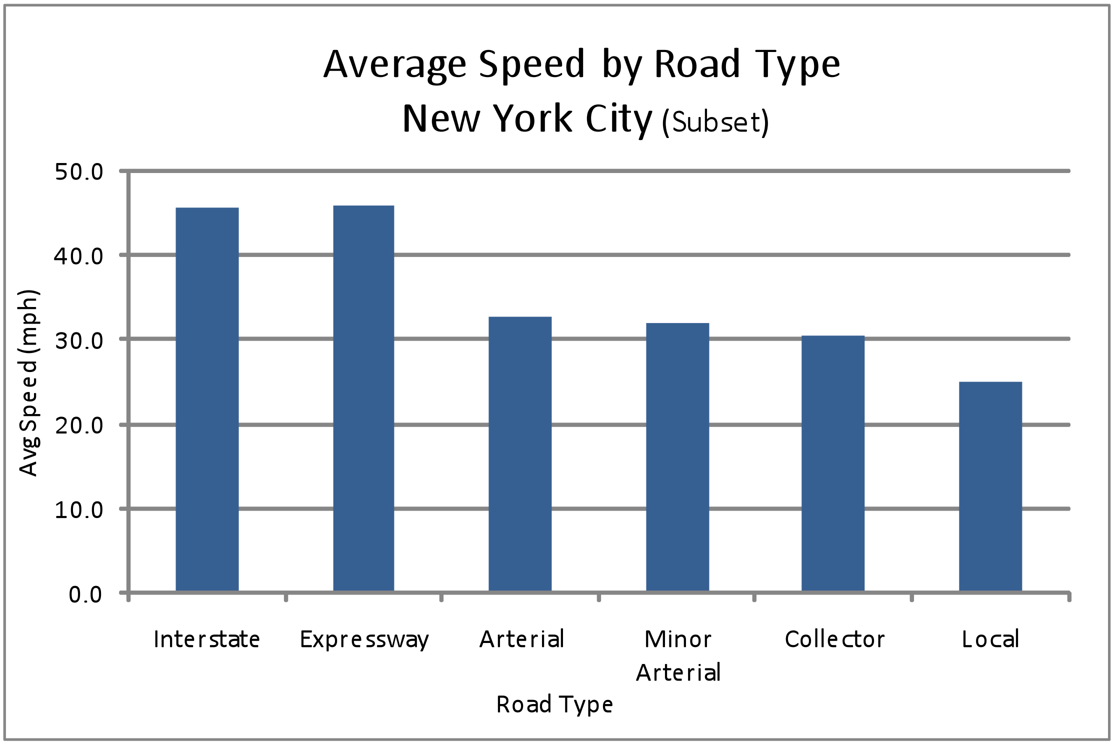


Figure 17. Average speed by road type.

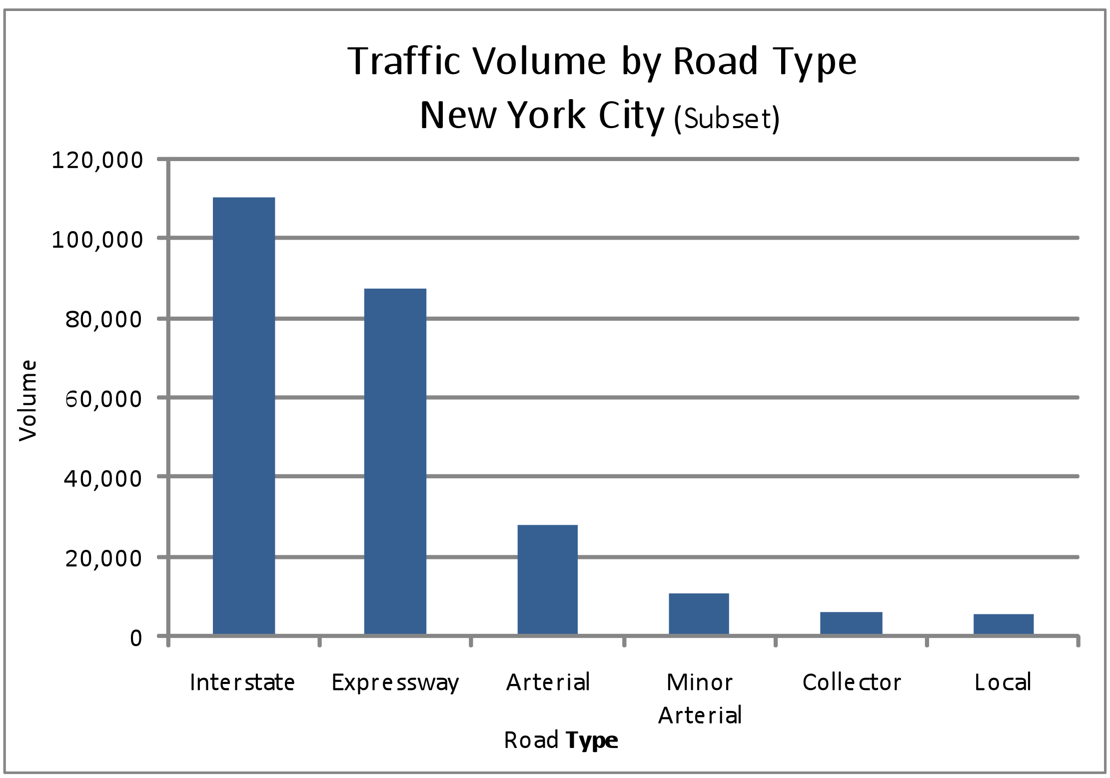


Figure 18. Traffic volume by road type.

Climate Zone Dry No Freeze: City of San Diego

The incorporated City of San Diego rests along the Pacific coast in the southwestern portion of San Diego County, California. The city has a total of 3370 miles of roadway and the entire system was used for analysis. A spatial version of HPMS data was not available. However, the city database included road type, speed, and volume attributes which were used to complete the analysis. An illustration of sample roadway data is shown in Figure 19.

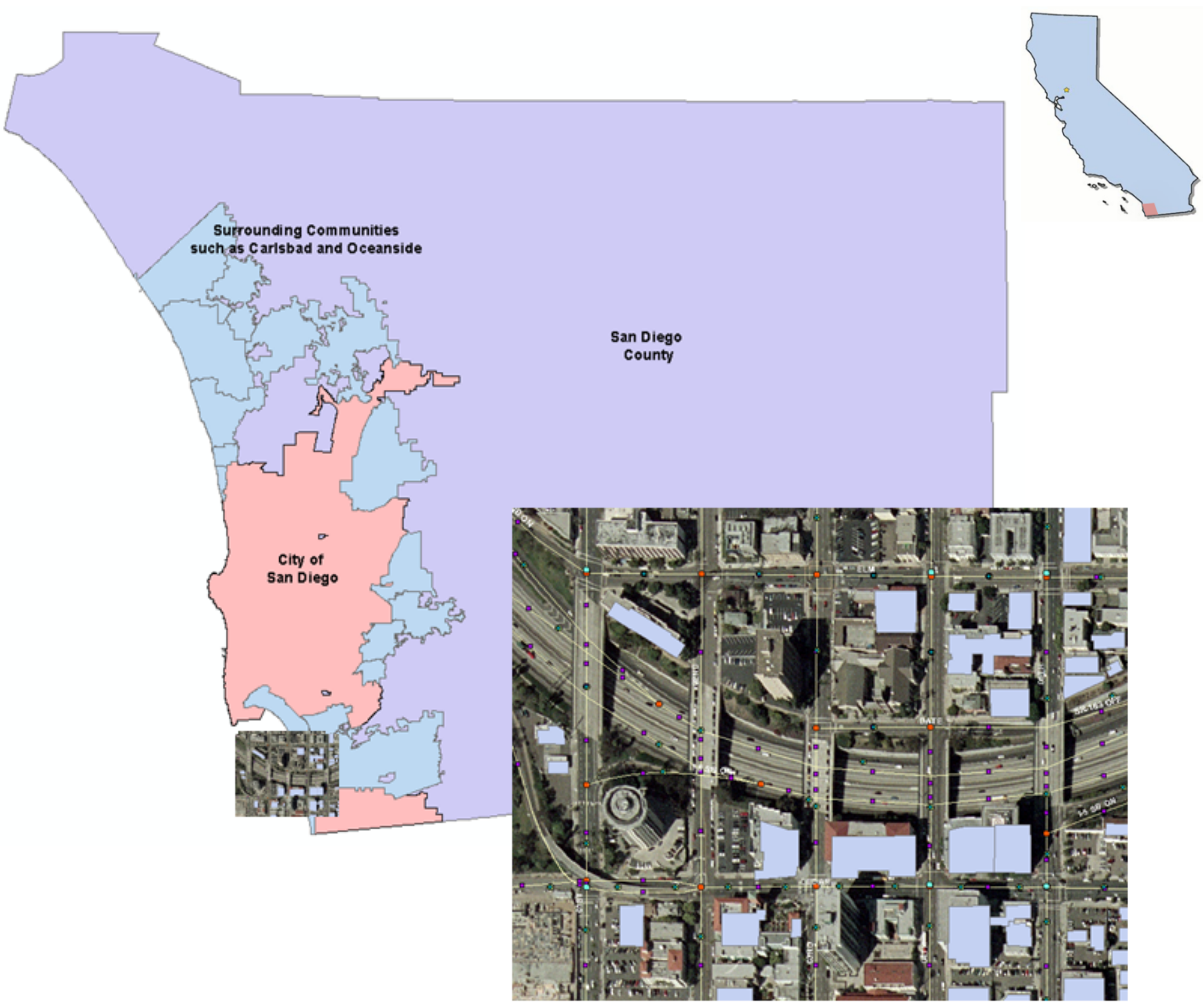


Figure 19. Illustration of roadway data from San Diego.

Figure 15 through Figure 18 depict the characteristics of the San Diego road system. Graphs include percent miles by road type, percent intersections by road type, average speed by road type, and average traffic counts by road type.

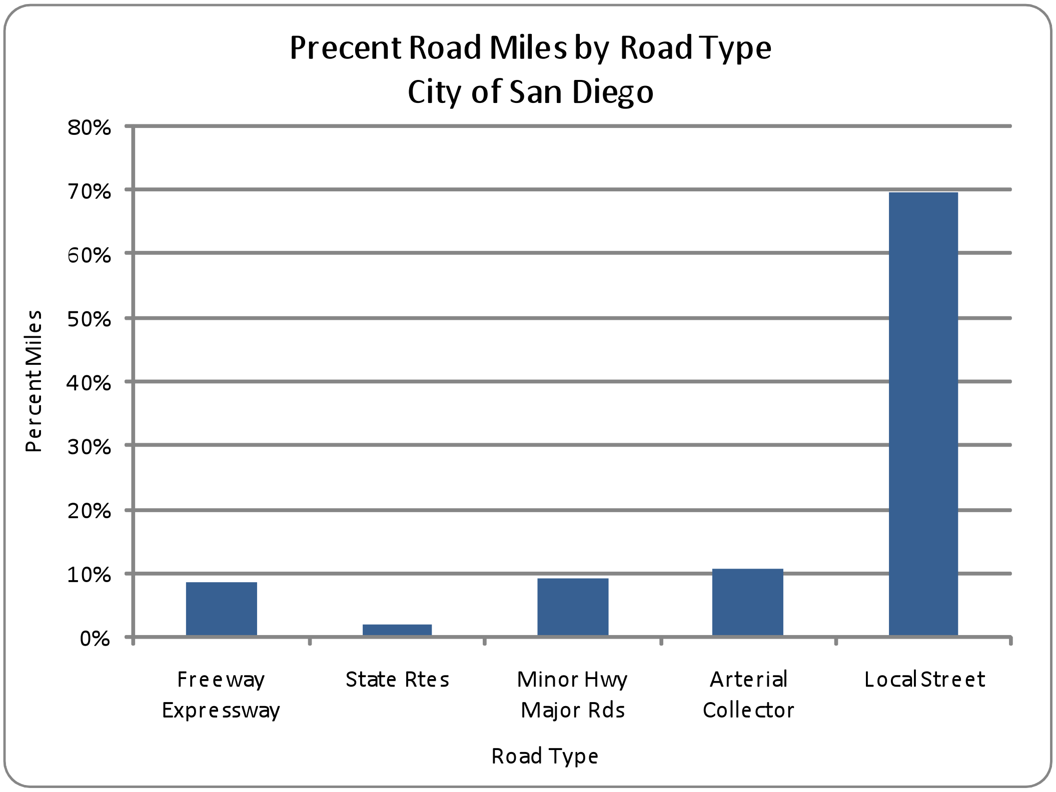


Figure 20. Percent road miles by road type in San Diego.

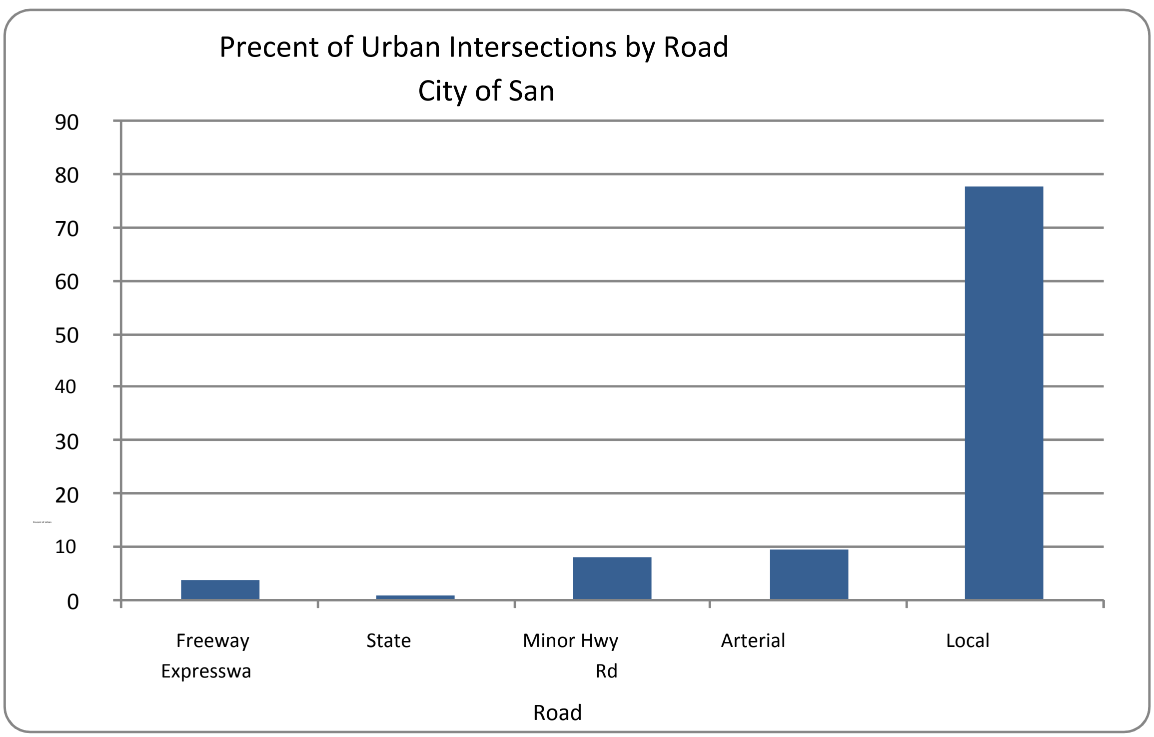


Figure 21. Percent of urban intersections by road type in San Diego.

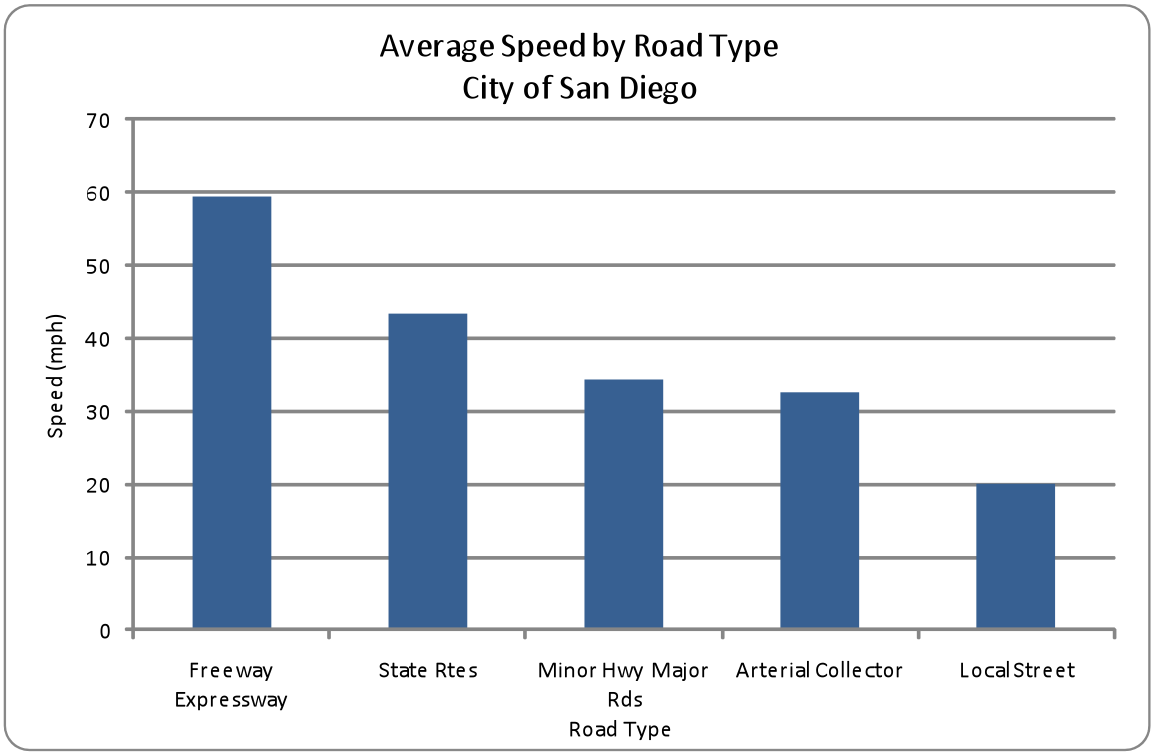


Figure 22. Average speed by road type in San Diego.

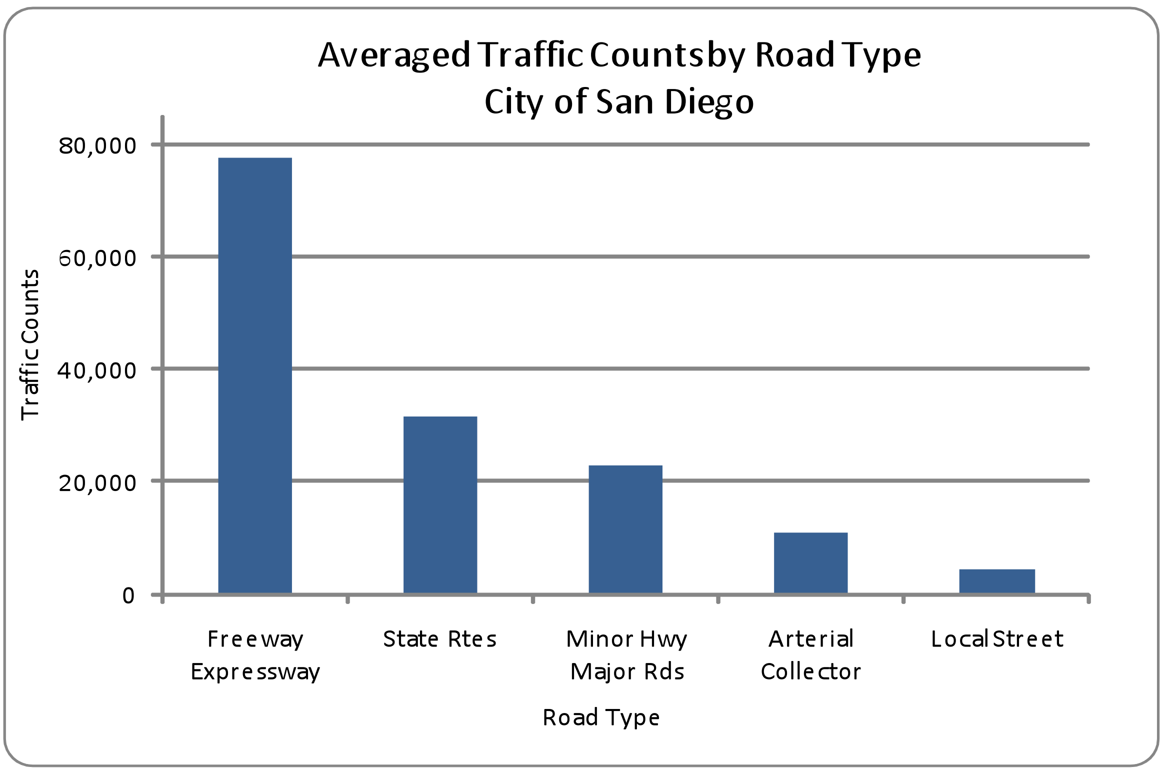


Figure 23. Average traffic counts by road type in San Diego.

Spatial Roadway Data and Urban Crashes-

While the interstate system reflects the uniform guidelines established by the American Association of State Highway and Transportation Officials (AASHTO), guidelines for urban road networks have evolved over time. Urban roads reflect the culture, economics, and various schools of planning to name just a few. Initial project efforts developed percent distributions of road miles and intersections by road type for five urban sites. These sites represent very different climates, geographic regions on both US coasts, and the Midwest. The chosen sites represent two of the four HPMS data categories associated with weather and pavement condition. A subset of the HPMS functional class descriptions were used to stratify the networks by type and account for the variance in how individual cities/regions categorize their roads by type. The results of the analysis are shown in Figure 24 and Figure 25 . These figures illustrate that urban road types are similar, with the exception of New York City, regardless of climate zone and network coverage. For example, San Diego and Chicago share similar distributions of road type and intersections with the exception of freeway/expressway access, yet Chicago has 26% more total road miles. The two road types with the largest differences among the sites are Freeway/Expressway and Arterial. The percentage distribution of local roads in each area is nearly the same with the exception of New York City.

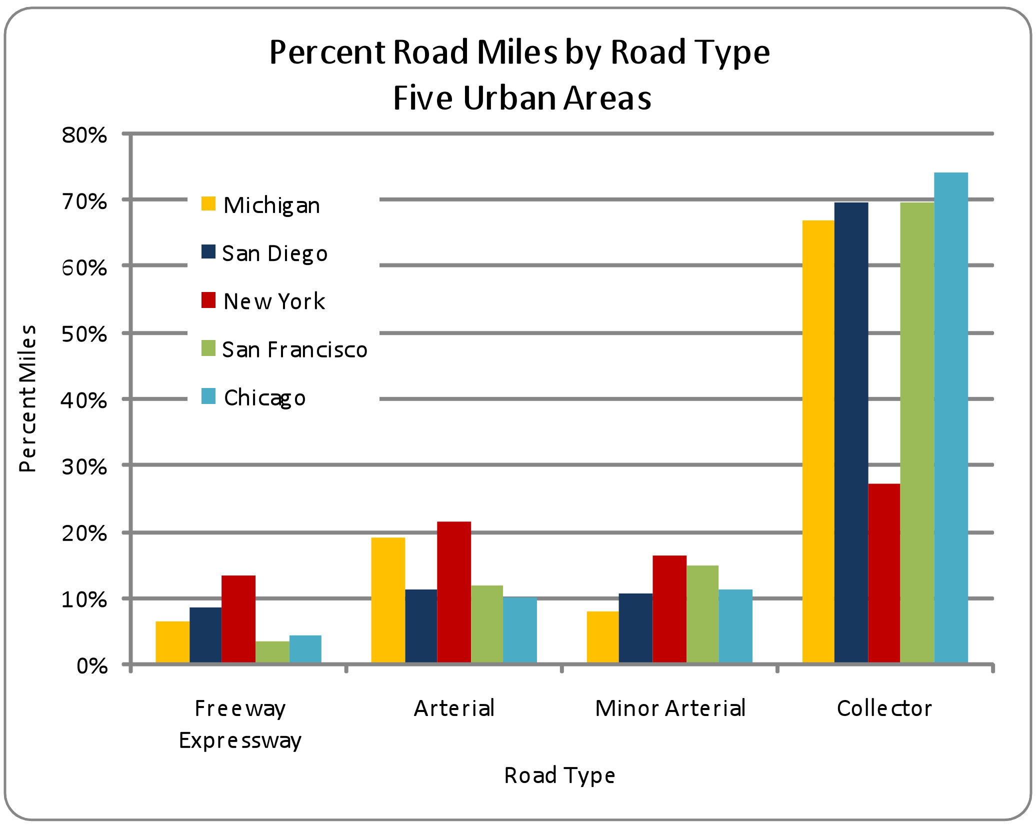


Figure 24. Percent road miles by road type in five urban areas.

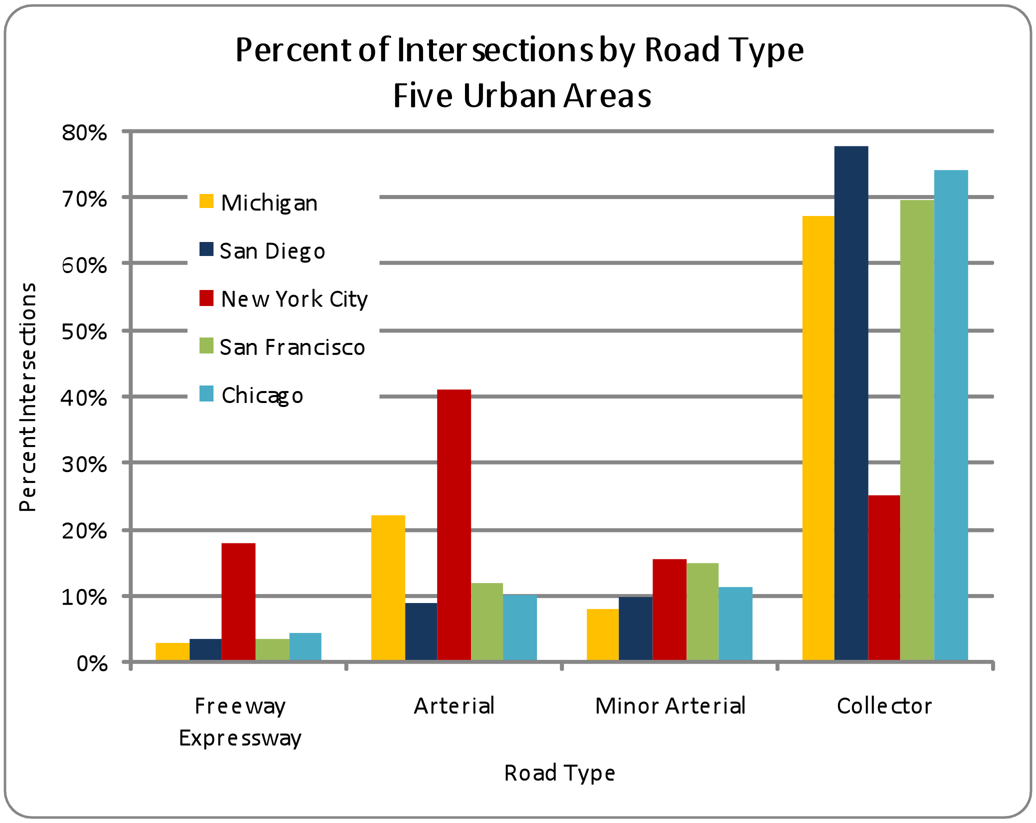


Figure 25. Percent intersections by road type in five urban areas.

To produce robust and smart on-board driver assist systems requires the identification of urban road network parameters that are representative of what drivers encounter. Crashes are an artifact of driving along any road system, urban or not. The challenge is identifying the parameters that typify the interaction between the driver and the road and contribute to crashes. What drivers encounter in the urban environment is an amalgam of the road system and the densely developed urban landscape. For example, while building footprints are not road data per se, they are fundamental to quantifying how the urban landscape may contribute to crashes caused by limited sight distance.

Summary and Conclusions

We have presented a series of analyses to characterize urban crashes and, to the extent possible, their causes. In addition, we present spatial data analyses that characterize the types of roads and other infrastructure encountered in typical urban driving. In many ways, urban and rural crashes are similar: rear-ends, road departures, and intersection crashes are common in both areas. However, urban drivers encounter a larger number (per mile) and wider variety of intersections than do rural drivers. In addition, urban crashes involve pedestrians and bicyclists far more often than rural crashes do. As a result, we chose to focus on the details of intersection crashes, non-intersection crashes, rear-ends, and pedicyclist crashes.

At intersections, drivers most often crash at traffic signals. However, uncontrolled intersections, such as driveways, alleys, and other small streets make up a disproportionately large number of crash locations. Most common crash types at intersections are rear-end into stopped vehicle, turning across path from the opposite direction, and perpendicular crashes into right or left side of another vehicle.

Rear ends into stopped vehicle most commonly occur at traffic signals and involve distracted drivers and related to speed. Turn across path crashes are more injurious than rear ends and involve primarily poor judgment—failure to yield. These are also common at traffic signals, though they occur at uncontrolled intersections 33% of the time as well. Perpendicular crashes typically involve failure to obey traffic signal and occur disproportionately at stop signs.

Crashes in urban areas occur away from intersections about half the time, though the risk is much lower per mile than at intersections. Away from intersections, many crashes are caused by drunk drivers. Typical configurations include forward into object, road departure, and rear end crashes. Distraction is also a common cause of crashes away from intersections, and speed is associated with road departure. Sideswipe crashes make up about 15% of non-intersection urban crashes, and these are generally caused by lane violations—the striking driver does not detect a vehicle in the next lane or misjudges the gap.

Pedestrians and cyclists also present a significant crash hazard to urban drivers. In these cases, the driver is unlikely to be hurt, but injury to the pedicyclist can be significant. Pedestrian events occur most often at signalized intersections and are disproportionately often in the dark. The vehicle is at fault about twice as often as the pedestrian, but dart-out is a significant problem and a major challenge for crash avoidance systems. Finally, drunk drivers and drunk pedestrians contribute to 11% of such crashes.

Cyclists are most often hit in daylight, crossing the path of the vehicle. The cyclist is at fault 33% of the time and the vehicle is at fault 41% of the time. Cyclist crashes occur about equally at signalized intersections, stop signs and away from intersections, making cyclists a hazard in urban driving under most conditions.

Although urban drivers cover the most miles on limited-access roads, the greatest crash risk is on slower-speed, lower-mileage roads such as arterials and local roads. These roads involve much greater complexity and there are more pedestrians and cyclists to avoid. Intersections, with and without signals, introduce hazards from four directions and the driver may find it difficult to manage all of the details of these situations: Is someone stopped in front of me? When is it safe to turn left? Is there a pedestrian with the right of way in my path? Is there a cyclist coming up to my right? Since pre-crash sensing systems are ever vigilant and since much of the urban driving problem involves driver error, vehicle based systems could provide a substantial reduction in urban crashes.

One of the challenges of putting together safety systems to ameliorate the urban crashing problem is that crashes are affected by multiple factors and systems can come at solutions from different directions. Put another way, the effects of different crash avoidance systems may overlap, and since each crash can only be prevented once, some sets of systems may be redundant.

While we cannot comment on the relative effectiveness and cost of different safety systems, we can identify the percent of crashes that can potentially be affected by different systems. For example, one package of safety systems might include an intersection crash-prevention system (i.e., one that "knows" the light cycle, can judge gaps for left turn and can detect vehicles that might run a red light) and road departure prevention (e.g., electronic stability control or road-departure warning). This pair could prevent up to 69% of urban crashes. A different approach might be to combine forward-collision prevention, road departure prevention, and lane-change warning. These systems could prevent up to 53% of urban crashes. A pedestrian detection system would be independent of any of the other systems and could prevent up to 2% of crashes. Though this is a small percentage of the whole problem, they tend to be very serious for the pedestrian.

The urban driver is at highest risk at intersections and on urban arterials. These higher-speed roads are generally not limited access, but the speeds and traffic volumes can create a challenging environment for the driver. Because situations develop much faster at high speeds, distraction, even for a short time, can have greater consequences on these roads. Systems that help the driver stay aware of potential hazards could reduce urban crashes, even if no action were taken by the vehicle. If the system can also control the vehicle to some degree, more crashes could be prevented or at least mitigated. Reducing crash speed by even 5-10 mph can have a dramatic effect on outcome.

Overall, the urban environment presents a challenge to the driver. Traffic volumes are high, and the amount of information to be processed is very high. Even an attentive driver must decide what to pay attention to and what to ignore. Drivers at intersections have to make decisions about when to move that may result in crashes. Vehicle systems have the potential to help the urban driver manage the large amount of information and to maintain constant vigilance, both especially critical tasks in the urban driving setting.

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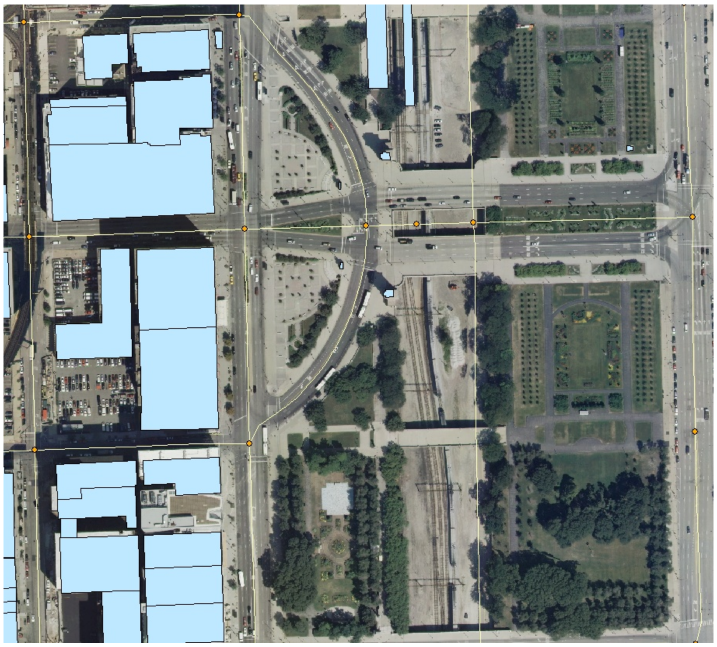
Appendix A

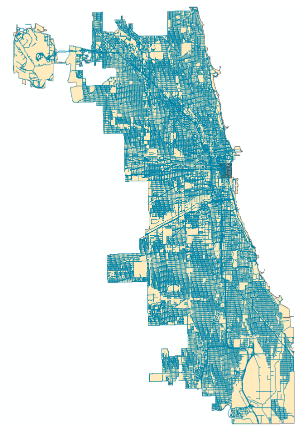
Crash Type	Percent of All Crashes	Cited for Violation	Driver Drunk	Speed-Related	Failed to Obey Traffic Control	Fail to Yield	Reckless	Traffic Light	Stop Sign	No Control	Driver Distracted
Rear end into stopped	17.91%	58.9%	6.5%	5.58%	0.00%	0.09%	13.41%	70.1%	7.1%	17.4%	22.6%
Turn across path (initial opposite)	13.93%	57.3%	5.5%	0.84%	0.78%	9.90%	28.14%	60.1%	3.6%	33.6%	11.8%
T-bone into right side	9.68%	61.4%	6.6%	0.69%	7.59%	6.69%	28.38%	41.3%	44.4%	7.0%	19.0%
T-bone into left side	9.32%	62.2%	6.8%	0.98%	5.68%	6.82%	31.69%	39.6%	46.7%	7.4%	16.2%
Turn into path in opposite dir (left side	8.34%	60.9%	3.5%	1.25%	3.00%	10.27%	30.97%	18.5%	40.6%	36.8%	13.4%
Forward into object	7.97%	34.2%	11.2%	5.74%	0.37%	1.47%	8.03%	38.5%	20.2%	36.5%	42.5%
Rear end into decelerating	5.51%	52.7%	4.0%	3.41%	0.00%	0.00%	7.48%	41.4%	4.7%	48.2%	18.8%
Turn into path, same dir (right side hit)	3.70%	61.6%	4.4%	1.09%	0.10%	1.84%	4.01%	51.5%	8.5%	33.9%	21.6%
Backing into vehicle	3.52%	51.9%	4.9%	0.75%	1.69%	8.65%	28.38%	24.3%	29.1%	42.8%	18.1%
Turn into path, same dir (left side hit)	3.50%	57.6%	8.1%	0.29%	0.00%	0.99%	4.00%	28.1%	13.8%	51.9%	15.7%
Turn across path initial same (from righ	2.80%	50.3%	6.2%	0.81%	2.62%	7.62%	24.23%	21.9%	34.7%	37.1%	18.5%
Road depart right	2.71%	49.6%	7.0%	1.42%	1.37%	2.44%	5.38%	29.8%	1.0%	61.8%	19.4%
Rear end into slower	2.39%	52.0%	18.4%	35.47%	0.26%	0.85%	16.48%	26.7%	12.9%	54.3%	43.9%
Turn across path initial same (from left	2.37%	43.8%	6.4%	3.91%	0.00%	0.01%	7.50%	53.7%	5.7%	35.4%	24.1%
Road depart left	1.83%	53.6%	3.3%	2.23%	0.00%	4.46%	4.84%	42.5%	2.0%	53.1%	12.9%
Sideswipe same dir	1.21%	35.5%	6.7%	3.64%	0.00%	0.00%	4.50%	56.3%	15.9%	20.3%	40.8%
Sideswipe cut-in from right	1.10%	43.0%	18.4%	44.01%	0.00%	0.05%	17.85%	19.1%	13.4%	59.4%	22.3%
Sideswipe cut-in from left	0.87%	43.9%	7.1%	2.98%	0.00%	0.00%	1.40%	61.2%	2.3%	31.3%	17.5%
Turn into opposite dir (head on)	0.83%	62.3%	5.2%	0.38%	0.00%	2.86%	4.08%	44.3%	1.2%	44.5%	27.2%
Sideswipe opposite dir	0.31%	64.8%	5.1%	4.31%	0.10%	2.47%	4.58%	50.7%	3.6%	39.7%	19.6%
Head on	0.20%	27.9%	4.9%	0.03%	0.00%	0.03%	3.57%	51.4%	0.7%	38.8%	12.9%
Rear end after avoidance	0.01%	100.0%	2.0%	4.75%	2.90%	6.68%	23.83%	30.8%	48.6%	12.9%	13.3%
All Crashes	100.00%	100.00%	6.7%	3.88%	1.76%	4.37%	18.30%	45.1%	19.1%	30.4%	20.9%

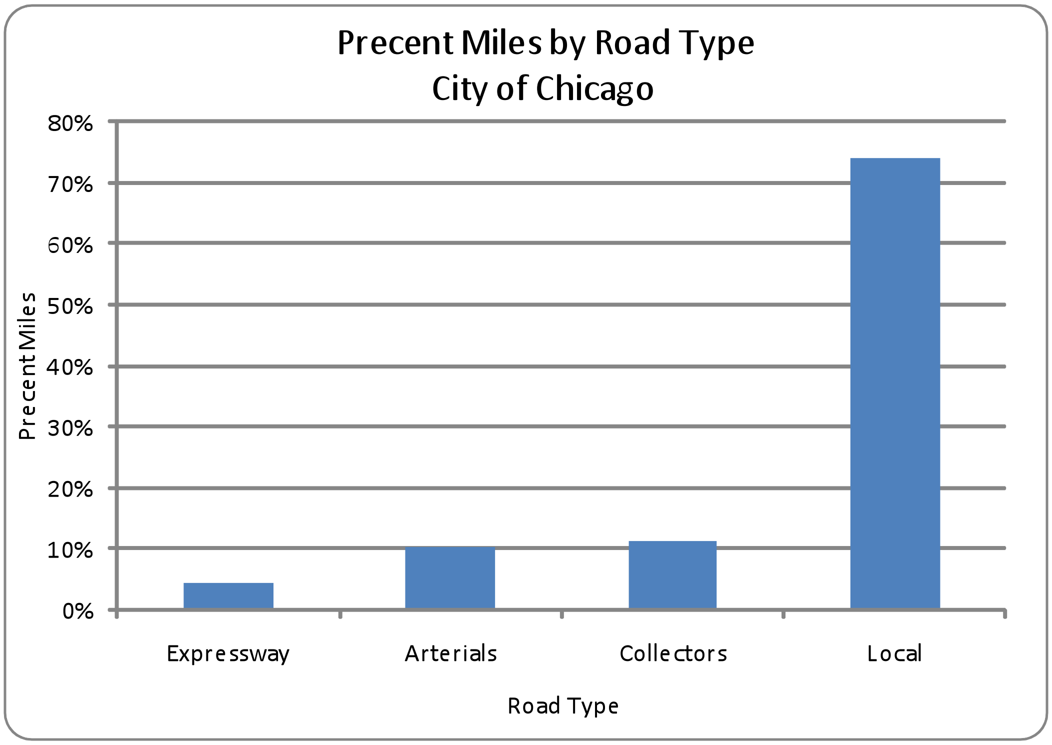
Appendix B

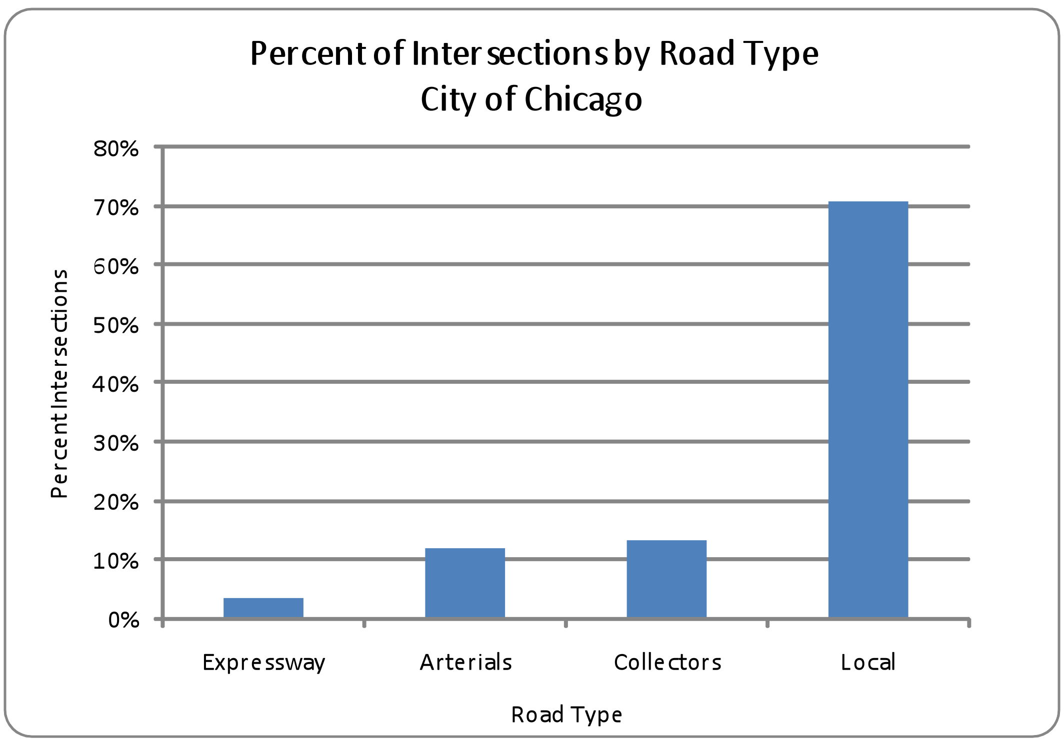
Chicago, Illinois

The Chicago road network is some 4500 miles. For the study, a subset of 4161 miles were used to develop the percent distribution of roads and intersections by type.



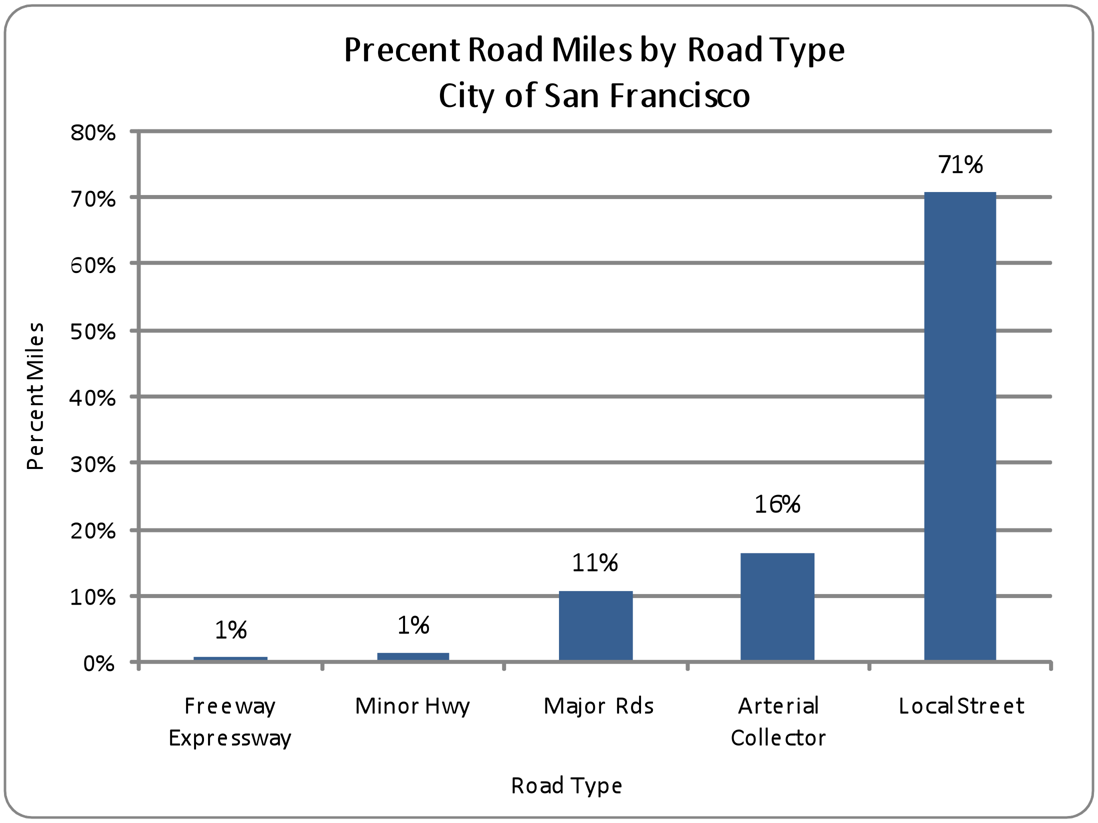


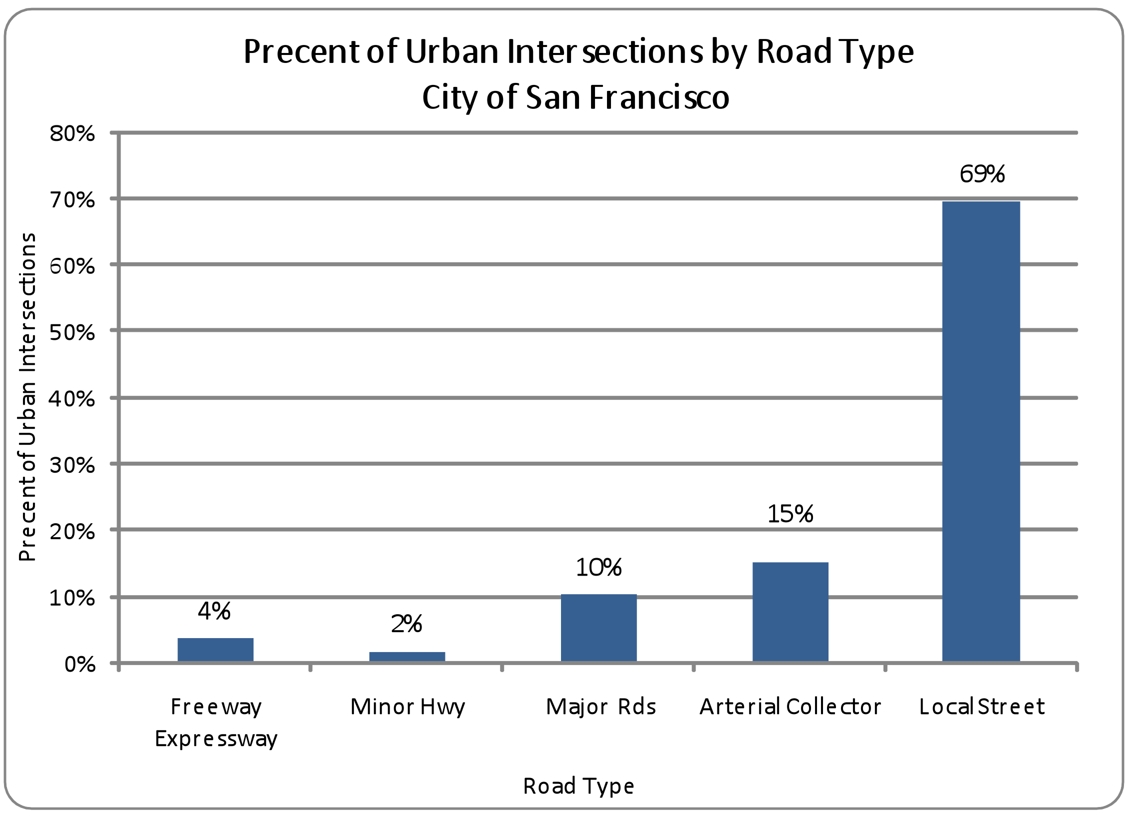

Precent Miles by Road Type
City of Chicago
80%
70%
60%
50%
40%
30%
20%
10%
0%
Precent Miles
Expressway
Arterials
Collectors
Local
Road Type


Percent of Intersections by Road Type
City of Chicago
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Intersections
Expressway
Arterials
Collectors
Local
Road Type

San Francisco, California

The city of San Francisco road network is some 850 miles. However, the current study used a subset of road data representing the greater San Francisco area of some 1170 miles to generate percent distribution of roads and intersections by type provided below.


Precent Road Miles by Road Type
City of San Francisco
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Miles
1%
1%
11%
16%
71%
Freeway Expressway
Minor Hwy
Major Rds
Arterial Collector
Local Street
Road Type


Precent of Urban Intersections by Road Type
City of San Francisco
80%
70%
60%
50%
40%
30%
20%
10%
0%
Precent of Urban Intersections
4%
2%
10%
15%
69%
Freeway Expressway
Minor Hwy
Major Rds
Arterial Collector
Local Street
Road Type

Houston, Texas

The city of Houston's total road network is approximately 6000 centerline miles. The project has requested additional road attribute data.