INVESTIGATION OF WEATHER CONDITIONS AND THEIR RELATIONSHIP TO CRASHES

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16. Abstract

The objectives of the research were to conduct a seasonal investigation of when winter weather conditions are a factor in crashes reported in Nebraska, to perform statistical analyses on Nebraska crash and meteorological data and identify weather conditions causing the significant safety concerns, and to investigate whether knowing the snowfall amount and/or storm intensity/severity could be a precursor to the number and severity of crashes.

Nebraska Department of Transportation (NDOT) crash data were combined with meteorological data on winter weather season basis, reported road surface condition at crash time, and reported weather conditions at crash time. Overall, the key finding of the analysis was most winter-weather related vehicular crashes in Nebraska were associated with relatively minimal winter weather conditions. The reported crashes typically occurred either with relatively low snowfall amounts or as a result of residual snowfall on the ground highlighting the need for winter maintenance operations activities and public service announcements to continue well after a storm has exited the region. Another key finding was that most crashes were of lower severity (i.e., relatively minor injuries) and fatal crashes were rare. An important caveat of this result is that traffic volumes are typically lower during winter storms and must be taken into account. This makes the actual risk of a crash larger than the findings of this analysis alone would suggest.

Modeling of crash injury severity showed higher injury severity associated with icy pavements; higher visibility associated with greater likelihood of crashes involving visible injuries but lower likelihood of disabling injury/fatality crashes. Snowfall was associated with greater visible injury crashes while greater snow depth was associated with fewer visible injury and disabling injury/fatality crashes. The analysis also showed that the type of weather system had implications for the frequency of vehicular crashes. These global weather patterns can be forecast months in advance and allow for long-range strategic planning for transportation agencies regarding potential expected impacts. Limitations of the research include spatial and temporal aggregation of weather data, non-availability of winter maintenance activity data (e.g., plowing, material application), and detailed traffic counts during winter weather events.

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NOTE: This report uses the term 'crash' to refer to vehicular collisions resulting in property damage and/or injuries and fatalities. However, the term 'accident' is also used when referring to legacy items or when referencing or quoting published literature.

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Abstract

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had implications for the frequency of vehicular crashes. These global weather patterns can be forecast months in advance and allow for long-range strategic planning for transportation agencies regarding potential expected impacts. Limitations of the research include spatial and temporal aggregation of weather data, non-availability of winter maintenance activity data (e.g., plowing, material application), and detailed traffic counts during winter weather events.

Chapter 1 Introduction

1.1 Background

Road traffic crashes are a major concern for all transportation agencies as they continue to take a toll on human lives, injuries, property damage and impose a significant negative impact on the national economy. The World Health Organization (WHO 2015) in recent years has strived to recognize the global issue of highway safety owing to approximately 1.25 million fatalities each year worldwide. These crashes cause a huge impact on the development of health sectors as they not only hinder growth in public-health sectors but also impede economic productivity; almost 3 percent of gross domestic product (GDP) is lost annually by countries worldwide. In addition, insurance services and legal systems are also affected owing to the economic costs associated with injuries and fatalities. The US Centers for Disease Control and Prevention (CDC) has highlighted that traffic crashes from 1999 to 2012 in the US were one of the leading causes of fatalities among all age groups (CDC 2012). Moreover, in 2005 the medical costs incurred due to fatal and non-fatal road crashes exceeded $99 billion (Naumann et al., 2010). Given these costs associated with traffic crashes, the CDC have emphasized the need to reduce traffic crashes and singled out injuries caused due to crashes a high priority “winnable battle” (CDC, 2014).

Among various factors affecting highway safety, adverse weather is known to be a major element. Changes in the weather conditions were a key factor when the relationship between traffic volume and road traffic injuries was analyzed for Southern California (Golob & Recker 2003). The United States Department of Transportation defines “weather-related” crashes as those that occur in adverse weather conditions such as, rain, snow, sleet, cloudy, severe crosswinds, fog, or some combination of these conditions. In addition, slick road conditions such as, snowy, wet, slushy, or icy also account for an increased crash likelihood (USDOT 2014). Figure 1.1 and 1.2 present weather-related crash statistics from the Federal Highway Administration (FHWA).

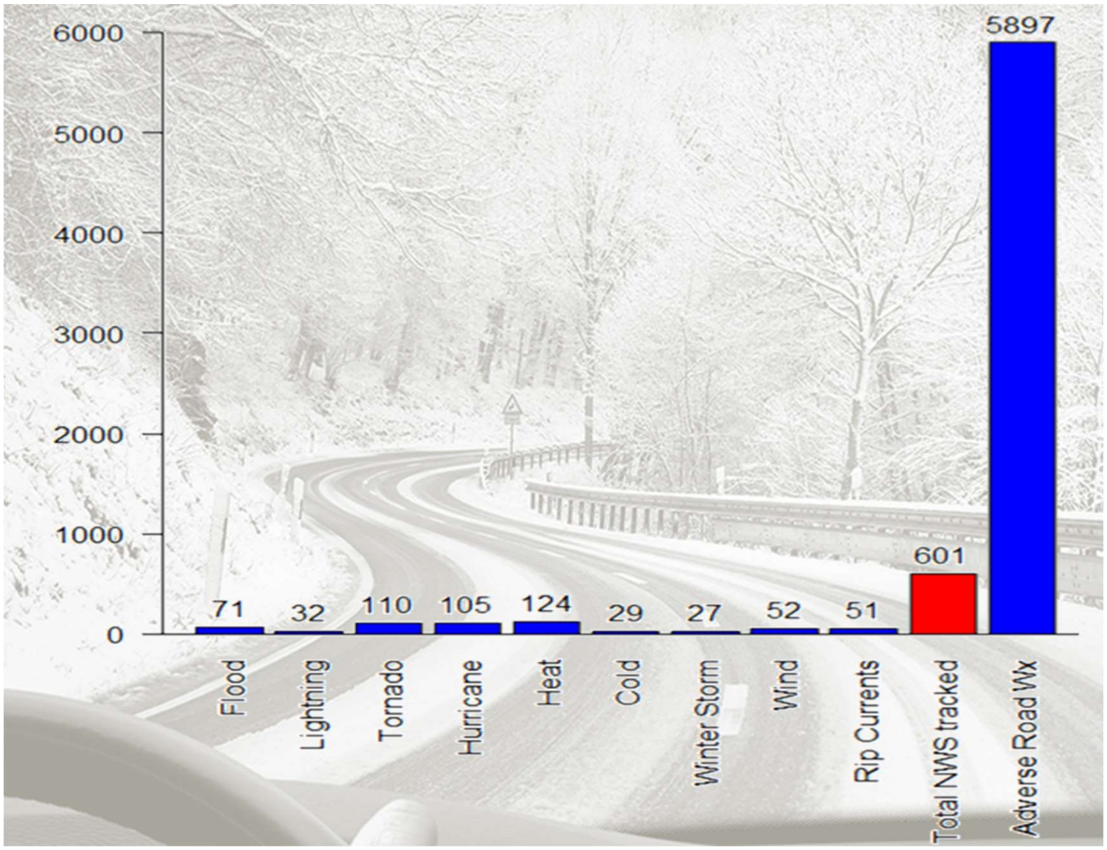


Figure 1.1 National impacts of adverse weather on roads compared to weather conditions (Source: FHWA)

Road Weather Conditions	Weather-Related Crash Statistics		
	10 Year Average (2007 - 2016)	10-year Percentages	
Wet Pavement	860,286 crashes	15% of vehicle crashes	70% of weather-related crashes
	324,394 persons injured	15% of crash injuries	78% of weather-related injuries
	4,050 persons killed	12% of crash fatalities	76% of weather-related fatalities
Rain	556,151 crashes	10% of vehicle crashes	46% of weather-related crashes
	212,647 persons injured	10% of crash injuries	51% of weather-related injuries
	2,473 persons killed	8% of crash fatalities	46% of weather-related fatalities
Snow/Sleet	219,942 crashes	4% of vehicle crashes	18% of weather-related crashes
	54,839 persons injured	3% of crash injuries	14% of weather-related injuries
	688 persons killed	2% of crash fatalities	13% of weather-related fatalities
Icy Pavement	156,164 crashes	3% of vehicle crashes	13% of weather-related crashes
	41,860 persons injured	2% of crash injuries	11% of weather-related injuries
	521 persons killed	2% of crash fatalities	10% of weather-related fatalities
Snow/Slushy Pavement	186,076 crashes	4% of vehicle crashes	16% of weather-related crashes
	42,036 persons injured	2% of crash injuries	11% of weather-related injuries
	496 persons killed	2% of crash fatalities	10% of weather-related fatalities
Fog	25,451 crashes	1% of vehicle crashes	3% of weather-related crashes
	8,902 persons injured	1% of crash injuries	3% of weather-related injuries
	464 persons killed	2% of crash fatalities	9% of weather-related fatalities

Figure 1.2 Weather related crashes statistics-FHWA (2007-16)

The national estimates on fatalities attributed to adverse weather show that approximately 24 percent of all highway crashes in the US from 1995 to 2005 were weather related, resulting in an annual average of 7,400 fatalities and 673,000 injuries (Pisano et al. 2008). It is also reported that annually in the US, 18 percent of fatal and 22 percent of injury crashes are associated with poor pavement conditions caused by adverse weather (Pisano et al. 2003).

1.2 Research Objectives

The main objective of this research was to correlate motor vehicle crash data to weather conditions associated with the time of the crash; the associated objectives were as follows.

1. To conduct a seasonal investigation of when winter weather conditions are a factor in crashes reported in Nebraska.

2. To perform statistical analyses on Nebraska crash and meteorological data and identify weather conditions causing the significant safety concerns, and potential implications for maintenance activities.
3. To investigate whether knowing the snowfall amount and/or storm intensity/severity could be a precursor to the number and severity of crashes.

1.3 Report Outline

This research was conducted in six steps.

1. A detailed literature review of crashes and their association with adverse weather conditions.
2. Collection of Nebraska crash data from 2008 to 2018.
3. Collection of meteorological observations from 2008 to 2018.
4. Statistical analyses of the traffic crash data.
5. Statistical analyses of the meteorological data.
6. Examination of the safety and meteorological information.

Figure 1.3 presents the framework adopted in this research.

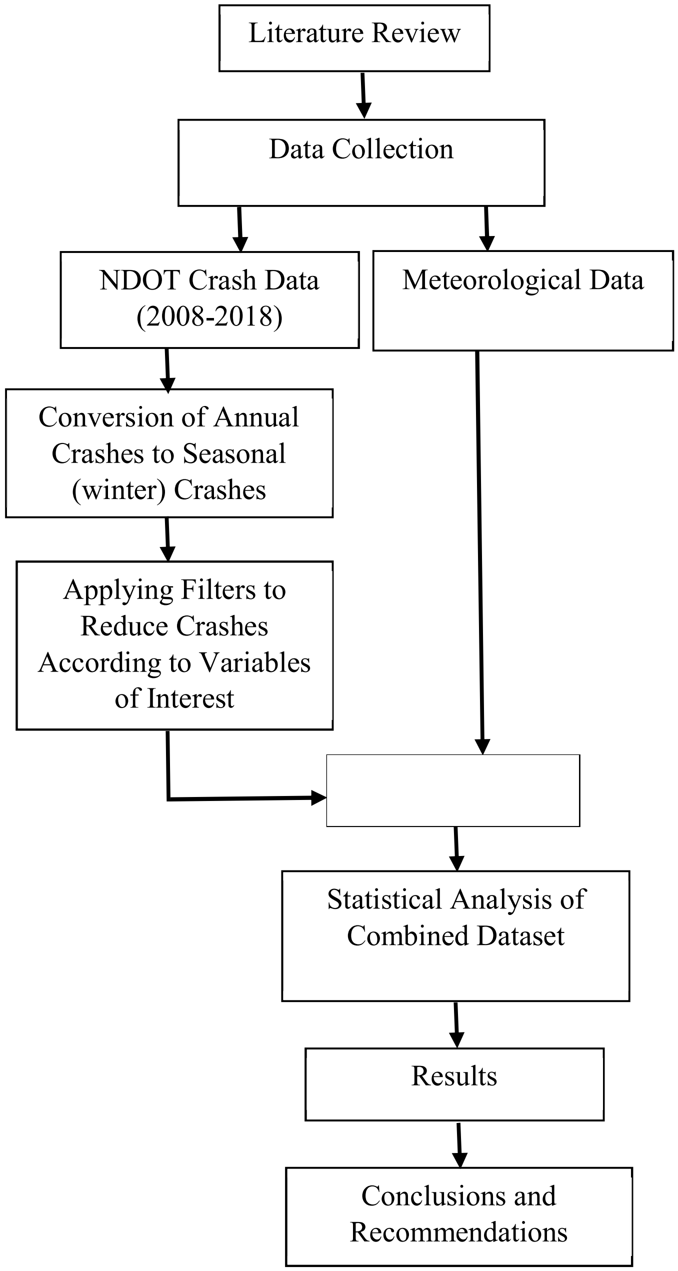


Figure 1.3 Research framework

Chapter 2 Literature Review

2.1 An Overview of Traffic Crashes

Highway safety continues to be a concern for all transportation agencies. The estimated economic cost attributed to the reported motor vehicle crashes exceeds $242 billion annually (NHTSA 2015) giving ample justification for investigating and reducing the occurrence and severity of highway crashes. In 2017 over 1.8 million motor vehicle crash injuries and about 34,000 fatalities were reported in the US (NHTSA 2019). Moreover, the major cause of death among individuals aged 24 years and under was also attributed to the highway crashes (NHTSA 2018). In addition, according to the World Health Organization (WHO), over the next 20 years, there will be an increase in fatalities and non-fatal injuries by approximately 65 percent if necessary remedial measures are not taken to improve the current state of road safety across the World (WHO 2015). With the objective to reduce traffic crashes, the traffic safety literature contains studies that focus on factors causing crashes as well as their impacts on the society and economy. Such factors may pertain to the physical transportation network including weather related features and/or user behavior. Physical factors may include infrastructure vulnerabilities as well as defects in vehicles while behavioral factors entail different attitudes and practices of driving such as driving under the influence of alcohol/drugs, reckless or aggressive driving, violating travel related laws, and fatigued driving, among others (Horberry et al. 2006; Eman et al. 2014; Taylor et al. 2013; Farooq & Ahmad 2017). Several researchers have also reported on crash costs and impacts on the economy (Blincoe 2015; Blincoe et al. 2000; Ansariet et al. 2000).

2.2 Traffic Crashes and Adverse Weather Conditions

Adverse weather contributes to traffic crashes in many ways such as from reduced visibility, loss of friction between vehicle tires and roadway surface, loss of stability due to high winds/gusts, etc. (Golob & Recker 2003). Ashley et al. (2015) showed that the number of fatalities due to weather related vehicular crashes exceeded the number of fatalities caused by eminent natural hazards such as floods, tropical cyclones, lightening and tornadoes. Furthermore, inclement weather conditions made up about 24 percent of traffic incidents across the U.S. (Pisano et al. 2008).

Among weather conditions that impact crashes, there are more studies in the literature that discuss crash relationship to snowfall, rainfall, and ice pellets compared to studies done on crash relationships to other weather conditions (Jaroszweski & McNamara 2014; Yu & Abdel-Aty 2014; Brijs et al. 2008; Khattak & Knapp 2001). The influence of temperature and rainfall on the aggregate numbers of injury crashes and casualties was studied by Scott (1986) who modelled monthly crashes in the UK from 1970 to 1978. In the United States, more than 70 percent of roads sustain snow during the winter season, receiving more than five inches of snowfall every year. Also, 70 percent of US population hails from regions encountering yearly snowfall. The risk of crash substantially increases due to snow and ice on pavements because they reduce the necessary pavement friction and vehicle maneuverability. Owing to this, roads affected by snow and ice experience reduced vehicular speeds, reduced level of service, and subsequent high crash risk (FHWA 2019). It is reported that 17 percent of all vehicle crashes occur during winter conditions (NHTSA 2019).

Snow and ice not only reduce the needed friction between vehicle tires and pavement surface but also reduce vehicle maneuverability, affecting overall roadway capacity and thereby contributing to additional crashes. Slushy pavements due to accumulation of snow for long periods reduce the mean arterial roadway vehicular speed by 30 to 40 percent while the reduction in freeway vehicular speeds is between 3 to 13 percent due to light snow and 5 to 40 percent in response to heavy snow. Snow accumulation affects travel times and reduces the overall capacity of the network. It is also reported that snowy weather conditions such as accumulation of snow, slush or ice on pavements cause 24 percent of annual traffic crashes while 15 percent of the annual traffic crashes are caused due to sleet and snowfall (Weng et al. 2013).

The total annual fatalities reported due to snowy, icy and slushy pavements are over 1,300 in the US however, around 116,800 road users sustain non-fatal injuries. Snowfall and sleet cause an annual 900 fatalities and 76,000 injuries in the US, besides increasing road and vehicular maintenance costs (FHWA 2019). Another important weather condition affecting crash rate is rainfall, which is responsible for the greatest number of weather-related crashes (Edwards 1999; Qiu and Nixon 2008). Rain causes crashes through a combination of several physical effects that challenge the driving environment, including a loss of friction between vehicle tires and road surface and impaired visibility through rain on the windshield and spray from other vehicles. Due to the combination of such adverse factors, the resulting strain on a driver's cognitive capacity leads to increased Crash rates (Cairney & Bennett 2008; Elvik 2006).

Heqimi et al. (2018) conducted a study in Michigan aimed at analyzing how annual snowfall affects crash rates by using spatial interpolation. The study was carried out at non-interchange freeway sections in Michigan from 2004 through 2014 and data were obtained from a series of weather stations during winter seasons. The authors utilized a Negative Binomial regression model to quantify how snowfall affected the occurrence of on-road crashes. It was observed from the study that snowfall had a statistically significant relationship with the risk of crash involvement. The study also highlighted that among different vehicular types, trucks and buses encountered the highest number of crashes during snowfall (Heqimi et al. 2018).

Eisenberg (2004) investigated the impact of precipitation on traffic crashes by analyzing crash data from 48 states in the US from 1975 through 2000. A Negative Binomial regression model was estimated based on two different analysis units i.e. state-month and state-days. The analysis revealed a negative relationship between the rate of monthly fatal crashes and monthly precipitation. However, for daily recorded data, it was observed that for every 1 cm rise in precipitation level, the likelihood of fatal crashes increased by 3 percent.

Sometimes in an event of extreme winter weather, a traffic crash may cause additional crashes, called chain reaction or multi-vehicle crashes. These crashes involve a chain of crashes related to one another. Call et al. (2018) highlighted these crashes where the occurrence of a single crash led to additional crashes because of an unexpected stoppage in traffic flow in adverse weather conditions. The authors investigated chain crashes by setting a minimum criterion of 10 vehicles in a multi-vehicle crash. It was observed that 25 percent of the crashes were reported during snowfall or blowing snow conditions. The study also highlighted that major multi-vehicle crashes occurred within an hour of high snowfall rates due to sudden reduction in visibility and rapid deterioration of road conditions under snow pileups. In the same manner, Black & Mote (2015) identified the likelihood of chain reaction crashes increased during evening peak hours owing to higher traffic volume. Unlike most previous studies that utilized monthly or annual crash data, Tom et al. (2008) utilized daily crash counts to investigate the effects of weather conditions on crash rates. The study also modelled the data in a time series context to account for temporal serial correlation in the data. The study introduced a new integer autoregressive modelling approach to model crash count data with time interdependencies. The results showed that weather related factors such as wind, temperature, precipitation, sunshine etc. were predominant factors affecting the daily counts of vehicle crashes (Brijis et al. 2008).

In the 2019 annual report of traffic crash facts, the Nebraska Department of Transportation (NDOT) reported 36,706 crashes for 2019 with 212 fatal crashes (248 total fatalities) and 11,939 injury crashes (NDOT Traffic Crash Facts, undated). Nebraska can experience extreme cold weather conditions such as recurring snowfall, icy and snowy pavements, and sleet etc. and therefore, there is merit in investigating the effects of adverse winter weather on traffic crashes. Moreover, as the weather community continues its efforts to provide improved Impact-Based Decision Support Services (IDSS) to build a Weather Ready Nation, it is becoming essential for forecasters to not only understand how to predict the weather but also estimate the consequences that extreme weather conditions may cause, such as traffic crashes (Uccellini and Hoeye 2019; Petr 2019). The traditional approach has relied on the analysis of weather information captured in the crash report. However, given advances in intelligent transportation systems and innovations in the field of Meteorology there is a compelling rationale to study detailed Nebraska weather conditions and the impacts on traffic crashes.

Chapter 3 Data Collection and Merging

The data collection process for this research consisted of obtaining crash data from NDOT for 2008-2018 and merging it with detailed meteorological data (e.g., temperature, visibility, snowfall depth etc.) for the same years. Details of crash and weather data are presented in this chapter.

3.1 Crash Data

Raw crash data for 2008-2018 received from NDOT were compared to the official NDOT annual crash reports and it was noted that the highest number of crashes were recorded in 2018 while 2012 had the least reported crashes (table 3.1). The differences in the raw crash data and the annual crash reports were due to inclusion of crashes that did not meet the estimated $1,000 damage threshold in the raw data.

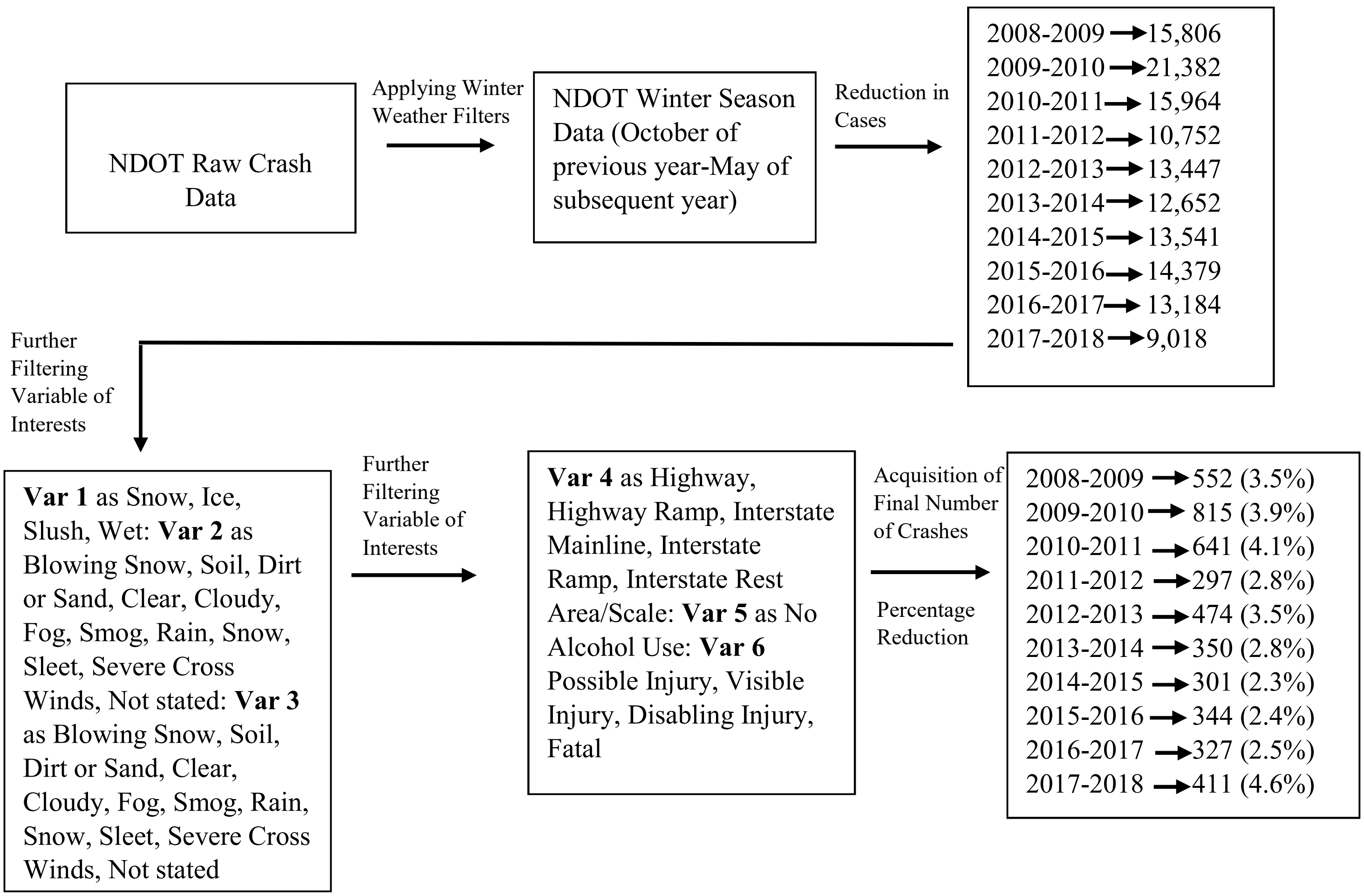
Table 3.1 Observed difference between crashes in NDOT raw crash data and official annual crash reports

Year	Crash Data	Annual Crash Report
2008	53406	34604
2009	53606	34665
2010	52208	33212
2011	50136	32302
2012	47375	30443
2013	48429	31377
2014	49816	32318
2015	51851	33988
2016	52999	34890
2017	52554	34999
2018	53565	36117

As the study was focused primarily on crashes reported during adverse winter weather conditions, an in depth data filtration process was carried out. At first, the annual crashes were converted to seasonal crashes by excluding summer crashes and including crashes that were recorded from October of the previous year to May of the subsequent year (fig. 3.1). This process resulted in a significant reduction in the number of crashes and it was observed that 2017-2018 had the lowest recorded crashes whereas 2009-2010 had the highest number of crashes i.e. 21,382.

The next step of data filtration was reducing the crash dataset to those reported during adverse winter weather conditions. This was accomplished by using multiple variables available in the dataset: road surface condition (Variable 1), weather condition I (Variable 2), weather condition II (Variable 3), road classification (Variable 4), alcohol use (Variable 5) and crash severity. The first filter was applied to the road surface condition and only crashes where the road surface condition was snow, ice, slush, or wet were included. Thenceforth, crashes were further reduced based on weather condition I and weather condition II as presented in figure 3.1. Crashes where Variable 1 was wet were only kept if Variables 2 and 3 had either snow or ice. In Variable 4, crashes on local roads/streets and recreational roads were excluded and to make sure crashes were only associated with adverse weather conditions, crashes involving alcohol usage were excluded. Crashes with property damage only were excluded i.e., crashes resulting in possible injury, visible injury, disabling injury or fatality (fig. 3.1) were retained. Note that disabling injury is referred to as suspected serious injury from 2015 onward.

The final analysis dataset had considerably fewer crashes than the original raw dataset; the highest number of crashes were reported during 2009-2010 while the fewest were reported during 2011-2012. Figure 3.1 presents the percentage reduction (reported in parenthesis) in the number of crashes between the original and the final analysis datasets.



Variable (Var) 1: Road Surface Condition
Variable (Var) 2: Weather Condition I
Variable (Var) 3: Weather Condition II
Variable (Var) 4: Road Classification
Variable (Var) 5: Alcohol Use
Variable (Var) 6: Crash Severity

Note:

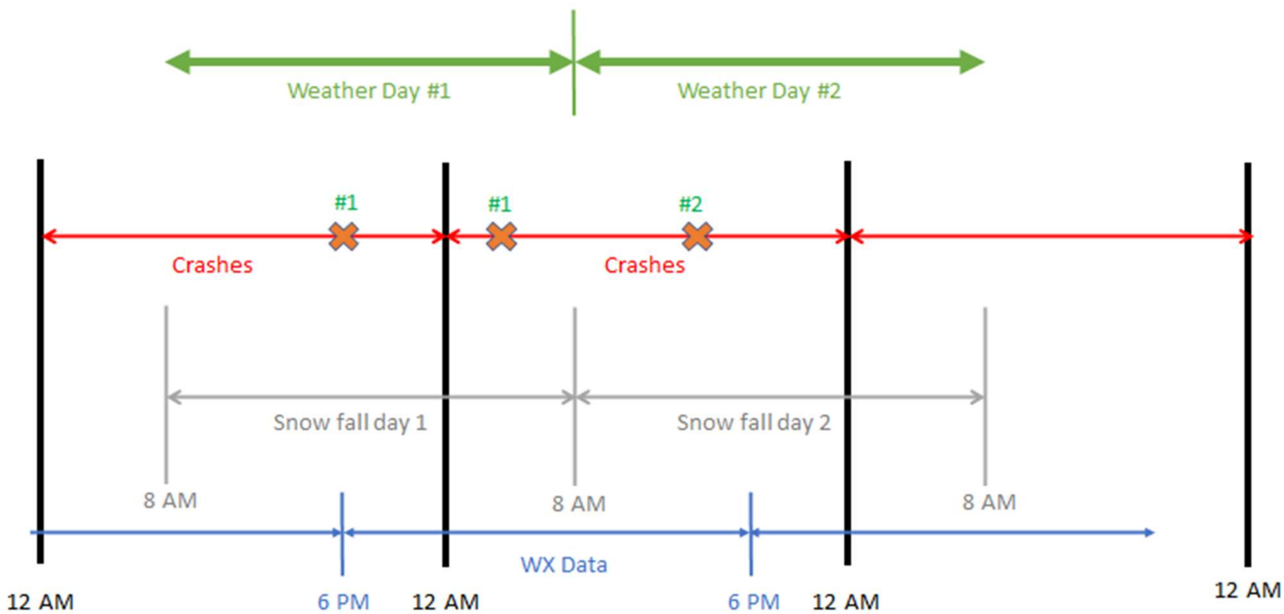
Var 1 if "Wet" was kept, when **Var 2** and **Var 3** were "Snow" or "Ice"

Figure 3.1 Data Filtration Process

3.2 Weather Data

To better understand weather conditions at the crash location, surface air temperatures, snowfall amounts, visibilities, and surface wind speeds as well as atmospheric conditions above the surface layer were obtained to augment the crash reports with detailed weather conditions. Surface weather parameters for the location and time of the crash were interpreted from archived automated surface observing system (ASOS) sites across Nebraska (Iowa Environmental Mesonet 2020). If a parameter had missing data at the ASOS station, data for the next closest time was obtained. If data at the next closest time was also missing, the next closest ASOS station was used for the original time of the crash. Air temperature data were chosen as a parameter to see if the surface condition would be frozen or not and with colder air temperatures the snowfall would be considered dryer than air temperatures associated near the freezing point. It should be noted these are air temperatures which are taken 5-ft (1.5 m) above the ground surface and may or may not represent the actual road surface temperatures. Visibility and wind speed data were obtained to represent whether there could be blowing snow at crash time.

Daily total snowfall data were obtained for a three-day window, starting two days prior to the crash, the day before the crash, and the day of the crash, using the National Operational Hydrologic Remote Sensing Center (NOHRSC) archive (NOHRSC 2020). Snowfall is usually reported around the 12 coordinated universal time (UTC, the primary time standard for regulating clocks and time) time frame each day. This is not a midnight to midnight observation period; however, more of a 6:00 am local time to 6:00 am local time the next day time frame. It necessitates the creation a weather day and not a calendar day for the analysis of crash data to better match with the weather parameters, especially the snowfall data. Therefore, all the weather data were collected on a 12 UTC to 12 UTC time frame for analysis periods (see fig. 3.2). Six-hour snowfall totals were obtained for one day before as well as the day of crash. Snowfall is usually reported around the 12 UTC time frame, so the six-hour totals covered the following times: 12-18 UTC, 18-00 UTC, 00-06 UTC, and 06-12 UTC. Crashes were then assigned to a six-hour period. A three-day snow snowfall total also was calculated by adding up the daily



snowfall totals before the crash.

Figure 3.2 Weather Day Versus a Normal 24-hour Period.

The National Weather Service (NWS) radar data were obtained to help determine if precipitation was falling at the location for the time of the crash (Iowa Environmental Mesonet 2020). The radar data were also obtained to determine how long the snowfall was occurring prior to a crash. Since radar observations are taken every five minutes, radar data were only obtained from the time of the crash to six hours prior to the crash. Radar returns were obtained to help understand the weather at the time of the crash, since sometimes the road surface parameters would indicate snow or ice on the road, however, the radar would show that nothing fell in the 48-hour timeframe.

A weather system analysis was used to classify the type of storm causing precipitation. The weather system analysis was separated into three categories: Colorado Low, Alberta Clipper, and Other to represent the types of storm systems affecting the Nebraska region. The type of system was identified by looking at surface and upper air conditions (UCAR 2020). The position and type of low-pressure system could be identified from the surface map, which shows temperature, pressure, dew point, wind speed and direction, sky conditions, and current precipitation. Upper air conditions, mainly the 850 hPa level, would further identify the moisture source for precipitation and movement of the storm system allowing for classification of the weather system.

A Colorado Low is defined as a winter storm moving from the Colorado/Kansas/Oklahoma area eastward or northeastward across the region producing precipitation over Nebraska. It is typically associated with wetter, heavier snow, longer duration, and spatially larger events than an Alberta Clipper, resulting in greater impact to the road network. An Alberta Clipper usually brings in colder and drier Canadian air across the Plains reducing the water content of the atmosphere resulting in relatively lighter snowfalls. The duration of an Alberta Clipper is usually only a few hours to a day since the system moves rapidly across the region. The final category, Other, was used for features that were not associated with a Colorado Low or an Alberta Clipper: including stationary fronts, overrunning, upper-level disturbances, and/or snow squalls. A Stationary front is an area where two different air masses (cold and warm) are not strong enough to overtake the other air mass and advance. Overrunning occurs when warm air is going over retreating cold air. An upper-level disturbance is an area of upward motion in the mid to upper part of the atmosphere. This upward motion can lead to storms forming. A snow squall is a small-scale quick band of snow, in this case not associated with a low pressure system. The system classification category was determined at the time of the traffic crash; however, sometimes the crash happened after a system had moved through the region, usually within one to two days, therefore the most recently occurred weather system was associated with that crash.

The 850 hPa flow, roughly 4,921 ft (1,500 m) above the surface, helps to show how the wind directions change when the weather system classification moves over an area. For instance, as a weather system moves through, the wind direction ahead of the system would usually have a southerly component. After the system moves through, the wind direction changes, and a more northerly wind would be associated at this level. The 850 hPa flow also helps explain the advection of moisture into the region, aiding in the determination of precipitation amounts with differing wind directions.

Moisture flow at 850 hPa also indicates where the moisture source region is found for the weather system. There were four moisture regions selected: Gulf of Mexico, Canadian Rockies, East Coast/Great Lakes, and Desert Southwest. Moisture from the Gulf of Mexico or East Coast/Great Lakes region is more likely related with heavy wet snowfalls and a Colorado Low moving through the area. Moisture transport from the Desert Southwest could also be a part of a Colorado Low; however, the amount of moisture is less than the Gulf of Mexico. Moisture flow from the Canadian Rockies is usually associated with Alberta Clippers and lighter, drier snowfalls.

In addition to the weather parameters, NWS Watches, Warnings, and Advisories (WWAs) (e.g., winter weather advisory, winter storm warning, blizzard warning, etc.) regarding winter weather were also obtained for the location and time of fatal crashes (Iowa Environmental Mesonet 2020) The WWAs were collected to determine if the area was identified as a hazard during the crash.

3.3 Nebraska Winter Severity Index (NEWINS)

The Nebraska Winter Severity Index (NEWINS; Walker et al. 2018; Walker et al. 2019a) was created to provide the Nebraska Department of Transportation (NDOT) with a metric to categorize and quantify the impact of individual winter storms in addition to the overall severity of a winter season statewide. The NEWINS metric is calculated for each NDOT maintenance district on a daily basis when snowfall is accumulating. It uses a weighted linear combination of snow accumulation, snow rate, air temperature, wind speed, visibility, duration, and district area averaged across an entire NDOT maintenance district to identify a daily category for a winter storm. It is possible for the same overall winter storm to receive more than one NEWINS categorical event classification if it spans multiple days. These categories are then accumulated over a winter season to provide a statewide winter season value.

The NEWINS metric does not presently account for freezing rain or residual blowing/drifting snowfall after an event that may still contribute to winter weather-related vehicular crashes. Higher impact storms in the NEWINS metric are typically those with larger snowfall accumulations. Similarly, higher severity winter seasons in the NEWINS metric are often those with the greatest number of classified events.

In the context of winter weather-related vehicular crashes in Nebraska, it is of interest to determine if there are any relationships between the NEWINS metric and the reported frequency and/or severity of vehicular crashes. There is precedent for this with states such as California, Montana, and Oregon relating their winter season severity index metrics to crash rates (Strong et al. 2005; Walker et al. 2019b) This analysis examines the distribution of NEWINS events and crashes from the 2008–2009 winter season through the 2017–2018 winter season. Additionally, this analysis will determine whether reported crashes were associated with an NEWINS event, meaning a crash could happen without an NEWINS event. NEWINS events with no reported crashes were also assessed.

It is important to first examine the distribution of events provided by the NEWINS metric (table 3.2) before any comparison with crash data. NEWINS Category 1 is the most frequent categorical classification across all winter seasons (occurring approximately 46.2% of the time overall) and the frequency distribution decreases with Category 6 as the least frequent (occurring approximately 0.45% of the time overall), with some winter seasons not reporting a single event of this magnitude. From the statewide perspective, the 2017–2018 winter season (6.01) had the greatest number of events (314); however, the 2009–2010 winter season was the most severe (6.21) due to a greater frequency of higher impact events, most notably Categories 5 and 6. The 2011–2012 winter season was both the least severe (2.63) and had the least number of events (134). The NEWINS metric average for the period was 4.68.

Table 3.2 NEWINS categorical event frequency distribution for the ten-winter season study period with percentage shown in parentheses.

NEWINS Category	**Winter Season**										**Category Total**
	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
1	123 (47.86)	129 (42.30)	114 (41.01)	65 (48.51)	113 (44)	136 (50.94)	112 (54.11)	127 (50.00)	75 (45.45)	132 (42.04)	1126 (46.20)
2	88 (34.24)	96 (31.48)	92 (33.09)	35 (26.12)	74 (28.91)	80 (29.96)	54 (26.09)	67 (26.38)	48 (29.09)	111 (35.35)	745 (30.57)
3	22 (8.56)	39 (12.79)	37 (13.31)	15 (11.19)	35 (13.67)	36 (13.48)	19 (9.18)	24 (9.45)	24 (14.55)	45 (14.33)	296 (12.15)
4	18 (7.00)	25 (8.20)	23 (8.27)	12 (8.96)	21 (8.20)	13 (4.87)	20 (9.66)	22 (8.66)	10 (6.06)	20 (6.37)	184 (7.55)
5	6 (2.33)	13 (4.26)	11 (3.96)	7 (5.22)	13 (5.08)	2 (0.75)	2 (0.97)	12 (4.72)	5 (3.03)	4 (1.27)	75 (3.08)
6	0 (0.00)	3 (0.98)	1 (0.36)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.79)	3 (1.82)	2 (0.64)	11 (0.45)
Event Total	257 (100.00)	305 (100.00)	278 (100.00)	134 (100.00)	256 (100.00)	267 (100.00)	207 (100.00)	254 (100.00)	165 (100.00)	314 (100.00)	2437 (100.00)
NEWINS Season Value	4.67	6.21	5.62	2.63	5.15	4.66	3.67	4.93	3.26	6.01	4.68

Chapter 4 Data Analysis

This chapter presents the salient features of the analysis dataset that contained 4511 crashes pertaining to the 2008-2018 winter weather. Crash characteristics are presented first followed by weather characteristics. Appendix A provides detailed statistics on the different variables in the dataset.

4.1 Crashes During Different Time Periods

Crash data accumulated from NDOT contained reported crashes during different time periods of the day. For a better assimilation of crashes associated with temporal variation, those crashes were classified in four successive six-hour periods starting from 12:00 AM and ending over a 24-hour period. A notable association between crashes and time of the day can be seen in Figure 4.1. Driver activity behavior is a major factor in crashes that varies by time of the day and is the reason for the pattern in figure 4.1, showing most crashes were reported during the 6:00 AM - 12:00 PM period followed by the 12:00 PM - 6:00 PM period for the analysis period (2008-2018). Past research has also highlighted a strong correlation between crashes and time of day. For example, Leone et al. (2017) highlighted that drivers exhibit careful driving patterns during the morning period. Moreover, Hasler et al. (2014) exhibited that people’s neural responses to monetary awards are substantially temporal. However, Fabbri et al. (2008) indicated there exists a higher level of subjective attentiveness in people during mid-day relative to mornings.

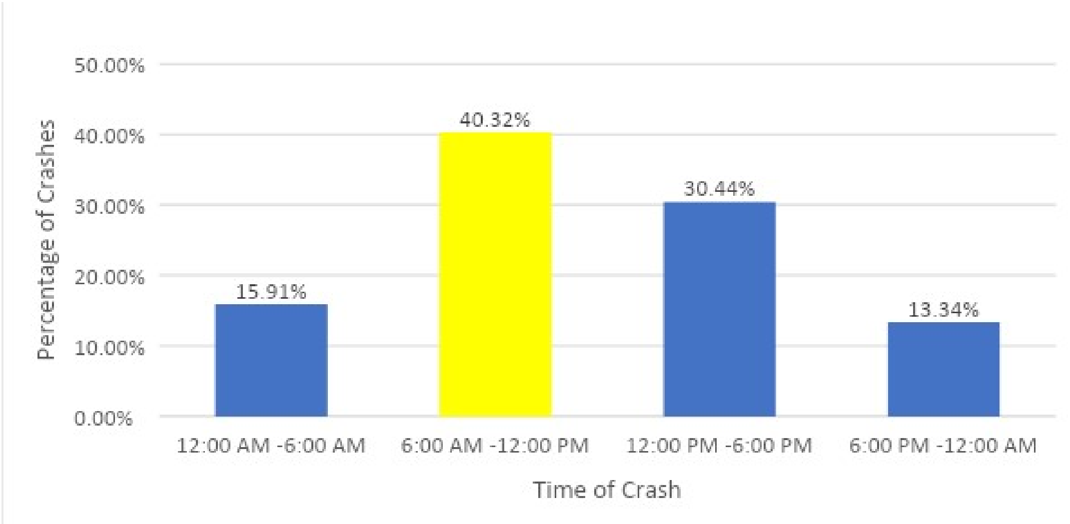


Figure 4.1 Percentage of crashes during different time periods of the day

4.2 Crashes on Different Road Surface Conditions

Past research shows that road surface conditions play an important role in crash occurrence as well as crash injury severity. Chen et al. (2017) highlighted that pavements with fair or good conditions have lower likelihood of crash occurrences compared to rough pavements. It is also evident from past research that longer accumulation of snow or ice on pavements decreases the functional and structural capacity of pavements, consequently causing more crashes (Chen et al., 2017; Cairney 2008). Crash data obtained from NDOT included a complete record on crashes on different road surface conditions having categories such as, ice, slush, snow, wet, dry, water etc. Crashes that exhibited a potential winter-weather road condition were kept for analysis (snow, ice, slush and wet). Figure 4.2 shows that the highest percentage of recorded crashes were on icy pavements (47.45%) followed by snowy pavements (41.67%) whereas the lowest number of crashes were recorded on wet pavements. Crashes with wet pavements were only considered when weather condition I or weather condition II were ice or snow.

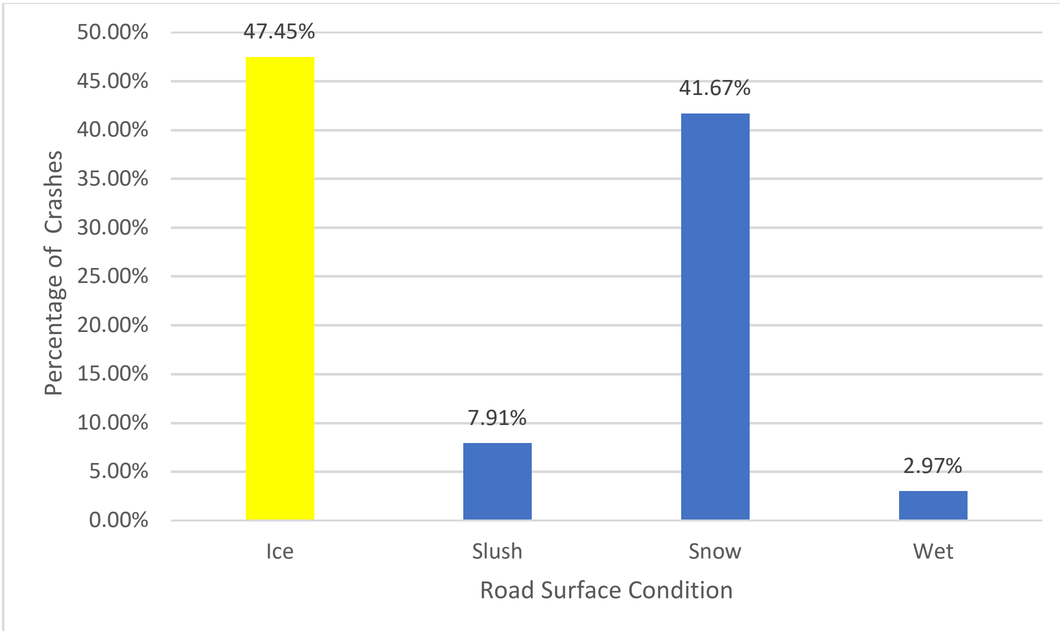


Figure 4.2 Percentage of crashes on different road surface conditions

4.3 Crashes During Different Weather Conditions

In the crash data variables labeled "Weather Condition I" and "Weather Condition II" recorded adverse weather conditions (i.e., rain, sleet, snow, fog, severe crosswinds, or blowing snow/sand/debris) at the time of crash occurrence. The data showed that the highest number of crashes recorded were in Snow condition followed by Sleet, Hail, Freezing Rain/Drizzle (fig. 4.3). It is worth noting that variable "Weather Condition II" is a continuation of variable "Weather Condition I" and recorded the cases where the investigator found there was an additional adverse condition to what was already reported in "Weather Condition I". For crashes where the crash investigator perceived no other adverse conditions impacting the crash, the variable was left Not Stated (fig. 4.4).

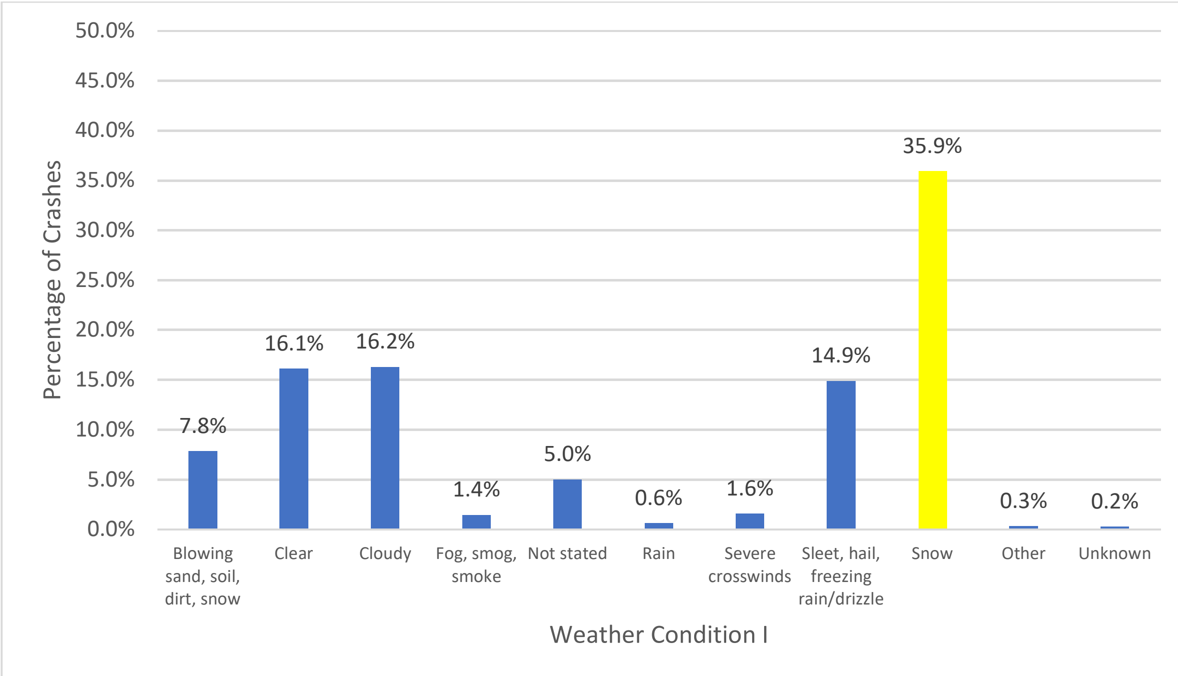


Figure 4.3 Percentage of crashes for the different Weather Condition I variables

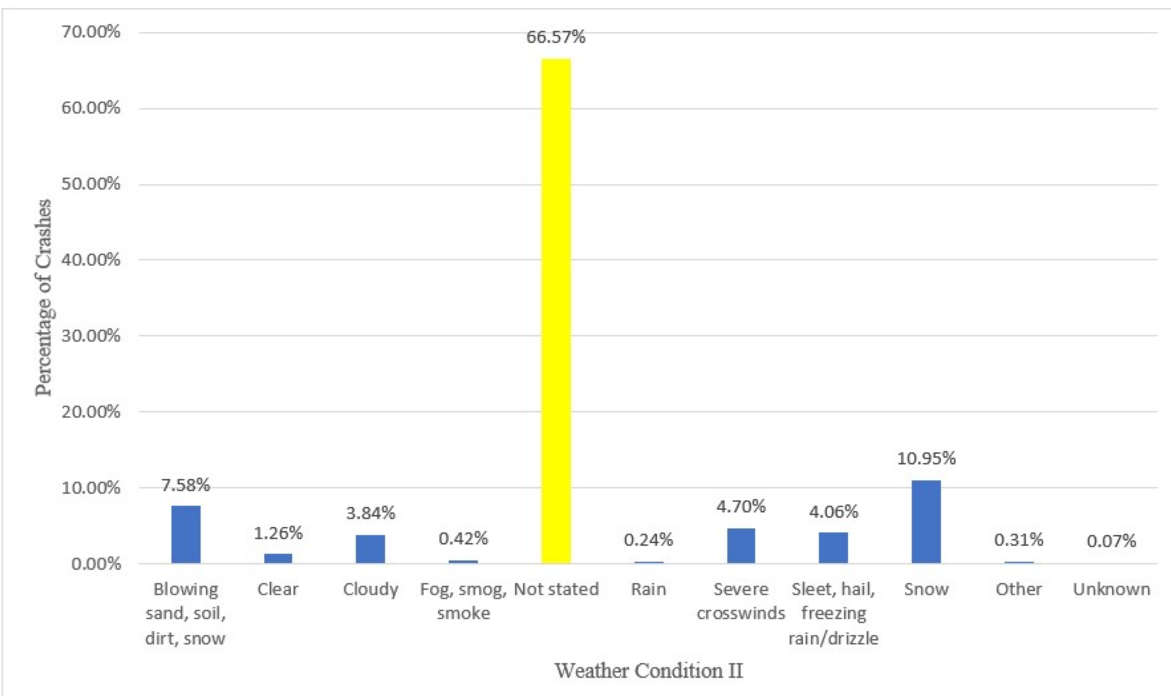


Figure 4.4 Percentage of crashes for the different Weather Condition II variables

4.4 Crashes on Different Road Classifications

Figure 4.5 presents the distribution of crashes on different road classifications. Most (72.5%) crashes during winter weather conditions were reported on highways followed by 24.4 percent crashes reported on Interstate highways. Relatively few were reported on ramps and in Interstate Rest Areas.

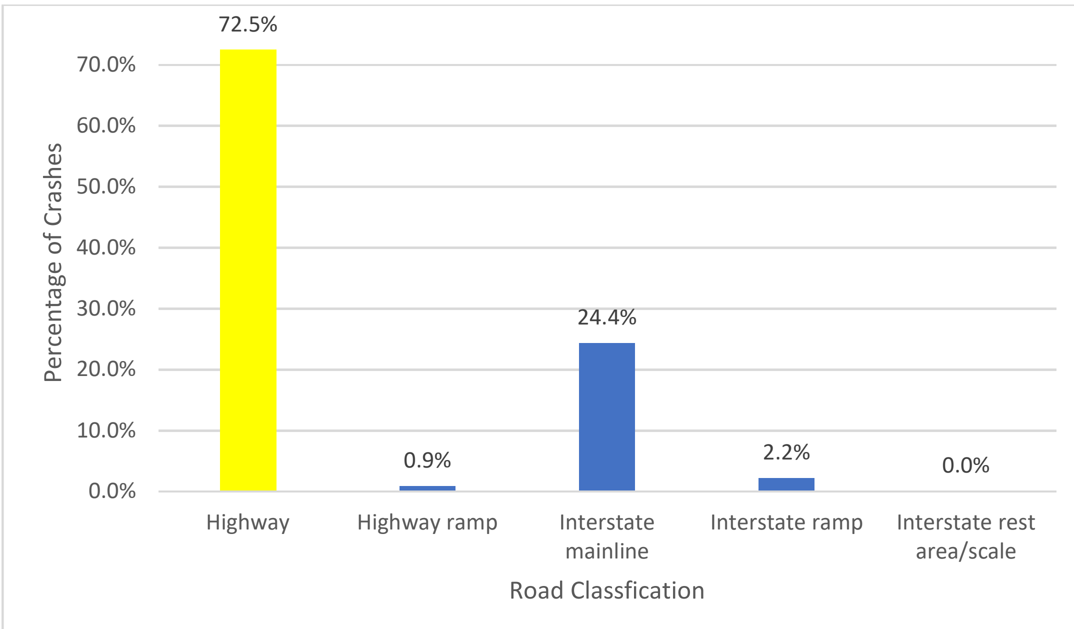


Figure 4.5 Percentage of crashes on different road classifications

4.5 Crashes on Different Road Surface Types

Road Surface type greatly influences ride quality, speeding patterns and driving conditions. The crash data showed that approximately 55% of the crashes were reported on concrete pavements whereas 43.94% of crashes were on asphalt pavements (fig. 4.6). Very few crashes were reported on any other type of road surface.

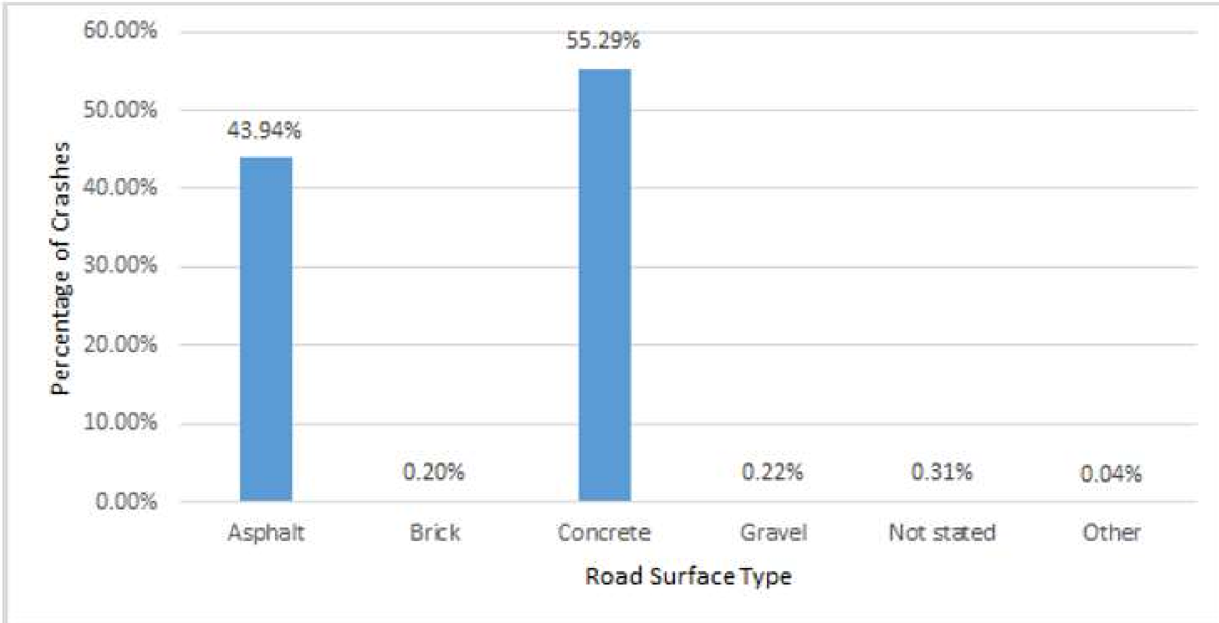


Figure 4.6 Percentage of crashes on different road surface types

4.6 Crashes in Different NDOT Districts

NDOT has eight field districts (numbered 1-8) that are responsible for the maintenance and construction of all state highways within the district boundaries. The crash data revealed that District 2 had the highest percentage of crashes (28.33%) for the study period followed by District 1 (21.3%) while the fewest crashes were reported in District 8 (fig. 4.7).

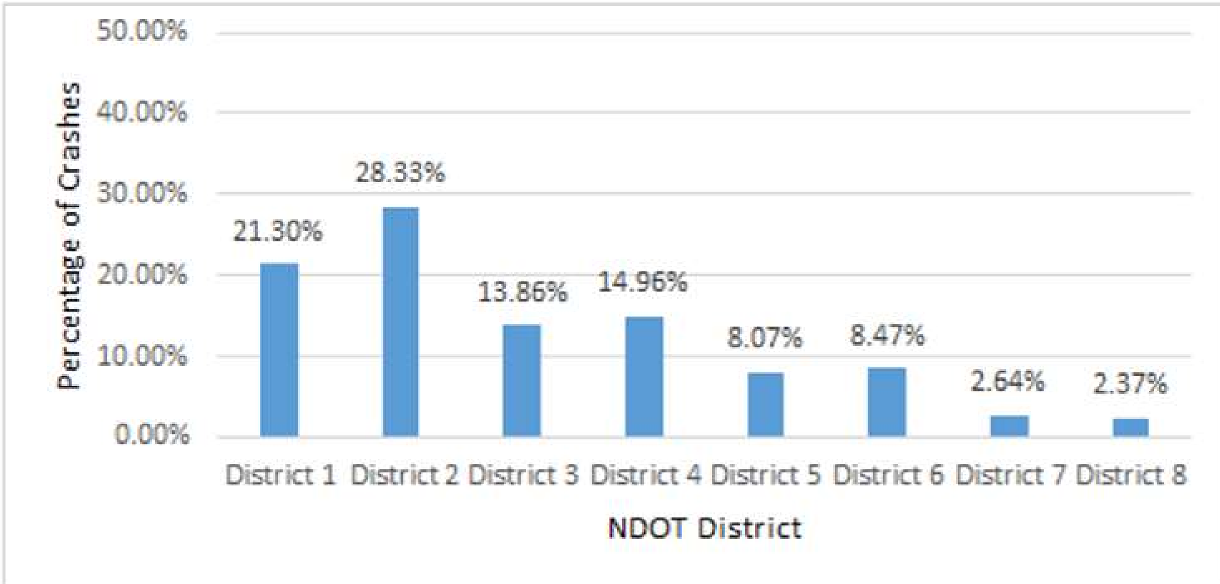


Figure 4.7 Percentage of crashes by different NDOT districts

4.7 Crashes by Population Group

Figure 4.8 shows the vast majority of the crashes (61.32%) were reported in rural areas followed by urban areas with a population greater than 300,000 (Omaha). Urban areas with populations in the range of 5,000 to 99,900 recorded 10.84% of the crashes while the urban areas with a population between 100,000 to 299,999 (Lincoln) recorded 7.23% of the reported crashes.

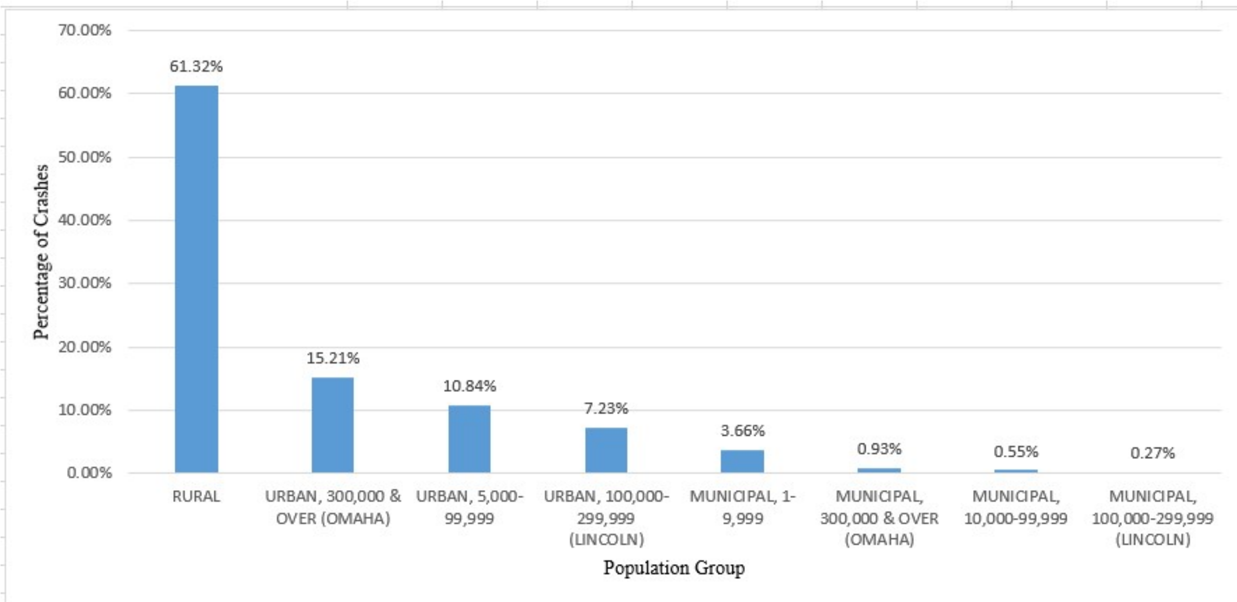


Figure 4.8 Percentage of crashes by different population groups

4.8 Total Crash Fatalities

Figure 4.9 shows that during the 10-year analysis period a total of 121 fatalities were recorded in 93 fatal crashes during winter weather conditions. Among total crashes, 1.66% of crashes had a single fatality whereas, the highest number of fatalities (4) were recorded for 0.07% of the total crashes during winter season (fig. 3.10). Moreover, the crash data shows that the winter season of 2009-2010 and 2012-2013 had the highest number of fatalities (i.e. total 22 fatalities) whereas, the least number of fatalities were recorded for the 2014-2015 (i.e. total 4 fatalities) winter season.

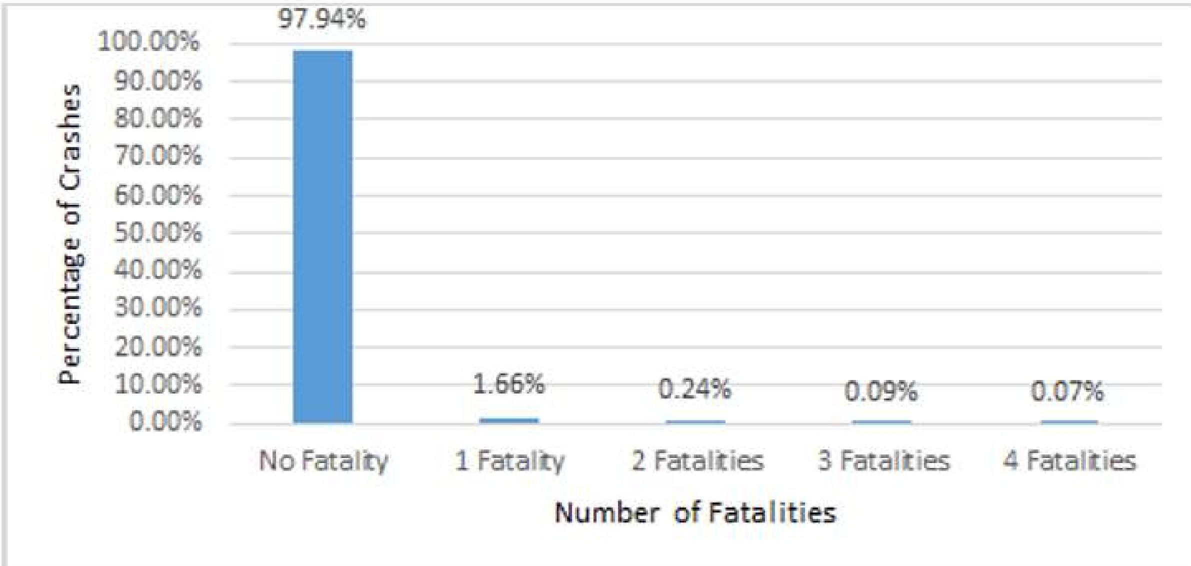


Figure 4.9 Percentage of crashes by fatalities

4.9 Total Crash Injuries

Figure 4.10 indicates the majority of the crashes had 1-5 injuries (98.71%) however, only one of the recorded crashes resulted in 20 injuries. For the 10 year period, a total of 6,507 injuries were recorded.

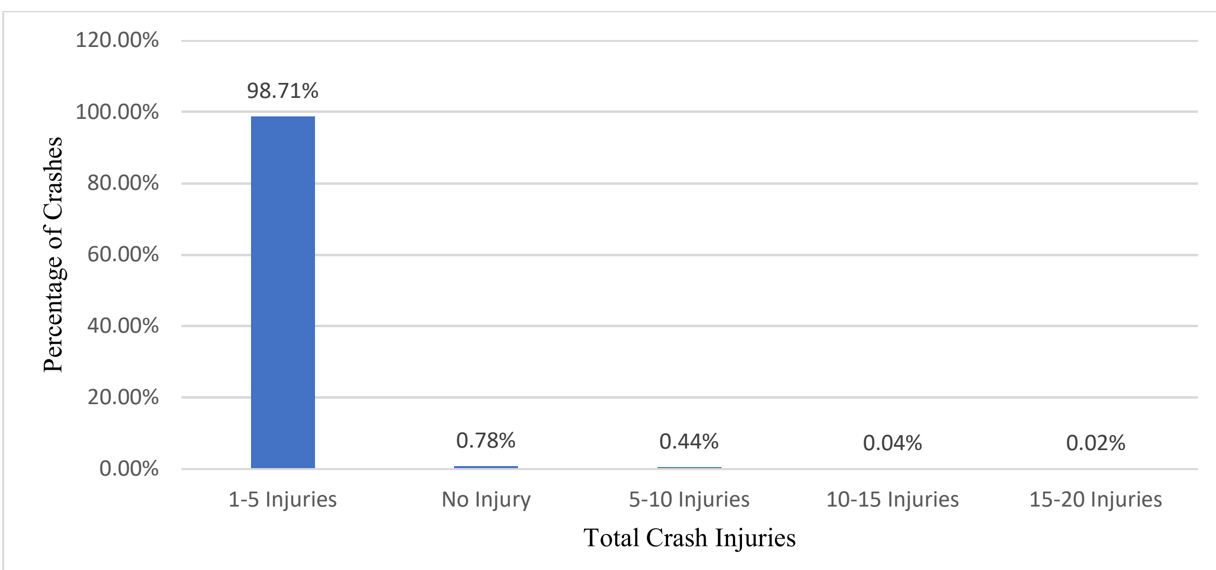


Figure 4.10 Percentage of injuries attributed to crashes

4.10 Crashes with School Buses and Trucks

According to National Safety Council (NSC) tabulations of data from the National Highway Traffic Safety Administration (NHTSA), school bus-related crashes killed 117 people nationwide in 2018. A school bus-related crash is defined by NHTSA as any crash in which a vehicle, regardless of body design, used as a school bus is directly or indirectly involved. This includes incidents involving school children getting in or out of a vehicle. The analysis dataset revealed 22 out of the 4,511 crashes had school bus involvement. In addition to school buses, 749 trucks were involved in crashes during the winter seasons of the study period.

4.11 Total Drivers and Occupants Involved in Crashes

The analysis dataset revealed that for the study period, 7,231 drivers were involved in crashes and the majority of crashes (99.53%) had less than 5 drivers involved and only one crash among 4,511 winter weather crashes had more than 30 drivers involved (fig. 4.11). The data also indicates that 11,149 vehicle occupants were involved in crashes during the study period with as many as 58 occupants for a single crash event.

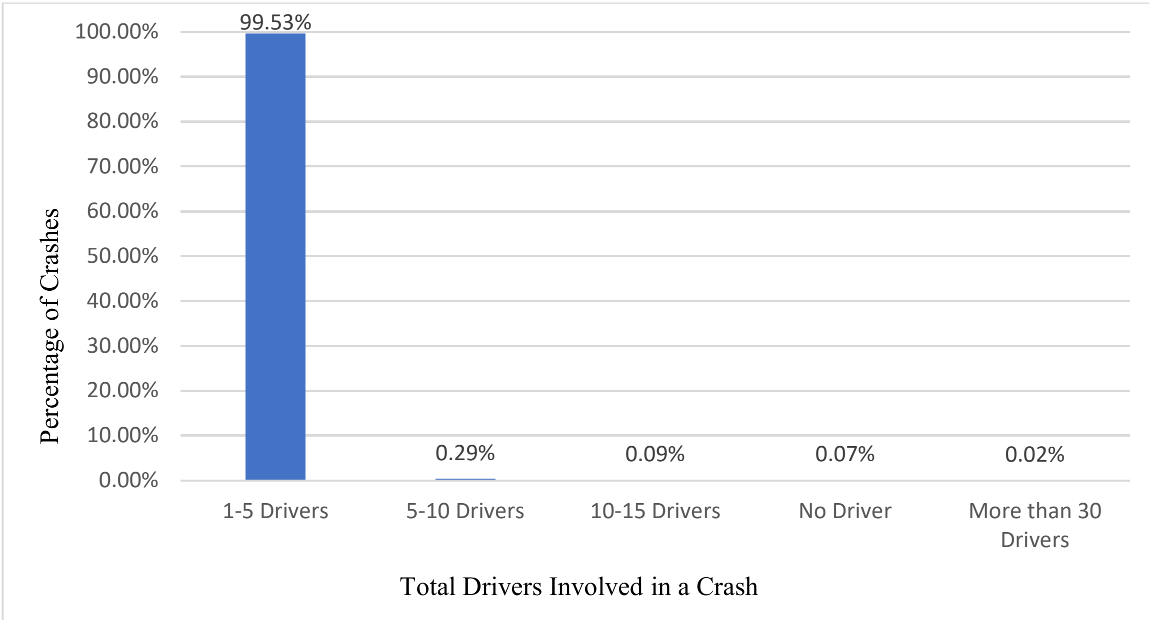


Figure 4.11 Percentage of drivers involved in crashes

4.12 Crashes with Young Drivers (13-19 or less than 25 years)

The crash database showed that for 614 (13.61%) crashes there was at least one driver between the age of 13-19 involved and for 1,567 (34.73%) crashes, at least one involved driver was less than 25 years old. The number of crashes by driver age varies as younger drivers are usually overrepresented in crashes.

4.13 Yearly Crash Distribution during Different Periods of the Day

Per table 4.1 there were 4,511 winter crashes during the ten-year study period; reported crashes were the highest during the 2009-2010 winter season (815, or 18.1% of the total) and lowest during the 2011-2012 season (297 or 6.6% of the total). On average 451 crashes were reported during each winter season in Nebraska.

Table 4.1 Yearly frequency and percentage (in parenthesis) of crashes during different time periods of the day

Time of the Crash	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	Total
12:00 AM -6:00 AM	101 (18.2)	73 (8.9)	103 (16.0)	54 (18.2)	83 (17.5)	67 (19.1)	50 (16.6)	60 (17.4)	51 (15.6)	76 (18.5)	718 (15.9)
6:00 AM - 12:00 PM	198 (35.8)	365 (44.7)	232 (36.2)	121 (40.7)	176 (37.1)	146 (41.7)	131 (43.5)	148 (43.0)	147 (44.9)	156 (37.9)	1820 (40.3)
12:00 PM -6:00 PM	185 (33.5)	227 (27.9)	236 (36.8)	93 (31.1)	149 (31.4)	100 (28.5)	77 (25.5)	89 (25.8)	90 (27.5)	127 (30.9)	1374 (30.4)
6:00 PM - 12:00 AM	68 (12.3)	150 (18.4)	70 (10.9)	29 (9.7)	66 (13.9)	37 (10.5)	43 (14.2)	47 (13.6)	38 (11.9)	52 (12.7)	602 (13.3)
Total	**552**	**815**	**641**	**297**	**474**	**350**	**301**	**344**	**326**	**411**	**4511**

4.14 Yearly Crashes on Different Road Surface Conditions

Table 4.2 presents the winter season yearly frequency and percentage of crashes on different road surface conditions. Overall, ice and snow on the road surface contributed to the bulk of road surface conditions. Specifically, 47.45 percent and 41.67 percent of the crashes in the database were on ice and snow road surfaces, respectively.

Table 4.2 Yearly frequency and percentage (in parenthesis) of crashes on different road surface conditions

Road Surface Condition	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2025-2016	2016-2017	2017-2018	Total
Ice	268 (48.6)	384 (47.0)	301 (47.0)	147 (49.5)	226 (47.7)	133 (38.0)	134 (44.5)	162 (47.1)	182 (55.7)	205 (49.9)	2142 (47.4)
Slush	28 (5.1)	50 (6.2)	45 (7.0)	23 (7.7)	54 (11.4)	47 (13.4)	25 (8.3)	46 (13.4)	31 (9.8)	6 (1.5)	357 (7.91)
Snow	244 (44.2)	360 (44.2)	280 (43.7)	110 (37.0)	175 (36.9)	161 (46.0)	133 (44.2)	124 (36.0)	98 (30.0)	195 (47.4)	1881 (41.6)
Wet	12 (2.2)	21 (2.6)	15 (2.3)	17 (5.7)	19 (4.0)	9 (2.6)	9 (3.0)	12 (3.5)	15 (4.6)	5 (1.2)	134 (2.9)
Grand Total	552	815	641	297	474	350	301	344	326	411	4511

4.15 Yearly Crashes during Different Weather Conditions Noted on Crash Reports

Tables 4.3 and 4.4 present yearly frequency and percentage of crashes during different weather conditions as reported on the crash form. Weather Condition I and II show the conditions at the time of crash. In many circumstances only Weather Condition I is reported and in relatively few instances both variables are filled out by the reporting officer.

Table 4.3 Yearly frequency and percentage (in parenthesis) of crashes during different Weather Condition I

Weather Condition I	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	Total
Snow	208 (37.6)	271 (33.1)	247 (38.5)	137 (46.1)	201 (42.4)	127 (36.2)	34 (11.3)	135 (39.2)	107 (32.7)	154 (37.4)	1621 (35.9)
Sleet, hail, freezing rain/drizzle	82 (14.8)	71 (8.69)	142 (22.1)	33 (11.1)	73 (15.4)	48 (13.7)	8 (2.66)	47 (13.6)	95 (29.0)	73 (17.7)	672 (14.8)
Blowing sand, soil, dirt, snow	33 (5.9)	89 (10.8)	28 (4.3)	10 (3.3)	23 (4.8)	38 (10.8)	19 (6.3)	49 (14.2)	26 (7.9)	38 (9.2)	353 (7.8)
Severe crosswinds	15 (2.7)	14 (1.8)	2 (0.5)	3 (1.0)	2 (0.4)	3 (0.8)	12 (3.9)	5 (1.4)	6 (1.8)	7 (1.7)	70 (1.5)
Cloudy	106 (19.2)	15 (19.7)	99 (15.4)	73 (24.5)	85 (17.9)	59 (16.8)	11 (3.6)	47 (13.6)	37 (11.3)	55 (13.3)	733 (16.2)
Fog, smog, smoke	6 (1.1)	20 (2.5)	6 (0.9)	4 (1.3)	21 (4.4)	2 (0.6)	2 (0.7)	2 (0.6)	1 (0.3)	0 (0.0)	64 (1.4)
Rain	2 (0.3)	5 (0.6)	1 (0.1)	2 (0.6)	3 (0.6)	6 (1.7)	0 (0.0)	2 (0.6)	4 (1.2)	1 (0.2)	26 (0.5)
Clear	92 (16.6)	178 (21.7)	114 (17.7)	32 (10.7)	63 (13.2)	64 (18.2)	1 (0.3)	55 (15.9)	47 (14.6)	80 (19.4)	727 (16.1)
Not stated	5 (0.9)	2 (0.2)	1 (0.1)	1 (0.3)	2 (0.4)	1 (0.3)	212 (70.4)	0 (0.0)	0 (0.0)	1 (0.2)	225 (4.9)
Other	0 (0)	3 (0.3)	1 (0.1)	1 (0.3)	0 (0.0)	1 (0.2)	2 (0.6)	2 (0.6)	2 (0.6)	1 (0.2)	13 (0.3)
Unknown	3 (0.5)	2 (0.2)	0 (0.0)	1 (0.3)	1 (0.2)	1 (0.3)	0 (0.0)	0 (0.0)	1 (0.3)	1 (0.3)	10 (0.2)
Grand Total	552	815	641	297	474	350	301	344	326	411	4511

Table 4.4 Yearly frequency and percentage (in parenthesis) of crashes during Weather Condition II

Weather Condition II	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	Total
Snow	53 (9.6)	75 (9.3)	56 (8.7)	29 (9.7)	44 (9.2)	53 (15.1)	34 (11.3)	43 (12.5)	39 (11.9)	67 (16.3)	494 (10.9)
Sleet, hail, freezing rain/drizzle	19 (3.44)	33 (4.0)	21 (3.3)	18 (6.0)	17 (3.6)	19 (5.4)	8 (2.6)	14 (4.0)	14 (4.6)	19 (4.6)	183 (4.0)
Blowing sand, soil, dirt, snow	57 (10.3)	77 (9.4)	48 (7.5)	16 (5.4)	35 (7.4)	21 (6.0)	19 (6.3)	22 (6.4)	19 (5.81)	28 (6.9)	342 (7.6)
Severe crosswinds	33 (5.9)	46 (5.6)	29 (4.5)	9 (3.0)	33 (6.7)	7 (2.0)	12 (3.4)	15 (4.36)	13 (3.9)	15 (3.6)	212 (4.7)
Cloudy	21 (3.8)	26 (3.3)	35 (5.4)	14 (4.7)	22 (4.6)	11 (3.1)	11 (3.6)	9 (2.6)	13 (3.9)	10 (2.4)	173 (3.8)
Fog, smog, smoke	1 (0.2)	4 (0.5)	6 (0.9)	1 (0.3)	2 (0.4)	1 (0.3)	2 (0.7)	1 (0.3)	1 (0.3)	0 (0.0)	19 (0.4)
Rain	1 (0.18)	18 (2.2)	2 (0.31)	3 (1.01)	2 (0.42)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.2)	27 (0.6)
Clear	9 (1.6)	2 (0.2)	13 (2.0)	3 (1.0)	2 (0.4)	3 (0.9)	1 (0.3)	1 (0.3)	2 (0.6)	5 (1.2)	41 (0.9)
Not stated	356 (64.5)	533 (65.3)	430 (67.1)	202 (68.0)	301 (63.5)	234 (66.8)	212 (70.4)	236 (68.6)	222 (67.9)	264 (64.3)	2990 (66.2)
Other	1 (0.2)	1 (0.1)	0 (0.0)	1 (0.4)	1 (0.2)	1 (0.3)	2 (0.7)	3 (0.9)	3 (0.9)	1 (0.2)	14 (0.3)
Unknown	1 (0.1)	0 (0.0)	1 (0.1)	1 (0.4)	15 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.3)	19 (0.4)
Grand Total	552	815	641	297	474	350	301	344	326	411	4511

4.16 Yearly Crashes on Different Road Classifications

Table 4.5 presents the reported crashes on different road classifications for each winter season. The bulk of the crashes were reported on highways followed by Interstate highways while very few were reported on ramps.

Table 4.5 Yearly frequency and percentage (in parenthesis) of crashes on different road classifications

Road Classification	2008-2009	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	Total
Highway	420 (76.1)	583 (71.4)	460 (71.8)	222 (74.7)	338 (71.3)	276 (78.9)	211 (70.1)	247 (71.8)	236 (72.4)	279 (67.9)	3273 (72.5)
Highway ramp	6 (1.1)	10 (1.3)	2 (0.3)	4 (1.3)	1 (0.2)	2 (0.6)	5 (1.7)	1 (0.3)	2 (0.6)	5 (1.2)	39 (0.9)
Interstate mainline	116 (21.0)	210 (25.7)	166 (25.9)	66 (22.2)	121 (25.5)	67 (19.1)	71 (23.6)	84 (24.4)	79 (24.2)	120 (29.2)	1100 (24.4)
Interstate ramp	10 (1.8)	10 (1.3)	13 (2.0)	5 (1.7)	14 (3.0)	5 (1.4)	14 (4.7)	12 (3.5)	9 (2.8)	7 (1.7)	100 (2.2)
Interstate rest area/scale	0 (0.0)	2 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.0)
Grand Total	552	815	641	297	474	350	301	344	326	411	4511

4.17 Snowfall

Snowfall is a major reason for crashes in the wintertime driving conditions and keeping the road surfaces snow and ice free is a major responsibility of transportation agencies. Therefore, whether snowfall was occurring at the time of a crash is an important observation. While crash reports indicate general weather conditions at the time of a crash, they do not list the snowfall amount or depth of fallen snow. Therefore, snowfall data were obtained for six-hourly time frames, the shortest period of time for snowfall collection. The crash time was then interpreted into one of the six-hourly time frames. More than 50% of the reported winter weather-related crashes occurred when there was no snowfall during the six-hour period of the crash (fig. 4.12). Over 30% of the crashes occurred when there was one inch or less of snow during the six-hourly period of the crash. Snowfall between one and two inches accounted for another 10% of the crashes. Overall, 40% of the crashes occurred when there was accumulating snowfall of less than two inches. Within the analysis dataset, Nebraska has very few occurrences of greater than two inches of snow during the six-hourly period associated with a crash. Six-hourly snowfall totals were only collected if there was a crash, so there is no knowledge of how many total (i.e., crash and non-crash) six-hourly periods had or did not have snowfall throughout the study period.

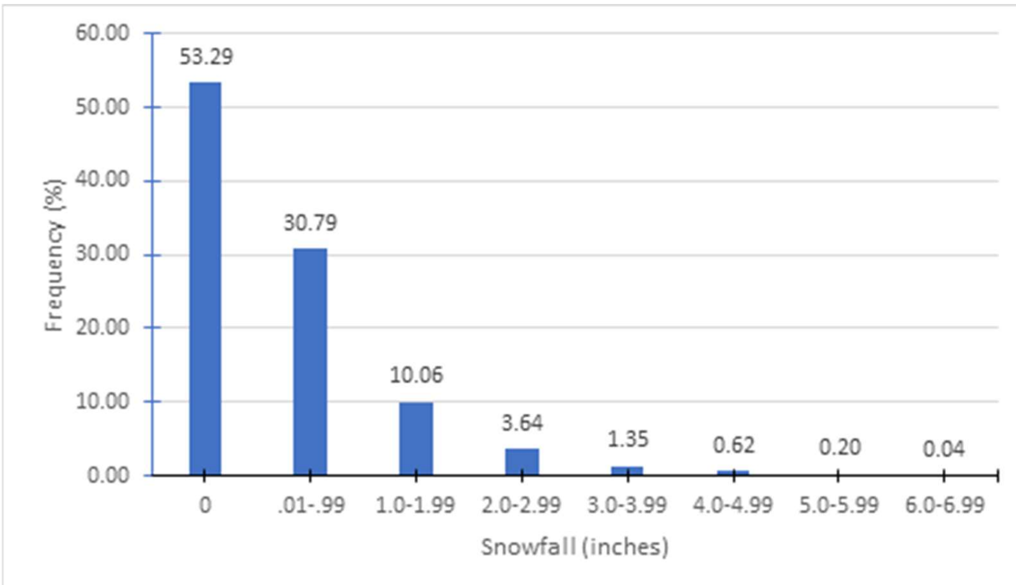


Figure 4.12 Total frequency of crashes with the snowfall amount that occurred in the six-hour timeframe of when the crash happened

It is important to note that road conditions on the crash report indicated snow or ice on the road surface during the crash. The crash could have also occurred in the very beginning of the six-hour window or at the end of the window, which might be affected by the amount of snow. There are other scenarios which could cause this type of situation. The first would be if it had snowed earlier in the weather day (i.e. another six-hourly period) and was not actually snowing at the time of the crash, still creating icy or snowy conditions on the road surface. The snowfall could have occurred during the previous time period or several days before the crash contributing to snow or ice cover from residual snowpack. Also, it could be snowing at the time of the crash; however, there was no accumulation of snow during the six-hourly period. It is difficult to determine the specific scenario with certainty, so different possibilities were investigated.

One further way to analyze the snowfall data is to look at the six-hour time period before the time of the crash and see how many crashes occurred with snowfall during the period before the crash (fig. 4.13). The results are very similar to the time period of the crash with over 50% having no snowfall during the six-hourly period before the crash. However, this considers only the results of the six-hourly period and does not compare the two periods together. When there was no snowfall during the six-hourly period of the crash and no accumulation during the previous six-hourly period, only 20% of these scenarios had snowfall in the previous six-hourly period. This indicates that, in most cases, there was snowfall more than six hours before the crash period.

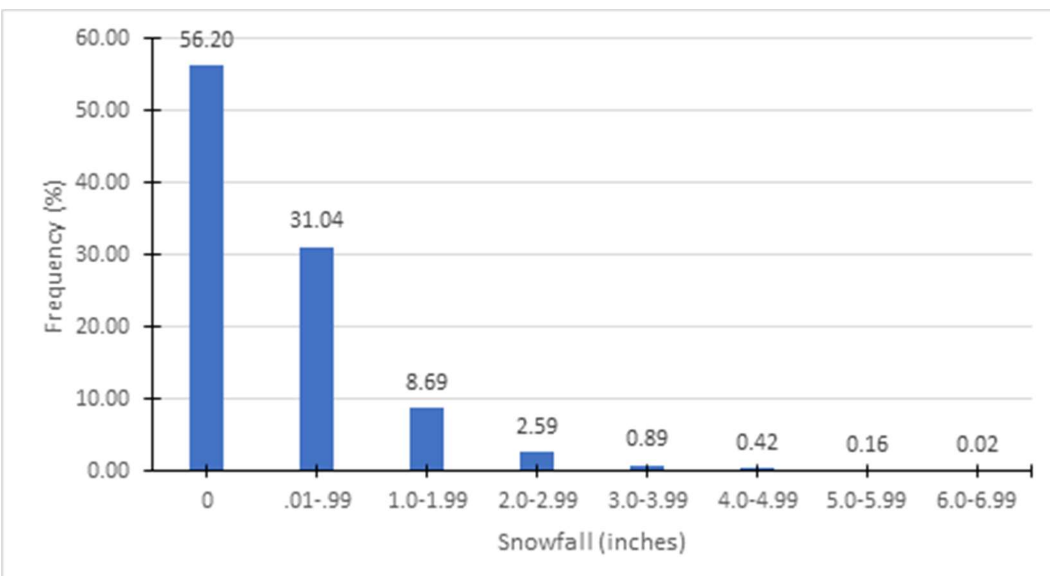


Figure 4.13 Total frequency of crashes with the snowfall amount that occurred six hours prior to the crash

The daily snowfall amount was obtained for all crashes for the study period (fig. 4.14). The results indicate that 48% of the reported crashes occurred when there was a snowfall of less than three inches the day of the crash and less than 10% of the time greater than three inches (as the weather day was defined for this research; see figure 3.2 in the previous chapter). There was no snowfall during the day 39% of time crashes occurred (fig. 4.14). This does not mean there was no ice or snow on the road surface, just that there was no snow accumulation the day of the crash. There could have been snow accumulation before the crash. Therefore, three-day total accumulations were obtained (fig. 4.15) to highlight the total snowfall amounts before and during the crash period. About 50% of the reported crashes occurred with an accumulation of less than four inches of snowfall. Only 20% of the crashes occurred without snowfall falling during the three-day period. Since there was ice or snow on the roadway, these cases probably had snowfall occurring before the data cutoff used for this research. The results would indicate that the snowfall accumulates over a several day period at the site of the crash.

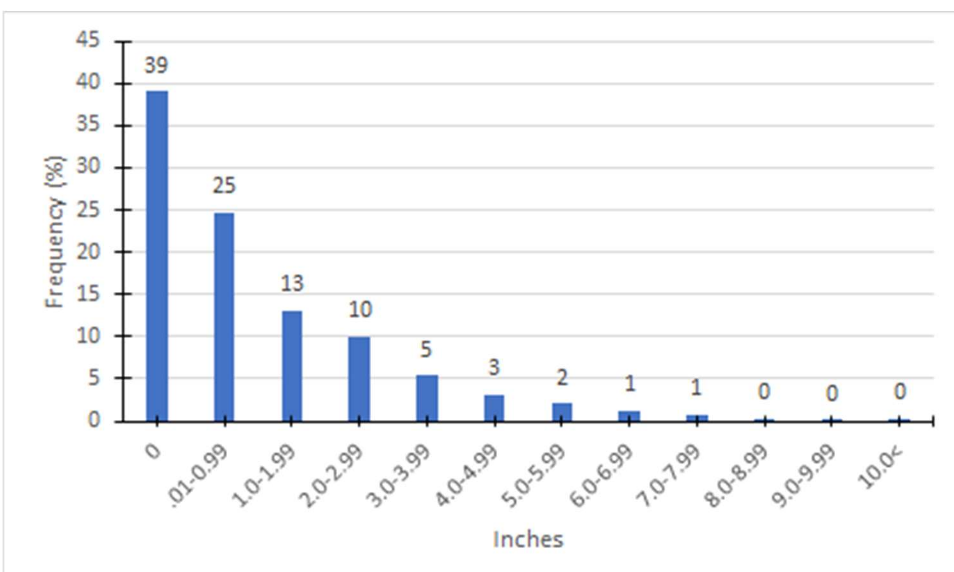


Figure 4.14 Total frequency of crashes with the daily snowfall amount on crash day

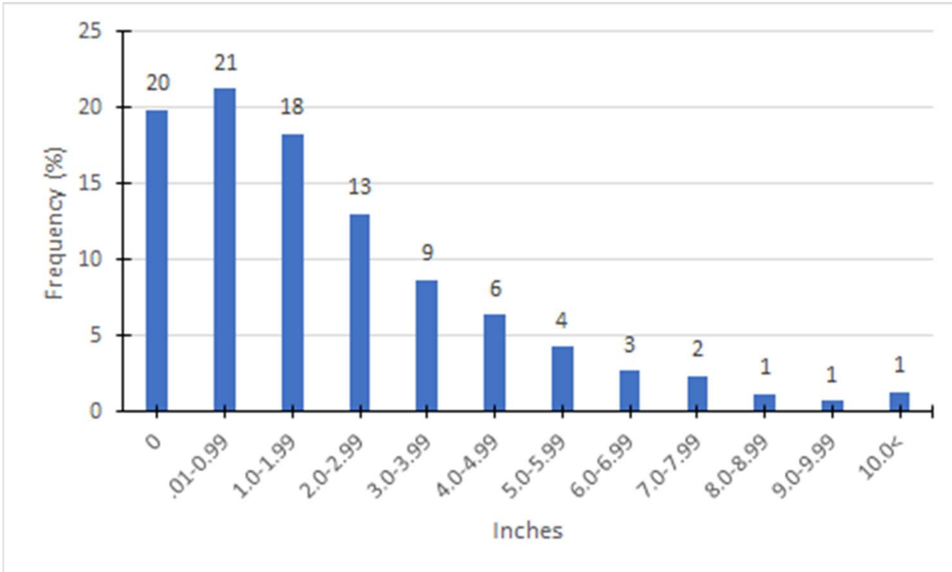


Figure 4.15 Total frequency of crashes with the three-day total snow depth

4.18 Temperature

Almost 50% of all reported crashes occurred when the air temperature was around the freezing point (fig. 4.15). This implies that almost half of all reported crashes occurred with temperatures warm enough for most deicing chemicals to be effective in melting snow. The warmer surface temperatures are also less likely to have snow blowing across a road after falling to the ground surface. Dry snows are usually associated with colder temperatures. If the surface winds are strong enough both wet (warmer) or dry (colder) snow will blow as it falls; however, wetter snow is less likely to blow after it has fallen onto the ground surface. Wet snow typically comes from the Colorado Low (discussed later), as it brings warmer temperatures into the region, than the Alberta Clippers (discussed later), especially during the winter months. The warmer, moist air matches with fig. 4.16, with Colorado Lows occurring with 42% of all reported crashes.

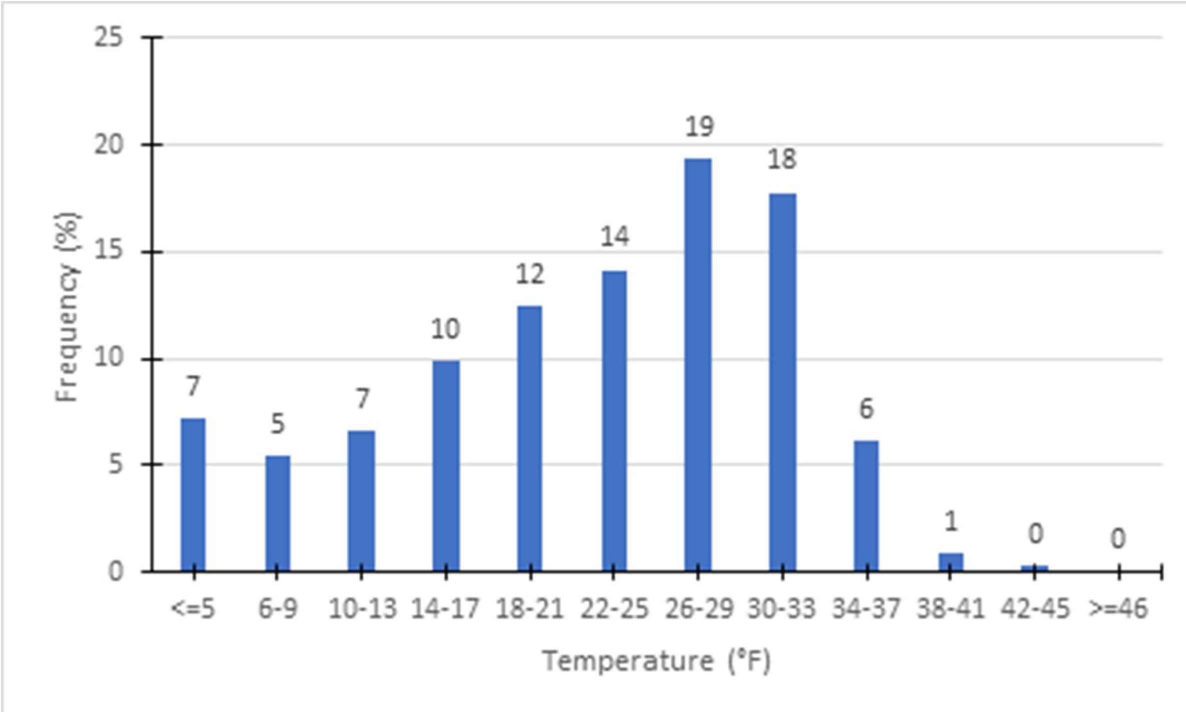


Figure 4.16 Total frequency of crashes with respect to temperature (degrees Fahrenheit)

4.19 Visibility

During snow events, reduction in visibility can be caused by several conditions such as high intensity of snowfall, blowing and drifting snow, low cloud cover, or fog. Visibilities of less than two miles or greater than or equal to 10 miles are responsible for almost 65% of all reported crashes during the study period (fig. 4.17). Low visibilities occur during the heaviest snow rates presenting the worst conditions for drivers. The higher visibilities are associated with the post-event, residual snow/ice crashes. The reduction in visibility is more likely caused by greater snowfall rates rather than blowing snow, since the winds speed analysis would indicate that lower winds speeds (less than 25 mph) were present during 80% of the reported crashes compared to high (greater than 25 mph) wind speeds (table 4.6). Higher wind speeds were more likely associated with blowing snow. Given that, as the visibility dropped the number of crashes would have gone up. When the visibility is greater than or equal to 10 miles, the snowing had already stopped but is still on the road surface, or it did not snow at all and ice caused crashes.

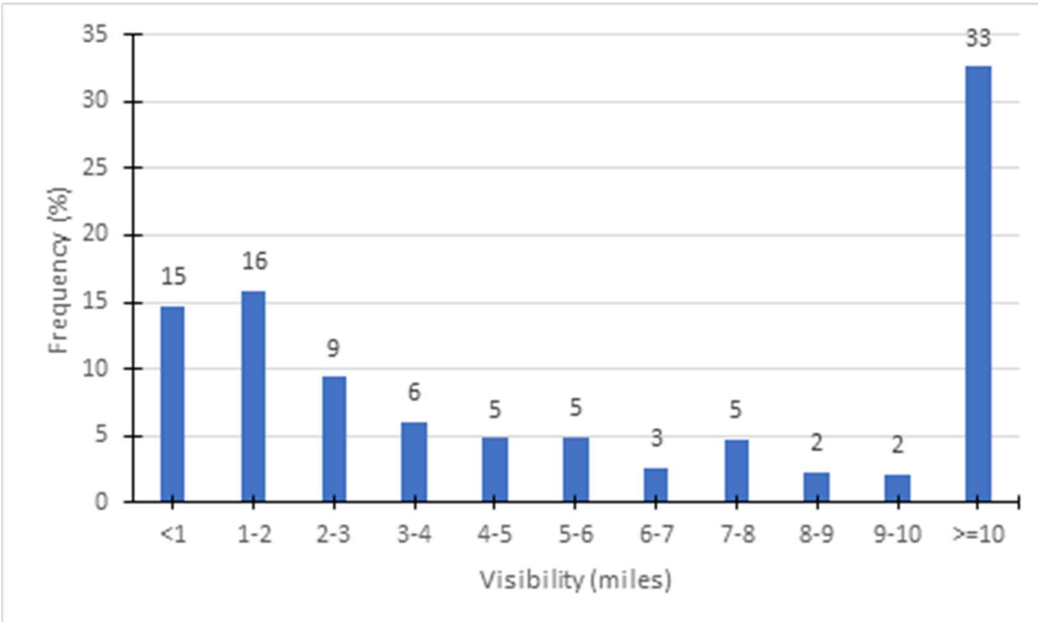


Figure 4.17 Ten-year winter season total frequency of crashes with visibility data

Table 4.6 Frequency and Percentage (in Parentheses) of Crashes with Respect to Wind Speed

Wind Speed (mph)	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**Total**
Number of Crashes	245 (5)	1057 (23)	1079 (24)	899 (20)	605 (13)	356 (8)	182 (4)	57 (1)	24 (1)	7 (0)	4511 (100)

4.20 Colorado Lows

Colorado Lows were associated with 42% of all crashes in the study period (fig. 4.18). Every winter season studied showed that Colorado Lows were involved in at least 30% of all reported crashes, except for the winter season of 2014, where it was responsible for less than 30% (fig. 4.19). Therefore, Colorado Lows are involved in more crashes than Alberta Clippers or the Other category. Colorado Lows are larger and last longer than Alberta Clippers. These lows form anywhere from the four corners region to the Wyoming/Colorado Border. Highway crashes could occur on multiple days across Nebraska due to the long time it takes a Colorado Low to traverse the entire state.

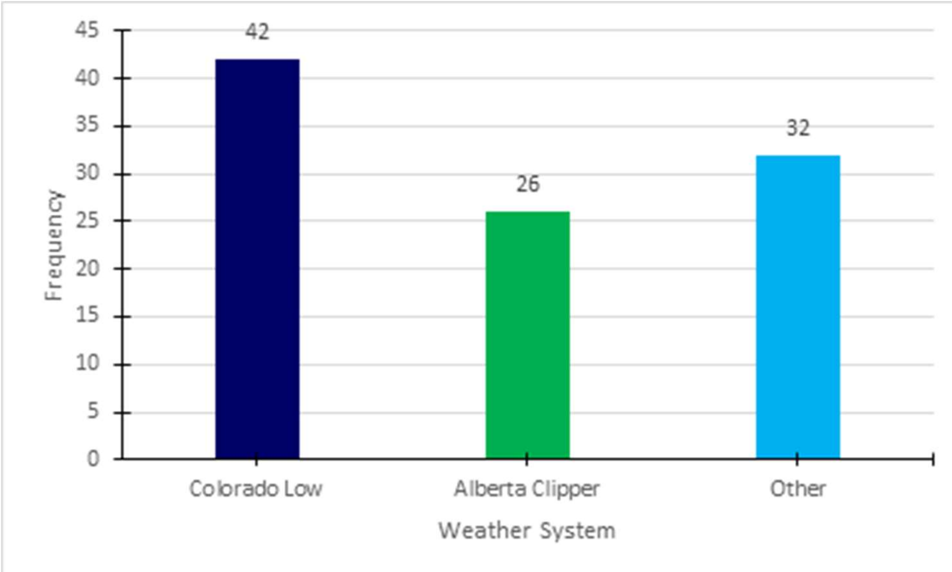


Figure 4.18 Frequency distribution of crashes by weather system type

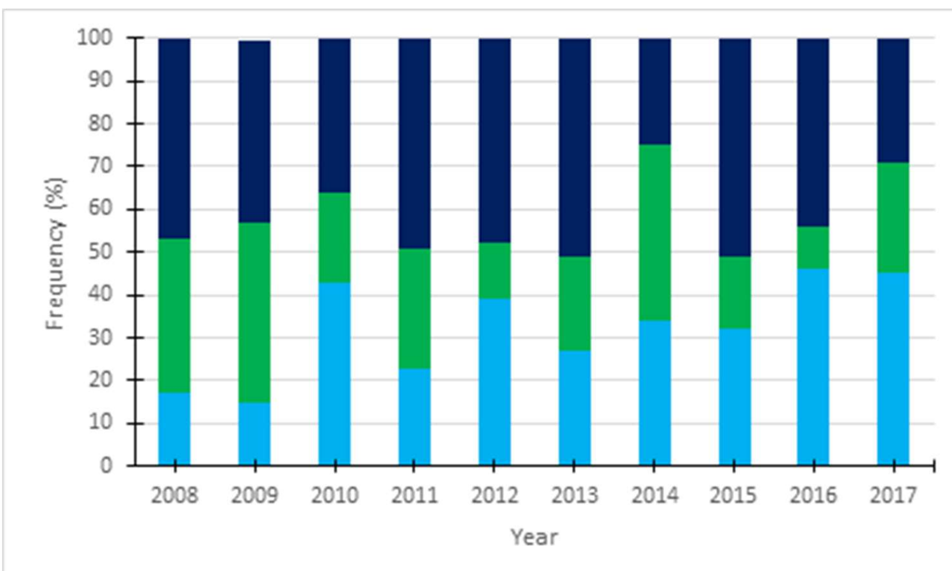


Figure 4.19 Yearly crashes by Colorado Low (dark blue), Alberta Clipper (green) and Other category (light blue)

The Colorado Low usually obtains moisture from the Gulf of Mexico, Great Lakes/East Coast, and the Desert Southwest (fig. 4.20). Moisture flow from the Gulf of Mexico implies that the weather system has ample supply of moisture to produce heavier snowfalls. When the moisture source region is the East Coast location, the low center would be farther to the east to be able to bring in moisture from this location. Lastly, moisture advected in from the Desert Southwest occurs when a Colorado Low is beginning to develop or when it was further to the south and/or southwest of the state. When the moisture source is from the Gulf of Mexico, greater than 70% of all crashes had the system being a Colorado Low (fig. 4.21). The other two origins, Great Lakes/East Coast and Desert Southwest were much greater for Colorado Lows than the Canadian Rockies source.

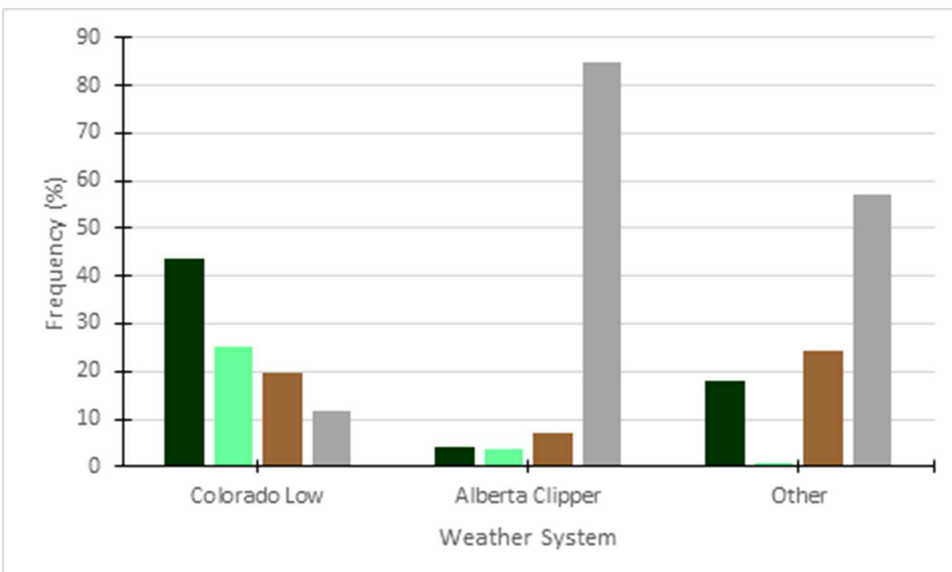


Figure 4.20 Crash frequency with respect to the weather system [with moisture flow from the following locations: Gulf of Mexico (dark green), Great Lakes/East Coast (light green), Desert Southwest (brown), Canadian Rockies (dark grey)]

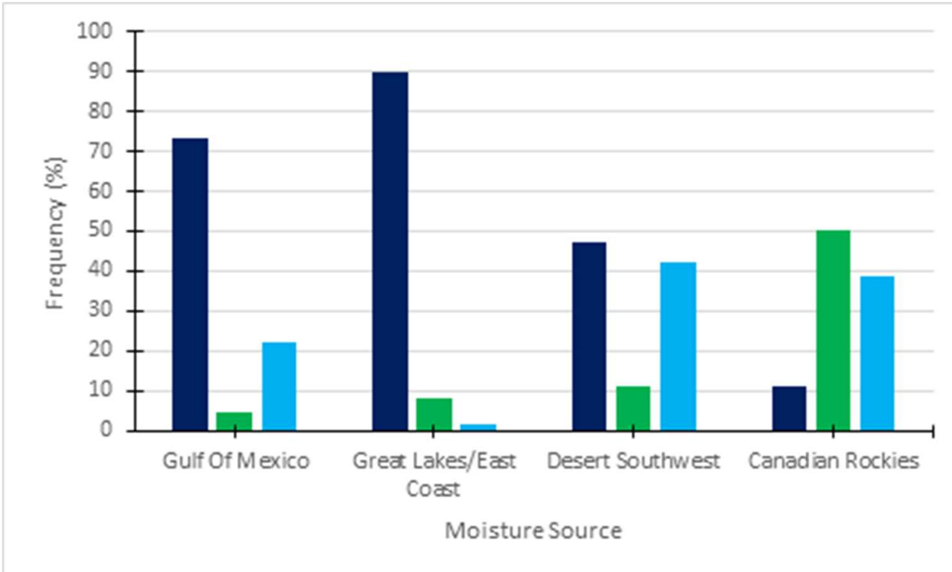


Figure 4.21 Crash frequency with moisture Flow by Colorado Low (dark blue), Alberta Clipper (green), and Other category (light blue)

The 850 hPa wind flow is another parameter which would represent the temperature and moisture advections occurring with the weather systems during a crash (fig. 4.22). As the Colorado Low approaches the Nebraska region, the flow is more from the southwesterly direction meaning that the low has less moisture from Desert Southwest resulting in less precipitation. The western portion of Nebraska would probably be affected the most from this flow pattern. As the system progresses eastward, the southerly wind components mean that the temperature and moisture source for a Colorado Low would be from the Gulf of Mexico. This indicates that the low is still affecting the Nebraska region and the winds would now supply moisture, and possibly warmer temperatures, to the storm. Crash numbers for this direction show fewer than expected crashes, since this scenario results in mixed precipitation (i.e., rain and snow). As the Colorado Low moves eastward, the wind fields will change in a counterclockwise direction so now the Great Lakes/East Coast area will be the source region for temperature and moisture.

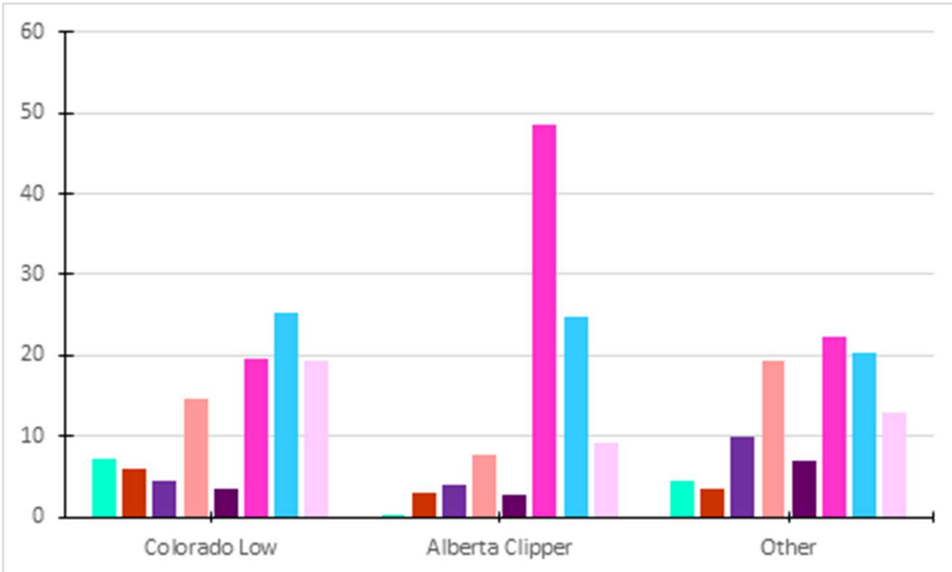


Figure 4.22 Crash frequency with respect to the weather system [850 hPa wind flow data from the following directions: east (teal), southeast (red), south (purple), southwest (rose), west (dark purple), northwest (pink), north (turquoise), northeast (lavender)]

As the Colorado Low continues to move eastward (well east of the Nebraska region), the winds are from a northerly direction. The northerly direction indicates colder temperatures and lower amounts of moisture in the atmosphere resulting in drier water content snowfalls. The dryer snow, colder temperatures, and sometimes increased wind speed, result in possible blowing snow that contributes to an increase in the number of crashes (fig. 4.23).

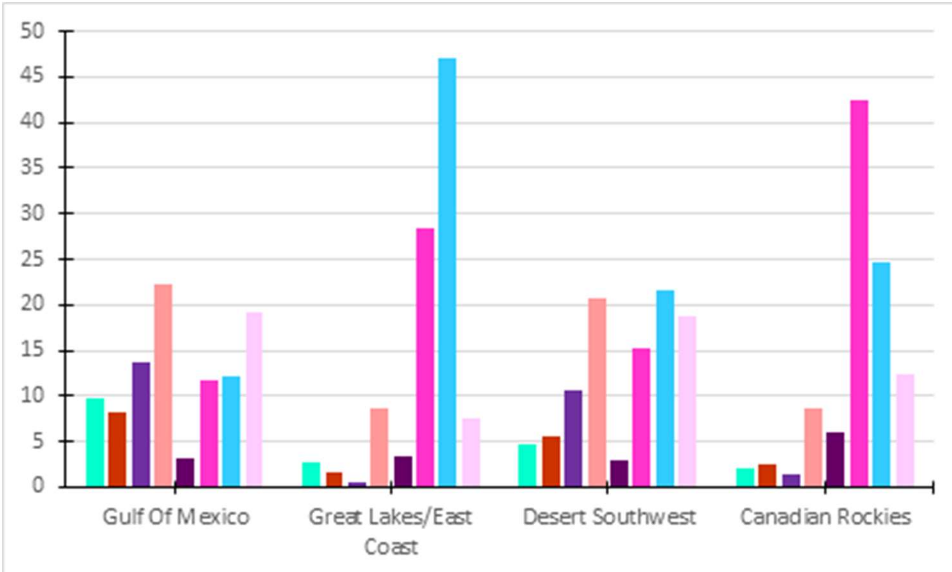


Figure 4.23 Crash frequency with respect to the moisture flow [850 hPa wind flow data from the following directions: east (teal), southeast (red), south (purple), southwest (rose), west (dark purple), northwest (pink), north (turquoise), northeast (lavender)]

4.21 Alberta Clippers

Alberta Clippers were associated with 26% of all crashes (fig. 4.18), which is lower than the Colorado Low. The annual frequency of crashes with Alberta Clippers also varied with season, with 2014-15 winter season having the most and 2012-13 season having fewer crashes (fig. 4.19). It should also be noted that the 2012-13 winter season was during a drought and there were fewer winter storm systems in general over Nebraska. Alberta Clippers over Nebraska usually tend to mostly occur in December through February.

Alberta Clippers' moisture source is almost always from the Canadian Rockies (fig. 4.20). The movement of this type of system is southeasterly across the upper Great Plains and can go as far south as Oklahoma and Texas before switching to a more easterly track. Throughout all of the movement, the moisture source stays consistent, unlike the Colorado Low. When the moisture source is from the Canadian Rockies, more than 80% of the crashes were associated with Alberta Clippers (fig. 4.21). The Alberta Clipper usually has a drier source; due to the clipper's short lifespan and dry moisture source, the amount of snow that could occur during these weather systems is minimal compared to a Colorado Low. However, while the amounts might be lower, the dryness of the snow and stronger winds results in blowing and drifting snow. Most of the crashes that occur with a moisture source from the Canadian Rockies have a northerly wind component about them (fig. 4.22). These systems bring cold temperatures and strong winds with them. Similar to Colorado Lows, clippers can be weak or strong, with the weaker systems producing much less snow.

4.22 Other Category

The Other category is associated with 32% of all reported crashes that occurred in the 10-winter season study period (fig. 4.18). The frequency also indicates that the Other category fluctuated with individual winter seasons (fig. 4.19). Moisture flow for the Other category is mostly from the Canadian Rockies (fig. 4.20). When the moisture flow does originate from the Gulf of Mexico or Desert Southwest, this is typically associated with a stationary front that lines up somewhere across Nebraska or nearby. An example of the Canadian Rockies moisture flow would be a snow squall that occurs for a few minutes to a few hours. The snow totals from these squalls can be from a quick inch or two, to half a foot in a couple of hours. When the Canadian Rockies are the moisture source, almost 40% of all crashes are from the Other category (fig. 4.21). This implies that dryer air, meaning dry snow, is a majority of what this percentage pertains to. More than 40% of all crashes associated with the Desert Southwest moisture source are from the Other category. Similar to when the moisture source is from the Canadian Rockies, the Desert Southwest would usually be a drier snow.

Other has more of a variety of where the winds are coming from than the Alberta Clipper and Colorado Low systems (fig. 4.22). The winds from a northerly or southwesterly component are associated with drier snow that is easy to blow around, causing reduced visibility. When winds are from the south or southeast, the type of snow is wet and can lead to a lot of snow in a matter of hours. Due to the variety of wind directions for the Other category, the distribution of crashes does not favor a specific direction (fig. 4.23). Whereas the Colorado Low and Alberta Clipper have preferred wind directions.

4.23 Crash Severity

In terms of the crash severity (i.e., injury versus fatality), possible injury type has the highest number of crashes than any other injury type (table 4.7). The number of crashes then decreases as the Crash severity increases. Colorado Lows are associated with the greatest number of crashes irrespective of the Crash severity (table 4.8). Colorado Lows are also the deadliest and most likely to cause some form of injury compared to Alberta Clippers. The percentage of crashes related to Crash injury are similar in table 4.8. The numbers offset the percentage in the total number of crashes. Crash severity was aggregated into three categories for the purpose of modeling its association with different variables including weather characteristics. The three categories were possible injury, visible injury, and disabling injury/fatal injury.

Table 4.7 Total frequency and percentage (in parentheses) of crashes with respect to weather system with crash severity data

Weather System	Possible	Visible	Disabling	Fatality	Total
Colorado Low	1158 (61)	497 (26)	209 (11)	38 (2)	1902 (100)
Alberta Clipper	725 (60)	324 (27)	147 (12)	21 (2)	1217 (100)
Other	832 (60)	373 (27)	153 (11)	34 (2)	1392 (100)
Total	2715	1194	509	93	4511

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table 4.8 Total frequency and percentage (in parentheses) of crashes with respect to crash severity with weather system data

Weather System Type	**Possible**	**Visible**	**Disabling**	**Fatality**	**Total**
Colorado Low	1158 (43)	497 (42)	209 (41)	38 (41)	1902
Alberta Clipper	725 (27)	324 (27)	147 (29)	21 23)	1217
Other	832 (31)	373 (31)	153 (30)	34 (37)	1392
Crash Severity Total	2715 (100)	1194 (100)	509 (100)	93 (100)	4511

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

4.24 National Weather System (NWS) Alerts

Out of the 93 fatal crashes in the analysis database, 56 occurred when a National Weather System (NWS) Winter Weather Advisory (WWA) was issued. Of those 56 fatal crashes, 35 had an active alert at the time of the crash (fig. 4.24). When looking at the no alert category, there were 37 total fatal crashes during the ten-year timeframe. These no alert fatal crashes have a majority of the road conditions being iced over, with the second highest amount being the snowy road condition (fig. 4.25). It is important to note that NWS typically only issues WWAs for periods of precipitation and not for residual adverse road conditions that may persist well beyond the end of the storm (NWS 2019).

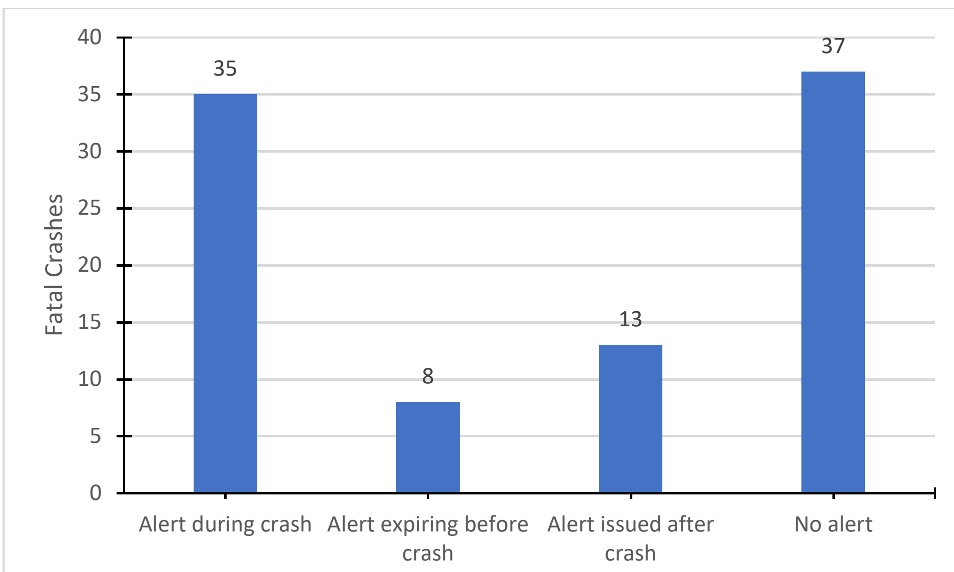


Figure 4.24 Fatal crashes and NWS alerts

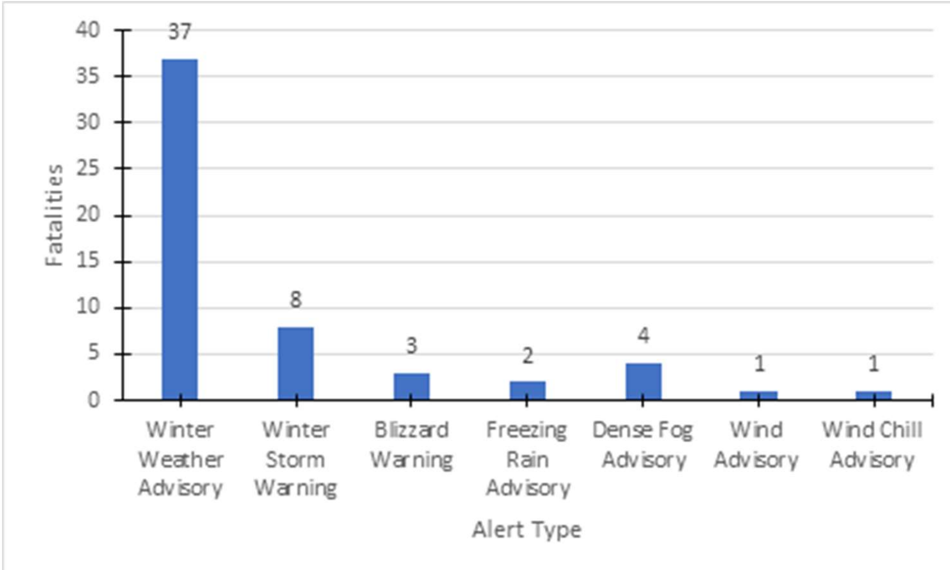


Figure 4.25 Fatal crash count when a NWS alert was issued

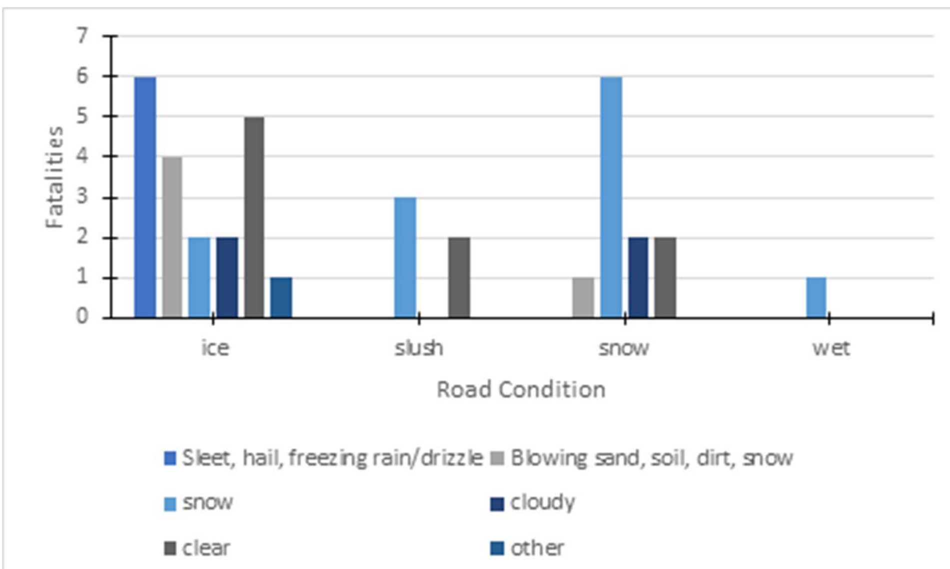


Figure 4.26 Fatal crash count when no alert was Issued by NWS by road conditions [weather conditions: sleet (blue), blowing snow (grey), snow (light blue), cloudy (dark blue), clear (dark grey), other (light navy blue)]

4.25 Modeling Crash Injury Severity

Crash severity is classified into discrete categories which describe the injury level of the most severely injured road user involved in a crash. These categories are usually ordered from the most severe crash (fatal) to the least severe crash (property-damage-only). Modeling is usually based on either ordered response models due to the ordinal nature of the dependent variable (Kockelman and Kweon 2002; Khattak et al. 2002; Khattak et al. 2003) or unordered response models that allow covariates to possess a non-monotonic effect on the predicted variable. The multinomial logit model is an example of the latter (Shankar and Mannering 1996; Ulfarsson and Mannering 2004).

A multinomial logit model was estimated for injury severity in this research with three categories of severity. Readers interested in the development of the multinomial logit model are referred to Mannering (1996) and Ulfarsson and Mannering (2004). Briefly, the logit model establishes a relationship among the different categories of the dependent variable with independent variables. The coefficients (βi) of the independent variables are estimated by the method of maximum likelihood. NLOGIT (Version 5.0) was used for model estimation in this research. The categories of crash severity were; possible injury (coded as 0), visible injury (coded as 1), and disabling injury/fatality (coded as 2). Tables 4.9 and 4.10 present the descriptions and coding of the dependent and independent variables used for modeling crash injury severity. Table 4.11 presents the estimated model for crash injury severity.

Table 4.9 Injury severity categories (dependent variable)

Injury Severity	**Number of Observations**	**Percentage of Observations**
Possible injury	2715	60.19%
Visible injury	1314	29.13%
Disabling injury/fatal	482	10.68%
Total	4511	100.00%

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table 4.10 Descriptions of Dependent and Independent Variables

S. No.	Selected Variable and Description	Mean	Standard Deviation
1	Crash severity (0 if possible injury, 1 if visible injury, 2 if disabling injury/fatality).	0.504	0.68
2	Ice indicator (1 if road surface condition is ice, 0 otherwise)	0.474	0.499
3	Rain indicator (1 if weather condition is rain, 0 otherwise)	0.002	0.049
4	Cloudy indicator (1 if weather condition is cloudy, 0 otherwise)	0.038	0.192
5	Clear indicator (1 if weather condition is clear, 0 otherwise)	0.012	0.111
6	Urban indicator (1 if the population group is urban 10,000-24,999 , 0 otherwise)	0.055	0.229
7	Shoulder indicator (1 if the vehicle hits a shoulder, 0 otherwise)	0.003	0.059
8	Asphalt indicator (1 if crash occurred on asphalt pavement, 0 otherwise)	0.439	0.496
9	Total vehicle (total vehicles involved in a crash—numeric variable)	1.633	0.930
10	Angled indicator (1 if direction of crash is angled, 0 otherwise)	0.144	0.351
11	Visibility (measure of the distance at which object is clearly discerned—numeric variable)	5.241	3.87
12	Temperature (numeric variable)	21.992	9.751
13	Snow fall (numeric variable)	1.110	1.711
14	Snow depth (numeric variable)	2.130	2.441

Table 4.11 Multinomial Logit Regression Results

Model Summary Statistics				
Number of observations	4,511			
Log- likelihood	-3978.92049			
Restricted log-likelihood	-4077.13364			
Chi-square (26 d.f)	196.42			
P-value	.00000			
McFadden pseudo R-squared	.0240888			
Injury Category → (Base: Possible Injury)	**Visible Injury**		**Disabling Injury/Fatality**	
Variables	Coefficient	P- value	Coefficient	P- value
Intercept	-0.9671	0.000	-2.154	0.000
Ice as a road surface condition	0.2521	0.0004	0.32465	0.0018
Rain as a weather condition	2.0601	0.0094	-	-
Cloudy as a weather condition	0.4681	0.0064	0.5256	0.0268
Clear as a weather condition	-0.5809	0.0910	-	-
Urban, 10,000-24,999	-0.3141	0.0465	-1.240	0.0004
Crash due to shoulder	-	-	1.221	0.0557
Angled crash direction	-	-	0.391	0.0046
Asphalt as pavement type	0.1518	0.0291	0.598	0.000
Total vehicles involved in crash	-0.1522	0.0021	-	-
Visibility	0.0269	0.0044	-0.032	0.0224
Temperature	0.0100	0.0059	-	-
Snow fall	0.0821	0.0043	-	-
Snow depth	-0.074	0.0002	-0.058	0.0469

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

To keep as many intuitive variables as possible in the estimated model, variables with 90% statistical significance were retained even though the predicted model has more variables with p value<0.05 (95% significance). Modeling results in table 4.11 show that icy road surface conditions statistically significantly increased crash injury severities. The estimated coefficients reveal that there is a higher likelihood of disabling injury/fatality followed by visible injury for crashes reported on icy pavements compared to the base category (possible injury crashes). Rain increased the chances of crashes with visible injuries compared to possible injury crashes but its effect on disabling injury/fatal crashes was statistically not significant. Cloudy weather increased the likelihood of visible injuries as well as disabling injury/fatality crashes compared to the base category. For clear weather conditions the model predicted a lower likelihood of visible injury crashes and its effect on disabling injury/fatality crashes was statistically not significant. In addition, population group, asphalt type of pavement and direction of crashes were also found affecting injury severity.

With respect to winter weather conditions, the model showed that higher visibility was statistically associated with increased likelihood of visible injury crashes but lower likelihood of disabling injury/fatality crashes. This might be because better visibility increases driving comfort even though there are adverse weather conditions that might encourage drivers to be less cautious or travel at high speeds, consequently causing severe crashes. The model showed that the risk of visible injuries increased with higher temperature; this finding is intuitive as the past research has shown that higher ambient temperature increases the risk of crash involvement (Kampe et al., 2016; Basangana et al., 2015). Furthermore, the model showed a higher likelihood of visible injuries with greater amounts of snowfall however, greater snow depth was associated with fewer visible injury crashes and fewer disabling injury/fatality crashes compared to the base category of crashes with possible injuries.

4.26 NEWINS Crash Analysis

An initial assessment to determine the utility of the NEWINS metric with respect to vehicular crashes is understanding how well NEWINS events align with the occurrence, or lack thereof, of vehicular crashes. table 4.12 summarizes the alignment among the following three criteria: (1) reported crashes that occurred during NEWINS events, (2) reported crashes that occurred outside of NEWINS events, and (3) NEWINS events that were not associated with any reported crashes. Overall, about half of the NEWINS events and reported crashes (52.08%) were associated with one another. Consideration of the crashes independently reveals that 68.34% of them occurred during an NEWINS event. A quarter of the NEWINS events and reported crashes (24.12%), or 31.66% of the crashes independently, were not associated with one another. A remaining quarter (23.8%) of the NEWINS events were not associated with any reported crashes.

Table 4.12 Frequency distribution of events based on association with NEWINS events (percentage shown in parentheses)

Identifier	**Winter Season**										**Identifier Percentage**
	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
Crashes During NEWINS Event	372 (53.37)	524 (54.24)	447 (57.02)	187 (49.87)	318 (51.13)	241 (46.17)	216 (50.59)	235 (47.67)	219 (51.05)	324 (53.55)	52.08
Crashes Not During NEWINS Event	180 (25.82)	291 (30.12)	194 (24.74)	110 (29.33)	156 (25.08)	109 (20.88)	85 (19.91)	109 (22.11)	107 (24.94)	87 (14.38)	24.12
NEWINS Events With No Crashes	145 (20.80)	151 (15.63)	143 (18.24)	78 (20.80)	148 (23.79)	172 (32.95)	126 (29.51)	149 (30.22)	103 (24.01)	194 (32.07)	23.80

In general, these results show relatively good alignment between the NEWINS events and crashes; however, there are some important caveats. First, recall that in this analysis crashes were defined only as those that resulted in injuries and/or fatalities. Property damage crashes were not included in the dataset but would likely improve the association between the NEWINS events and crashes with their inclusion. Another caveat is that the NEWINS metric only categorizes events during precipitation periods. This means that any crash occurring outside of that period, regardless of the resultant road conditions, would not explicitly be associated with the NEWINS event. It was observed in the crash data that crashes had occurred up to several days after an event due to blowing/drifting snow and/or refreezing of melted snow on the pavement (i.e., crashes that occur with no new snowfall). A final caveat worth noting is that the NEWINS event metric is spatially limited in that it considers relatively large areas of precipitation. Smaller, more localized icing and/or precipitation events (e.g., freezing fog, overnight frost, bridge/roadway icing) may not be detected by the NEWINS algorithm, yet still contribute to winter weather-related vehicular crashes. Despite these caveats, the NEWINS metric has potential to better understand the nature of winter weather-related crashes.

4.27 NEWINS Crash Severity Analysis

The most informative analysis is determining the relationships among the NEWINS categorical event classifications and the associated vehicular crash severity. Tables 4.13 through 4.18 contain vehicular crash severity distribution for each NEWINS event category while table 4.19 contains the NEWINS categorical distribution of crashes irrespective of crash severity. Overall, there is not substantive season to season variability. NEWINS Category 2 had the greatest overall crash frequency (1001 crashes, 32.48%), despite NEWINS Category 1 having the greatest frequency of occurrence (see table 3.2). NEWINS Category 6 had the fewest associated crashes (22 total crashes, 0.71%) which aligns with its relatively low frequency of occurrence (see table 3.2).

Table 4.13 Crash severity frequency distribution for NEWINS Category 1 for the ten-winter season study period with percentage shown in parentheses

NEWINS Category	Crash Severity	Winter Season										Total Crashes
		2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
1	Possible Injury	91 (68.94)	108 (60.34)	55 (59.14)	22 (43.14)	48 (55.17)	41 (53.25)	41 (61.19)	43 (56.58)	45 (56.25)	58 (58.00)	552 (58.60)
	Visible Injury	26 (19.70)	54 (30.17)	24 (25.81)	22 (43.14)	25 (28.74)	21 (27.27)	16 (23.88)	23 (30.26)	21 (26.25)	27 (27.00)	259 (27.49)
	Disabling Injury	13 (9.85)	15 (8.38)	12 (12.90)	7 (13.73)	13 (14.94)	12 (15.58)	9 (13.43)	8 (10.53)	12 (15.00)	13 (13.00)	114 (12.10)
	Fatality	2 (1.52)	2 (1.12)	2 (2.15)	0 (0.00)	1 (1.15)	3 (3.90)	1 (1.49)	2 (2.63)	2 (2.50)	2 (2.00)	17 (1.80)
	NEWINS Cat 1 Total	132 (100.00)	179 (100.00)	93 (100.00)	51 (100.00)	87 (100.00)	77 (100.00)	67 (100.00)	76 (100.00)	80 (100.00)	100 (100.00)	942 (100.00)

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table 4.14 Crash severity frequency distribution for NEWINS Category 2 for the ten-winter season study period with percentage shown in parentheses

NEWINS Category	Crash Severity	Winter Season										Total Crashes
		2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
2	Possible Injury	81 (62.79)	108 (55.96)	84 (61.76)	22 (55.00)	49 (58.33)	49 (63.64)	28 (47.46)	31 (58.49)	50 (59.52)	88 (60.27)	590 (58.94)
	Visible Injury	33 (25.58)	51 (26.42)	32 (23.53)	13 (32.50)	22 (26.19)	14 (18.18)	26 (44.07)	20 (37.74)	23 (27.38)	40 (27.40)	274 (27.37)
	Disabling Injury	15 (11.63)	27 (13.99)	18 (13.24)	5 (12.50)	10 (11.90)	12 (15.58)	4 (6.78)	1 (1.89)	10 (11.90)	15 (10.27)	117 (11.69)
	Fatality	0 (0.00)	7 (3.63)	2 (1.47)	0 (0.00)	3 (3.57)	2 (2.60)	1 (1.69)	1 (1.89)	1 (1.19)	3 (2.05)	20 (2.00)
	NEWINS Cat 2 Total	129 (100.00)	193 (100.00)	136 (100.00)	40 (100.00)	84 (100.00)	77 (100.00)	59 (100.00)	53 (100.00)	84 (100.00)	146 (100.00)	1001 (100.00)

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table 4.15 Crash severity frequency distribution for NEWINS Category 3 for the ten-winter season study period with percentage shown in parentheses

NEWINS Category	**Crash Severity**	**Winter Season**										**Total Crashes**
		2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
3	Possible Injury	27 (77.14)	40 (59.70)	81 (69.83)	23 (62.16)	47 (61.84)	27 (57.45)	23 (56.10)	30 (66.67)	24 (63.16)	33 (67.35)	355 (64.43)
	Visible Injury	7 (20.00)	16 (23.88)	30 (25.86)	8 (21.62)	16 (21.05)	12 (25.53)	13 (31.71)	12 (26.67)	8 (21.05)	10 (20.41)	132 (23.96)
	Disabling Injury	1 (2.86)	8 (11.94)	4 (3.45)	4 (10.81)	9 (11.84)	5 (10.64)	3 (7.32)	2 (4.44)	5 (13.16)	4 (8.16)	45 (8.17)
	Fatality	0 (0.00)	3 (4.48)	1 (0.86)	2 (5.41)	4 (5.26)	3 (6.38)	2 (4.88)	1 (2.22)	1 (2.63)	2 (4.08)	19 (3.45)
	NEWINS Cat 3 Total	35 (100.00)	67 (100.00)	116 (100.00)	37 (100.00)	76 (100.00)	47 (100.00)	41 (100.00)	45 (100.00)	38 (100.00)	49 (100.00)	551 (100.00)

Table 4.16 Crash severity frequency distribution for NEWINS Category 4 for the ten-winter season study period with percentage shown in parentheses

NEWINS Category	**Crash Severity**	**Winter Season**										**Total Crashes**
		2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
4	Possible Injury	28 (59.57)	36 (59.02)	41 (60.29)	26 (60.47)	18 (52.94)	22 (64.71)	21 (58.33)	24 (64.86)	6 (50.00)	17 (62.96)	239 (59.90)
	Visible Injury	12 (25.53)	19 (31.15)	19 (27.94)	10 (23.26)	8 (23.53)	9 (26.47)	10 (27.78)	11 (29.73)	5 (41.67)	4 (14.81)	107 (26.82)
	Disabling Injury	7 (14.89)	6 (9.84)	7 (10.29)	6 (13.95)	7 (20.59)	2 (5.88)	5 (13.89)	2 (5.41)	1 (8.33)	6 (22.22)	49 (12.28)
	Fatality	0 0.00)	0 (0.00)	1 (1.47)	1 (2.33)	1 (2.94)	1 (2.94)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	4 (0.60)
	NEWINS Cat 4 Total	47 (100.00)	61 (100.00)	68 (100.00)	43 (100.00)	34 (100.00)	34 (100.00)	36 (100.00)	37 (100.00)	12 (100.00)	27 (100.00)	399 (100.00)

Table 4.17 Crash severity frequency distribution for NEWINS Category 5 for the ten-winter season study period with percentage shown in parentheses

NEWINS Category	Crash Severity	Winter Season										Total Crashes
		2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
5	Possible Injury	20 (68.97)	12 (75.00)	18 (62.07)	15 (93.75)	31 (83.78)	1 (20.00)	8 (61.54)	14 (73.68)	0 (0.00)	0 (0.00)	119 (71.26)
	Visible Injury	5 (17.24)	3 (18.75)	8 (27.59)	0 (0.00)	4 (10.81)	3 (60.00)	4 (30.77)	5 (26.32)	2 (66.67)	0 (0.00)	34 (20.36)
	Disabling Injury	4 (13.79)	1 (6.25)	3 (10.34)	1 (6.25)	2 (5.41)	0 (0.00)	1 (7.69)	0 (0.00)	1 (33.33)	0 (0.00)	13 (7.78)
	Fatality	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (20.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.60)
	NEWINS Cat 5 Total	29 (100.00)	16 (100.00)	29 (100.00)	16 (100.00)	37 (100.00)	5 (100.00)	13 (100.00)	19 (100.00)	3 (100.00)	0 (0.00)	167 (100.00)

Table 4.18 Crash severity frequency distribution for NEWINS Category 6 for the ten-winter season study period with percentage shown in parentheses

NEWINS Category	**Crash Severity**	**Winter Season**										**Total Crashes**
		2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
6	Possible Injury	0 (0.00)	5 (62.50)	4 (80.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (20.00)	2 (100.00)	1 (50.00)	13 (59.09)
	Visible Injury	0 (0.00)	2 (25.00)	1 (20.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	3 (60.00)	0 (0.00)	0 (0.00)	6 (27.27)
	Disabling Injury	0 (0.00)	1 (12.50)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (20.00)	0 (0.00)	1 (50.00)	3 (13.64)
	Fatality	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
	NEWINS Cat 6 Total	0 (0.00)	8 (100.00)	5 (100.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	5 (100.00)	2 (100.00)	2 (100.00)	22 (100.00)

Table 4.19 Crash frequency distribution segmented by NEWINS categorical event classification for the ten-winter season study period with percentage shown in parentheses

NEWINS Category	Winter Season										Total Crashes
	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	
Cat 1	132 (35.48)	179 (34.16)	93 (20.81)	51 (27.27)	87 (27.36)	77 (32.08)	67 (31.02)	76 (32.34)	80 (36.53)	100 (30.86)	942 (30.56)
Cat 2	129 (34.68)	193 (36.83)	136 (30.43)	40 (21.39)	84 (26.42)	77 (32.08)	59 (27.31)	53 (22.55)	84 (38.36)	146 (45.06)	1001 (32.48)
Cat 3	35 (9.41)	67 (12.79)	116 (25.95)	37 (19.79)	76 (23.90)	47 (19.58)	41 (18.98)	45 (19.15)	38 (17.35)	49 (15.12)	551 (17.88)
Cat 4	47 (12.63)	61 (11.64)	68 (15.21)	43 (22.99)	34 (10.69)	34 (14.17)	36 (16.67)	37 (15.74)	12 (5.48)	27 (8.33)	399 (12.95)
Cat 5	29 (7.80)	16 (3.05)	29 (6.49)	16 (8.56)	37 (11.64)	5 (2.08)	13 (6.02)	19 (8.09)	3 (1.37)	0 (0.00)	167 (5.42)
Cat 6	0 (0.00)	8 (1.53)	5 (1.12)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	5 (2.13)	2 (0.91)	2 (0.62)	22 (0.71)
Total Crashes	372 (100.00)	524 (100.00)	447 (100.00)	187 (100.00)	318 (100.00)	240 (100.00)	216 (100.00)	235 (100.00)	219 (100.00)	324 (100.00)	3082 (100.00)

In terms of crash severity, regardless of the NEWINS event category, the Possible Injury crash severity represents approximately 60% of the NEWINS-associated crashes. The next severity level, Visible Injury, represents approximately 25% of the NEWINS-associated crashes. Disabling Injuries (referred to as Suspected Serious Injuries from 2015 onward) represent approximately 10% of the NEWINS-associated crashes. Last, Fatality NEWINS-associated crashes represent 5% or less of the remaining data.

The NEWINS-associated crash results align with the weather data. Most crashes occur in far lower "impact" events (i.e., Categories 1 and 2, lower snowfall amounts). This observation has a few possible explanations including the relatively high frequency of these events as well as the difficulty communicating and recognizing the dangers posed by these more "nuisance" type events. For the higher "impact" events (i.e., Categories 4–6), there is generally a greater awareness of the hazard by motorists and messaging well in advance of the event by transportation agencies and meteorologists. Roads may be closed preemptively, and schools/businesses may close as well. For the lower tier events, there may be a greater propensity to attempt to conduct business as usual. Motorists may not adjust speed and vehicle following distance/gaps sufficiently to avoid crashes. Recent work (Petr 2019) shows the dangers posed by these high-impact, sub-advisory or "HISA" events in which there may be relatively minimal messaging in advance of a storm, relatively minor snowfall accumulations, and yet there are widespread impacts to mobility such as numerous crashes. Indeed, these results may suggest areas for improvement in the NEWINS framework to consider increasing the weight of these lower tier events given their more robust and uncertain impacts. The implications overall suggest that messaging campaigns such as Pathfinder (FHWA 2020) may need to target seemingly lower tier events that have an overexposed impact footprint.

Chapter 5 Summary and Conclusions

To summarize, this research focused on understanding how winter weather conditions contributed to the occurrence of vehicular crashes in Nebraska from the 2008-2009 winter season through the 2017-2018 winter season. Crash data were filtered to ensure the analysis considered only those crashes that were either directly, or most likely, associated with winter weather conditions. Also, this analysis considered only injury and fatality crashes due to the relative importance of these higher severity crashes with respect to road closures, emergency services personnel deployment, and human costs. Weather data up to 72 hours prior to a crash as well as conditions at the time of the crash were assessed to understand the nature of contributing conditions. The combined crash and weather data were further analyzed based on individual parameters and aggregate groups such as the type of weather system or the NEWINS storm classification.

Overall, the key finding of the analysis was most winter-weather related vehicular crashes were associated with relatively minimal winter weather conditions. The reported crashes typically occurred either with relatively low snowfall amounts or as a result of residual snowfall on the ground even though it was no longer precipitating. This highlights the need for winter maintenance operations activities to continue well after a storm has exited the region and also the need for continued messaging of hazardous weather conditions. Another key finding was that most crashes are of lower severity (i.e., relatively minor injuries) and fatal crashes tend to be relatively rare events. An important caveat of this result is that traffic volumes are typically lower during winter storms and must be taken into account. This makes the actual risk of a crash larger than the findings of this analysis alone would suggest.

Modeling of crash injury severity showed higher injury severity associated with icy pavements; higher visibility was associated with visible injury crashes but not with lower likelihood of disabling injury/fatal crashes. The risk of serious injuries increased with higher temperature, which was similar to past findings reported in the literature. While snowfall has implications for crash occurrence, it is also associated with greater crash injury severity. Greater snow depth was associated with lower levels of crash severity, perhaps reflecting drivers' more careful driving behavior when large amounts of snow are deposited.

The importance of looking at winter-weather related vehicular crashes from a winter season perspective rather than annually is because the annual perspective captures only a portion of two separate, distinct winter seasons. The seasonal perspective allows for broader consideration of weather conditions across the specific season that contributed to the crash severity distribution. Meteorologically, the winter season perspective also allows for consideration of sub-seasonal to seasonal impact forecasting. Large-scale (i.e., synoptic), global weather patterns and their associated relationships (i.e., teleconnections) can be correlated with individual storm systems and their resultant impacts. For example, El-Nino or La-Nina represent commonly reported global teleconnection patterns over the Pacific Ocean that have significant influences on winter weather in Nebraska. El-Nino conditions may favor larger snowstorms (i.e., Colorado Lows) with heavier, wetter snowfalls while La-Nina conditions may favor smaller snowstorms (i.e., Alberta Clippers) with lighter, drier albeit more frequent snowfalls. As this analysis has shown, the type of weather system can have implications for the frequency of vehicular crashes. These global weather patterns can be forecast months in advance and allow for long-range strategic planning for transportation agencies regarding potential expected impacts. There are a few limitations worth noting in the scope of the present analysis. In terms of the crash data, property damage and non-reportable crashes or slide-offs were not considered in the crash data. Injury and fatality crashes are typically associated with higher resource needs; however, many property damage crashes can have significant road impacts as well (e.g., jackknifed semi-trailer obstructing all lanes of an interstate highway). In the future, consideration of all crashes would be important to develop a more complete picture. Another limitation was the criteria used to define a winter weather-related crash. While the criteria were intended to maximize the number of crashes in the analysis, some outliers remain. For example, wildlife-involved vehicle crashes that occurred with adverse road and/or weather conditions may or may not be truly attributable to the conditions alone. Without a detailed crash narrative or self-report from the involved motorist, it would be impossible to determine how conditions contributed to the collision.

There are additional limitations regarding the weather data as well such as the temporal resolution and availability of weather data. Snowfall data, in particular, are only available at six-hourly increments. Similarly, the NEWINS metric is only computed on a daily basis. These data do not allow for more detailed consideration (e.g., hourly or sub-hourly) of the weather conditions immediately coincident with the occurrence of crashes. Spatially, unless a crash occurs in the immediate vicinity of a weather station, there is some reasonable assumption of the similarity of conditions across distances that may be several miles apart. One final limitation worth noting in this study is that the road specific conditions along the segment on which a crash occurred are unknown. Additionally, there is no knowledge of maintenance activities (e.g., plowing, material application) that may or may not have occurred along that particular segment and what the cycle times may have been. One potential solution to this lack of road and maintenance activity knowledge would be leveraging traffic and snow plow camera datasets to provide better validation of real-time, in-situ conditions.

Future directions of the research beyond this analysis are plentiful. First, as noted above, inclusion of all crashes would be worthwhile for a more robust assessment of crashes and weather conditions. Next, refinement of the NEWINS to serve as an impact-forecast metric may be informative not only for a crash analysis but also for related winter maintenance activities such as public messaging, personnel staffing decisions, and resource allocation. Third, also as noted above, inclusion of additional datasets (e.g., cameras) would provide further understanding of road-segment specific weather conditions that contribute to crashes. One final additional analysis worth undertaking would be a “hotspot” identification in which particularly problematic road segments with several crashes during winter weather conditions are identified. These road segments may be locations in which additional safety measures (e.g., lightning, guardrails, roadway redesign) could be implemented to reduce crash frequency and/or severity.

In conclusion, the ability to characterize, quantify, and associate specific weather conditions with the frequency and severity of vehicular crashes provides crucial insight for transportation personnel. This information may inform winter maintenance activities, operational decisions, and public messaging campaigns. The fundamental purpose of the transportation agency is to provide the greatest level of service and safety at the most efficient resource allocation level. This analysis may facilitate future determination of adjustments in resource allocation and/or safety improvements that can be undertaken by the agency. Broadly, this analysis will also better inform both the transportation and meteorological communities of the ever-present dangers presented by weather on the roads.

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Appendix A

2008-2009

Table A1 Time of crash

Time of the Crash	**Number of Crashes**
12:00 AM -6:00 AM	101
6:00 AM -12:00 PM	198
12:00 PM -6:00 PM	185
6:00 PM -12:00 AM	68
Total	**552**

Table A2 Road surface condition

Road Surface Condition	**Number of Crashes**
Ice	268
Slush	28
Snow	244
Wet	12
Grand Total	**552**

Table A3 Months

Months	**Number of Crashes**
Nov	53
Dec	163
Jan	179
Feb	93
Mar	48
Apr	16
May	0
Grand Total	**552**

Table A4 Weather condition I

Weather Condition I	**Number of Crashes**
Snow	208
Sleet, hail, freezing rain/drizzle	82
Blowing sand, soil, dirt, snow	33
Severe crosswinds	15
Cloudy	106
Fog, smog, smoke	6
Rain	2
Clear	92
Not stated	5
Unknown	3
Grand Total	**552**

Table A5 Weather condition II

Weather Condition II	**Number of Crashes**
Snow	53
Sleet, hail, freezing rain/drizzle	19
Blowing sand, soil, dirt, snow	57
Severe crosswinds	33
Cloudy	21
Fog, smog, smoke	1
Rain	1
Clear	9
Not stated	356
Unknown	1
Other	1
Grand Total	**552**

Table A6 Road classification

Road Classification	**Number of Crashes**
Interstate Mainline	116
Interstate Ramp	10
Highway	420
Highway Ramp	6
Grand Total	**552**

Table A7 Crash severity

Crash Severity	Number of Crashes
Possible Injury	340
Visible Injury	139
Disabling Injury	68
Fatal	5
Grand Total	**552**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A8 Light conditions

Light Condition	Number of Crashes
Dawn	18
Daylight	326
Dusk	17
Dark - lighted roadway	83
Dark -rdwy not lighted	97
Dark-unk rdwy lighting	6
Not stated	4
Unknown	1
Grand Total	**552**

Table A9 Road characteristics

Road Characteristics	Number of Crashes
Straight and level	363
Straight and on hilltop	19
Straight and on slope	106
Curved and level	26
Curved and on hilltop	3
Curved and on slope	32
Not stated	3
Grand Total	**552**

Table A10 Road surface type

Road Surface Type	Number of Crashes
Asphalt	257
Concrete	289
Gravel	1
Not stated	5
Grand Total	**552**

Table A11 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	9
Lane closure	3
Not applicable	471
Other	3
Work on shoulder or median	66
Grand Total	**552**

Table A12 Road junction type

Road Junction Type	Number of Crashes
Crossover	4
Driveway	9
Five-point, or more	1
Four-way intersection	88
Not at junction	361
Not stated	43
Off-ramp	15
On-ramp	13
T-intersection	17
Y-intersection	1
Grand Total	**552**

Table A13 First harmful event

First Harmful Event	Number of Crashes
Animal	5
Bicycle (Pedal cycle)	1
Bridge pier or abutment	1
Bridge rail	12
Culvert	7
Ditch	15
Embankment	8
Fence	6
Guardrail end	1
Guardrail face	11
Highway traffic sign post	3
Jackknife	7
Light/luminaire support	9
Mail box	1
Median barrier	19
Motor vehicle in transport	290
Other fixed object	5
Other movable object	1
Other post, pole, or suppt	6
Overturn/rollover	120
Parked motor vehicle	7
Pedestrian	1
Tree	9
Unknown	1
Unknown non-collision	1
Utility pole	5
Grand Total	**552**

2009-2010

Table A14 Time of crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	73
6:00 AM -12:00 PM	365
12:00 PM -6:00 PM	226
6:00 PM -12:00 AM	151
Total	**815**

Table A15 Road surface condition

Road Surface Condition	Number of Crashes
Snow	361
Ice	386
Slush	51
Wet	17
Grand Total	**815**

Table A16 Months

Months	Number of Crashes
Oct	40
Nov	11
Dec	250
Jan	219
Feb	256
Mar	38
Apr	1
May	0
Grand Total	**815**

Table A17 Weather condition I

Weather Condition I	Number of Crashes
Snow	271
Sleet, hail, freezing rain/drizzle	72
Blowing sand, soil, dirt, snow	89
Severe crosswinds	13
Cloudy	161
Fog, smog, smoke	20
Clear	179
Rain	5
Not stated	2
Other	3
Grand Total	**815**

Table A18 Weather condition II

Weather Condition II	Number of Crashes
Snow	76
Sleet, hail, freezing rain/drizzle	33
Blowing sand, soil, dirt, snow	77
Severe crosswinds	46
Cloudy	25
Fog, smog, smoke	4
Clear	18
Rain	2
Not stated	533
Other	1
Grand Total	**815**

Table A19 Road classification

Road Classification	Number of Crashes
Interstate mainline	210
Interstate ramp	11
Interstate rest area/scale	2
Highway	582
Highway ramp	10
Grand Total	**815**

Table A20 Crash severity

Crash Severity	Number of Crashes
Possible Injury	491
Visible Injury	217
Disabling Injury	88
Fatal	19
Grand Total	**815**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A21 Light condition

Light Condition	Number of Crashes
Dark - lighted roadway	103
Dark -roadway not lighted	157
Dark-unknown roadway lighting	2
Dawn	41
Daylight	486
Dusk	24
Not stated	2
Grand Total	**815**

Table A22 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	65
Curved and on hilltop	2
Curved and on slope	38
Not stated	2
Straight and level	510
Straight and on hilltop	18
Straight and on slope	180
Grand Total	**815**

Table A23 Road surface type

Road Surface Type	Number of Crashes
Asphalt	316
Brick	3
Concrete	492
Gravel	2
Not stated	2
Grand Total	**815**

Table A24 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	4
Lane closure	2
Not applicable	802
Other	7
Work on shoulder or median	2
Grand Total	**815**

Table A25 Roadway junction type

Roadway Junction Type	Number of Crashes
Crossover	7
Driveway	6
Five-point, or more	1
Four-way intersection	118
Not at junction	551
Not stated	51
Off-ramp	13
On-ramp	16
Railroad grade crossing	1
T-intersection	43
Unknown	2
Y-intersection	6
Grand Total	**815**

Table A26 First harmful event

Harmful Event	**Number of Crashes**
Bridge pier or abutment	2
Bridge rail	22
Culvert	3
Curb	2
Ditch	38
Embankment	12
Fence	3
Guardrail end	1
Guardrail face	21
Highway traffic sign post	11
Impact attenuator/cr cushn	1
Jackknife	6
Light/luminaire support	13
Mail box	1
Median barrier	24
Motor vehicle in transport	447
Other	2
Other fixed object	2
Other movable object	1
Other non-collision	1
Other post, pole, or suppt	7
Overturn/rollover	168
Parked motor vehicle	14
Tree	8
Utility pole	7
Grand Total	**815**

2010-2011

Table A27 Time of crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	103
6:00 AM -12:00 PM	232
12:00 PM -6:00 PM	236
6:00 PM -12:00 AM	70
Total	641

Table A28 Road surface condition

Road Surface Condition	Number of Crashes
Snow	280
Ice	301
Slush	45
Wet	15
Grand Total	**641**

Table A29 Months

Months	Number of Crashes
Jan	199
Feb	142
Mar	79
Apr	17
May	2
Nov	73
Dec	129
Grand Total	**641**

Table A30 Weather condition I

Weather Condition I	Number of Crashes
Blowing sand, soil, dirt, snow	28
Clear	114
Cloudy	99
Fog, smog, smoke	6
Not stated	1
Other	1
Rain	1
Severe crosswinds	2
Sleet, hail, freezing rain/drizzle	142
Snow	247
Grand Total	**641**

Table A31 Weather condition II

Weather Condition II	Number of Crashes
Blowing sand, soil, dirt, snow	48
Clear	13
Cloudy	35
Fog, smog, smoke	6
Not stated	430
Rain	2
Severe crosswinds	29
Sleet, hail, freezing rain/drizzle	21
Snow	56
Unknown	1
Grand Total	**641**

Table A32 Road classification

Road Classification	Number of Crashes
Highway	460
Highway ramp	2
Interstate mainline	166
Interstate ramp	13
Grand Total	**641**

Table A33 Crash severity

Crash Severity	Number of Crashes
Possible Injury	391
Visible Injury	169
Disabling Injury	71
Fatal	10
Grand Total	**641**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A34 Light condition

Light Conditions	Number of Crashes
Dark - lighted roadway	83
Dark -rdwy not lighted	126
Dark-unk rdwy lighting	2
Dawn	33
Daylight	372
Dusk	17
Not stated	5
Other	1
Unknown	2
Grand Total	**641**

Table A35 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	47
Curved and on hilltop	4
Curved and on slope	27
Not stated	4
Straight and level	411
Straight and on hilltop	23
Straight and on slope	125
Grand Total	**641**

Table A36 Road surface type

Road Surface Type	Number of Crashes
Asphalt	258
Brick	2
Concrete	374
Gravel	2
Not stated	5
Grand Total	**641**

Table A37 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	8
Lane closure	4
Not applicable	617
Other	21
Work on shoulder or median	1
Grand Total	**641**

Table A38 Roadway junction type

Roadway Junction Type	Number of Crashes
Crossover	6
Driveway	2
Five-point, or more	1
Four-way intersection	111
Not at junction	432
Not stated	44
Off-ramp	11
On-ramp	8
T-intersection	21
Y-intersection	5
Grand Total	**641**

Table A39 First harmful event

First Harmful Event	Number of Crashes
Animal	4
Bridge pier or abutment	1
Bridge rail	22
Culvert	5
Curb	1
Ditch	17
Embankment	6
Fence	6
Guardrail end	3
Guardrail face	20
Highway traffic sign post	9
Jackknife	9
Light/luminaire support	11
Median barrier	32
Motor vehicle in transport	314
Not stated	1
Other fixed object	4
Other post, pole, or suppt	5
Overturn/rollover	147
Parked motor vehicle	5
Pedestrian	4
Tree	10
Utility pole	5
Grand Total	**641**

2011-2012

Table A40 Time of crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	54
6:00 AM -12:00 PM	121
12:00 PM -6:00 PM	93
6:00 PM -12:00 AM	29
Total	**297**

Table A41 Road surface condition

Road Surface Conditions	Number of Crashes
Ice	147
Slush	23
Snow	110
Water	1
Wet	16
Grand Total	**297**

Table A42 Month

Crash Date	Number of Crashes
Jan	46
Feb	101
Mar	2
Apr	1
Nov	32
Dec	115
Grand Total	**297**

Table A43 Weather condition I

Weather Condition I	**Number of Crashes**
Blowing sand, soil, dirt, snow	10
Clear	32
Cloudy	73
Fog, smog, smoke	4
Not stated	1
Other	1
Rain	2
Severe crosswinds	3
Sleet, hail, freezing rain/drizzle	33
Snow	137
Unknown	1
Grand Total	**297**

Table A44 Weather condition II

Weather Condition II	**Number of Crashes**
Blowing sand, soil, dirt, snow	16
Clear	3
Cloudy	14
Fog, smog, smoke	1
Not stated	202
Other	1
Rain	3
Severe crosswinds	9
Sleet, hail, freezing rain/drizzle	18
Snow	29
Unknown	2
Grand Total	**297**

Table A45 Road classification

Road Classification	**Number of Crashes**
Highway	222
Highway ramp	4
Interstate mainline	66
Interstate ramp	5
Grand Total	**297**

Table A46 Crash severity

Crash Severity	Number of Crashes
Possible Injury	172
Visible Injury	82
Disabling Injury	38
Fatal	5
Grand Total	**297**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A47 Light condition

Light Conditions	Number of Crashes
Dark - lighted roadway	56
Dark -rdwy not lighted	111
Dark-unk rdwy lighting	1
Dawn	3
Daylight	120
Dusk	2
Not stated	1
Other	1
Unknown	2
Grand Total	**297**

Table A48 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	21
Curved and on hilltop	3
Curved and on slope	24
Not stated	1
Straight and level	179
Straight and on hilltop	9
Straight and on slope	60
Grand Total	**297**

Table A49 Road surface type

Road Surface Type	Number of Crashes
Asphalt	137
Brick	1
Concrete	159
Grand Total	**297**

Table A50 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	4
Lane closure	14
Not applicable	216
Other	21
Work on shoulder or median	42
Grand Total	**297**

Table A51 Road junction type

Roadway Junction Type	Number of Crashes
Crossover	2
Driveway	2
Four-way intersection	43
Not at junction	226
Not stated	9
Off-ramp	2
On-ramp	5
T-intersection	7
Y-intersection	1
Grand Total	**297**

Table A52 First Harmful event

First Harmful Event	Number of Crashes
Animal	1
Bridge parapet end	1
Bridge pier or abutment	1
Bridge rail	10
Culvert	2
Curb	1
Ditch	13
Embankment	5
Fence	1
Guardrail end	2
Guardrail face	11
Highway traffic sign post	10
Jackknife	8
Light/luminaire support	2
Median barrier	13
Motor vehicle in transport	118
Other	1
Other fixed object	1
Other post, pole, or suppt	2
Overturn/rollover	81
Parked motor vehicle	4
Pedestrian	1
Tree	5
Utility pole	3
Grand Total	**297**

2012-2013

Table A53 Time of crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	83
6:00 AM -12:00 PM	176
12:00 PM -6:00 PM	149
6:00 PM -12:00 AM	66
Total	**474**

Table A54 Road surface condition

Road Surface Condition	**Number of Crashes**
Ice	226
Slush	54
Snow	175
Wet	19
Grand Total	**474**

Table A55 Month

Crash Date	**Number of Crashes**
Jan	13
Feb	55
Mar	12
Apr	8
Oct	43
Nov	43
Dec	215
Grand Total	**474**

Table A56 Weather condition I

Weather Condition I	**Number of Crashes**
Blowing sand, soil, dirt, snow	23
Clear	63
Cloudy	85
Fog, smog, smoke	21
Not stated	2
Rain	3
Severe crosswinds	2
Sleet, hail, freezing rain/drizzle	73
Snow	201
Unknown	1
Grand Total	**474**

Table A57 Weather condition II

Weather Condition II	Number of Crashes
Blowing sand, soil, dirt, snow	35
Clear	2
Cloudy	22
Fog, smog, smoke	2
Not stated	301
Other	1
Rain	2
Severe crosswinds	33
Sleet, hail, freezing rain/drizzle	17
Snow	44
Unknown	15
Grand Total	**474**

Table A58 Road classification

Road Classification	Number of Crashes
Highway	338
Highway ramp	1
Interstate mainline	121
Interstate ramp	14
Grand Total	**474**

Table A59 Crash severity

Crash Severity	Number of Crashes
Possible Injury	284
Visible Injury	114
Disabling Injury	60
Fatal	16
Grand Total	**474**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A60 Light conditions

Light Conditions	Number of Crashes
Dark - lighted roadway	66
Dark -roadway not lighted	83
Dark-unknown roadway lighting	4
Dawn	30
Daylight	275
Dusk	14
Not stated	1
Other	1
Grand Total	**474**

Table A61 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	32
Curved and on slope	24
Straight and level	302
Straight and on hilltop	22
Straight and on slope	94
Grand Total	**474**

Table A62 Road surface type

Road Surface Type	Number of Crashes
Asphalt	223
Brick	1
Concrete	247
Gravel	2
Not stated	1
Grand Total	**474**

Table A63 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	4
Lane closure	14
Not applicable	216
Other	21
Work on shoulder or median	42
Grand Total	**474**

Table A64 Roadway junction type

Roadway Junction Type	Number of Crashes
Crossover	8
Driveway	3
Four-way intersection	69
Not at junction	374
Not stated	2
Off-ramp	1
On-ramp	9
T-intersection	6
Y-intersection	2
Grand Total	**474**

Table A65 First Harmful event

First Harmful Event	Number of Crashes
Animal	1
Bridge rail	13
Culvert	4
Curb	2
Ditch	13
Embankment	4
Fence	10
Guardrail end	2
Guardrail face	22
Highway traffic sign post	11
Immersion	1
Jackknife	7
Light/luminaire support	1
Mail box	1
Median barrier	18
Motor vehicle in transport	238
Other fixed object	2
Other movable object	1
Other post, pole, or suppt	3
Overturn/rollover	105
Parked motor vehicle	5
Pedestrian	2
Tree	4
Utility pole	3
Work zone maint. equipment	1
Grand Total	**474**

2013-2014

Table A66 Time of crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	67
6:00 AM -12:00 PM	146
12:00 PM -6:00 PM	100
6:00 PM -12:00 AM	37
Total	**350**

Table A67 Months

Months	Number of Crashes
Jan	40
Feb	116
Mar	38
Apr	38
May	2
Oct	4
Nov	28
Dec	84
Grand Total	**350**

Table A68 Road surface conditions

Road Surface Conditions	Number of Crashes
Ice	133
Slush	47
Snow	161
Wet	9
Grand Total	**350**

Table A69 Weather condition I

Weather Condition I	**Number of Crashes**
Blowing sand, soil, dirt, snow	38
Clear	64
Cloudy	59
Fog, smog, smoke	2
Not stated	1
Other	1
Rain	6
Severe crosswinds	3
Sleet, hail, freezing rain/drizzle	48
Snow	127
Unknown	1
Grand Total	**350**

Table A70 Weather condition II

Weather Condition II	**Number of Crashes**
Blowing sand, soil, dirt, snow	21
Clear	3
Cloudy	11
Fog, smog, smoke	1
Not stated	234
Other	1
Severe crosswinds	7
Sleet, hail, freezing rain/drizzle	19
Snow	53
Grand Total	**350**

Table A71 Road classification

Road Classification	**Number of Crashes**
Highway	276
Highway ramp	2
Interstate mainline	67
Interstate ramp	5
Grand Total	**350**

Table A72 Crash severity

Crash Severity	Number of Crashes
Possible Injury	203
Visible Injury	90
Disabling Injury	45
Fatal	12
Grand Total	**350**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A73 Light conditions

Light Conditions	Number of Crashes
Dark - lighted roadway	55
Dark -rdwy not lighted	64
Dark-unk rdwy lighting	1
Dawn	16
Daylight	205
Dusk	7
Not stated	1
Other	1
Grand Total	**350**

Table A74 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	31
Curved and on hilltop	3
Curved and on slope	13
Straight and level	229
Straight and on hilltop	5
Straight and on slope	69
Grand Total	**350**

Table A75 Road surface type

Road Surface Type	Number of Crashes
Asphalt	162
Concrete	188
Grand Total	**350**

Table A76 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	2
Lane closure	12
Not applicable	280
Other	42
Work on shoulder or median	14
Grand Total	**350**

Table A77 Roadway junction type

Roadway Junction Type	Number of Crashes
Crossover	14
Driveway	7
Four-way intersection	74
Not at junction	214
Not stated	4
Off-ramp	4
On-ramp	21
T-intersection	3
Y-intersection	9
Grand Total	**350**

Table A78 First harmful event

First Harmful Event	**Number of Crashes**
Animal	2
Bridge overhead structure	1
Bridge pier or abutment	2
Bridge rail	7
Culvert	3
Curb	2
Ditch	8
Embankment	4
Fence	8
Guardrail end	1
Guardrail face	7
Highway traffic sign post	7
Impact attenuator/Cr cushion	1
Jackknife	7
Light/luminaire support	11
Median barrier	17
Motor vehicle in transport	161
Other fixed object	2
Other movable object	3
Other non-collision	1
Other post, pole, or support	5
Overturn/rollover	67
Parked motor vehicle	7
Pedestrian	3
Tree	8
Utility pole	5
Grand Total	**350**

2014-2015

Table A79 Time of the crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	50
6:00 AM -12:00 PM	131
12:00 PM -6:00 PM	77
6:00 PM -12:00 AM	43
Total	**301**

Table A80 Road surface condition

Road Surface Condition	Number of Crashes
Ice	134
Slush	25
Snow	133
Wet	9
Grand Total	**301**

Table A81 Months

Months	Number of Crashes
Jan	47
Feb	86
Mar	3
Apr	3
May	5
Nov	66
Dec	91
Grand Total	**301**

Table A82 Weather condition I

Weather Condition I	Number of Crashes
Blowing sand, soil, dirt, snow	47
Clear	61
Cloudy	31
Fog, smog, smoke	3
Other	1
Rain	1
Sleet, hail, freezing rain/drizzle	27
Snow	130
Grand Total	**301**

Table A83 Weather condition II

Weather Condition II	Number of Crashes
Blowing sand, soil, dirt, snow	19
Clear	1
Cloudy	11
Fog, smog, smoke	2
Not stated	212
Other	2
Severe crosswinds	12
Sleet, hail, freezing rain/drizzle	8
Snow	34
Grand Total	**301**

Table A84 Road classification

Road Classification	Number of Crashes
Highway	211
Highway ramp	5
Interstate mainline	71
Interstate ramp	14
Grand Total	**301**

Table A85 Crash severity

Crash Severity	Number of Crashes
Possible Injury	177
Visible Injury	91
Disabling Injury	29
Fatal	4
Grand Total	**301**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A86 Light condition

Light Condition	Number of Crashes
Dark - lighted roadway	53
Dark -roadway not lighted	56
Dark-unknown roadway lighting	3
Dawn	14
Daylight	163
Dusk	10
Not stated	1
Other	1
Grand Total	**301**

Table A87 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	14
Curved and on hilltop	1
Curved and on slope	29
Straight and level	190
Straight and on hilltop	10
Straight and on slope	57
Grand Total	**301**

Table A88 Road surface type

Road Surface Type	Number of Crashes
Asphalt	146
Concrete	154
Gravel	1
Grand Total	**301**

Table A89 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	7
Lane closure	17
Not applicable	212
Other	41
Work on shoulder or median	24
Grand Total	**301**

Table A90 Roadway junction type

Roadway Junction Type	Number of Crashes
Crossover	4
Driveway	3
Four-way intersection	56
Not at junction	202
Not stated	8
Off-ramp	8
On-ramp	12
T-intersection	7
Unknown	1
Grand Total	**301**

Table A91 First harmful event

First Harmful Event	Number of Crashes
Bicycle (Pedal cycle)	1
Bridge pier or abutment	1
Bridge rail	5
Culvert	1
Ditch	3
Embankment	3
Fence	4
Guardrail end	2
Guardrail face	11
Highway traffic sign post	1
Jackknife	6
Light/luminaire support	10
Median barrier	9
Motor vehicle in transport	157
Other non-collision	1
Other post, pole, or suppt	5
Overhead sign support	2
Overturn/rollover	64
Parked motor vehicle	2
Pedestrian	3
Tree	5
Utility pole	5
Grand Total	**301**

2015-2016

Table A92 Time of the crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	60
6:00 AM -12:00 PM	148
12:00 PM -6:00 PM	89
6:00 PM -12:00 AM	47
Total	**344**

Table A93 Road Surface conditions

Road Surface Conditions	Number of Crashes
Ice	174
Slush	54
Snow	74
Wet	42
Grand Total	**344**

Table A94 Months

Months	Number of Crashes
Jan	105
Feb	46
Mar	28
Apr	3
May	2
Nov	66
Dec	94
Grand Total	**344**

Table A95 Weather condition I

Weather Condition I	Number of Crashes
Blowing sand, soil, dirt, snow	49
Clear	55
Cloudy	47
Fog, smog, smoke	2
Other	2
Rain	2
Severe crosswinds	5
Sleet, hail, freezing rain/drizzle	47
Snow	135
Grand Total	**344**

Table A96 Weather condition II

Weather Condition II	Number of Crashes
Blowing sand, soil, dirt, snow	22
Clear	1
Cloudy	9
Fog, smog, smoke	1
Not stated	236
Other	3
Severe crosswinds	15
Sleet, hail, freezing rain/drizzle	14
Snow	43
Grand Total	**344**

Table A97 Road classification

Road Classification	Number of Crashes
Highway	247
Highway ramp	1
Interstate mainline	84
Interstate ramp	12
Grand Total	**344**

Table A98 Crash severity

Crash Severity	Number of Crashes
Possible Injury	208
Visible Injury	107
Suspected Serious Injury	23
Fatal	6
Grand Total	**344**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A99 Light conditions

Light Conditions	Number of Crashes
Dark - lighted roadway	57
Dark -roadway not lighted	72
Dawn	23
Daylight	185
Dusk	5
Other	2
Grand Total	**344**

Table A100 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	16
Curved and on hilltop	1
Curved and on slope	26
Not stated	1
Straight and level	221
Straight and on hilltop	12
Straight and on slope	67
Grand Total	**344**

Table A101 Road surface type

Road Surface Type	Number of Crashes
Asphalt	164
Concrete	178
Other	2
Grand Total	**344**

Table A102 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	9
Lane closure	21
Not applicable	216
Other	67
Work on shoulder or median	31
Grand Total	**344**

Table A103 Roadway junction type

Roadway Junction Type	Number of Crashes
Crossover	4
Driveway	2
Four-way intersection	48
Not at junction	247
Not stated	10
Off-ramp	11
On-ramp	8
T-intersection	12
Y-intersection	2
Grand Total	**344**

Table A104 First harmful event

First Harmful Event	**Number of Crashes**
Animal	2
Bridge parapet end	1
Bridge rail	11
Curb	1
Ditch	4
Embankment	2
Fence	3
Guardrail face	11
Highway traffic sign post	7
Jackknife	8
Light/luminaire support	2
Median barrier	21
Motor vehicle in transport	157
Other fixed object	2
Other non-collision	2
Other post, pole, or suppt	1
Overturn/rollover	88
Parked motor vehicle	6
Pedestrian	3
Tree	9
Utility pole	3
Grand Total	**344**

2016-2017

Table A105 Time of the crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	51
6:00 AM -12:00 PM	147
12:00 PM -6:00 PM	90
6:00 PM -12:00 AM	39
Total	**327**

Table A106 Road surface conditions

Road Surface Conditions	Number of Crashes
Ice	183
Slush	32
Snow	98
Wet	14
Grand Total	**327**

Table A107 Months

Months	Number of Crashes
Jan	97
Feb	72
Mar	24
Apr	7
May	2
Oct	2
Nov	17
Dec	106
Grand Total	**327**

Table A108 Weather condition I

Weather Condition I	Number of Crashes
Blowing sand, soil, dirt, snow	26
Clear	49
Cloudy	37
Fog, smog, smoke	1
Other	2
Rain	4
Severe crosswinds	6
Sleet, hail, freezing rain/drizzle	95
Snow	107
Grand Total	**327**

Table A109 Weather condition II

Weather Condition II	Number of Crashes
Blowing sand, soil, dirt, snow	19
Clear	2
Cloudy	13
Fog, smog, smoke	1
Not stated	222
Other	3
Severe crosswinds	13
Sleet, hail, freezing rain/drizzle	15
Snow	39
Grand Total	**327**

Table A110 Road classification

Road Classification	Number of Crashes
Highway	238
Highway ramp	2
Interstate mainline	79
Interstate ramp	8
Grand Total	**327**

Table A111 Crash severity

Crash Severity	Number of Crashes
Possible Injury	190
Visible Injury	90
Suspected Serious Injury	42
Fatal	5
Grand Total	**327**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A112 Light conditions

Light Conditions	Number of Crashes
Dark - lighted roadway	43
Dark -roadway not lighted	70
Dawn	10
Daylight	195
Dusk	8
Other	1
Grand Total	**327**

Table A113 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	11
Curved and on hilltop	2
Curved and on slope	16
Straight and level	223
Straight and on hilltop	10
Straight and on slope	65
Grand Total	**327**

Table A114 Road Surface type

Road Surface Type	Number of Crashes
Asphalt	148
Concrete	179
Grand Total	**327**

Table A115 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	8
Lane closure	31
Not applicable	196
Other	71
Work on shoulder or median	21
Grand Total	**327**

Table A116 Roadway junction type

Roadway Junction Type	Number of Crashes
Crossover	1
Driveway	1
Four-way intersection	56
Not at junction	232
Not stated	9
Off-ramp	2
On-ramp	7
T-intersection	18
Traffic circle/roundabout	1
Grand Total	**327**

Table A117 First harmful event

First Harmful Event	Number of Crashes
Animal	4
Bridge rail	3
Culvert	1
Ditch	11
Embankment	1
Fence	1
Guardrail end	3
Guardrail face	6
Highway traffic sign post	8
Jackknife	4
Light/luminaire support	4
Median barrier	5
Motor vehicle in transport	170
Other fixed object	2
Other post, pole, or suppt	1
Overturn/rollover	71
Parked motor vehicle	3
Pedestrian	6
Tree	16
Utility pole	6
Work zone maint. equipment	1
Grand Total	**327**

2017-2018

Table A118 Time of the crash

Time of the Crash	Number of Crashes
12:00 AM -6:00 AM	76
6:00 AM -12:00 PM	156
12:00 PM -6:00 PM	127
6:00 PM -12:00 AM	52
Total	**411**

Table A119 Road surface conditions

Road Surface Conditions	Number of Crashes
Ice	205
Slush	6
Snow	195
Wet	5
Grand Total	**411**

Table A120 Months

Months	Number of Crashes
Jan	75
Feb	124
Mar	35
Apr	62
Oct	12
Nov	7
Dec	96
Grand Total	**411**

Table A121 Weather condition I

Weather Condition I	Number of Crashes
Blowing sand, soil, dirt, snow	38
Clear	80
Cloudy	55
Not stated	1
Other	1
Rain	1
Severe crosswinds	7
Sleet, hail, freezing rain/drizzle	73
Snow	154
Unknown	1
Grand Total	**411**

Table A122 Weather condition II

Weather Condition II	Number of Crashes
Blowing sand, soil, dirt, snow	28
Clear	5
Cloudy	10
Not stated	264
Other	1
Rain	1
Severe crosswinds	15
Sleet, hail, freezing rain/drizzle	19
Snow	67
Unknown	1
Grand Total	**411**

Table A123 Road classification

Road Classification	Number of Crashes
Highway	279
Highway ramp	5
Interstate mainline	120
Interstate ramp	7
Grand Total	**411**

Table A124 Crash severity

Crash Severity	Number of Crashes
Fatal	11
Possible Injury	260
Visible Injury	94
Suspected Serious Injury	46
Grand Total	**411**

Note: Disabling injury referred to as suspected serious injury from 2015 onward.

Table A125 Light conditions

Light Conditions	Number of Crashes
Dawn	20
Daylight	240
Dusk	15
Dark - lighted roadway	65
Dark -roadway not lighted	66
Dark-unknown roadway lighting	3
Other	1
Unknown	1
Grand Total	**411**

Table A126 Road characteristics

Road Characteristics	Number of Crashes
Curved and level	31
Curved and on hilltop	3
Curved and on slope	21
Not stated	1
Straight and level	275
Straight and on hilltop	11
Straight and on slope	69
Grand Total	**411**

Table A127 Road surface type

Road Surface Type	Number of Crashes
Asphalt	170
Brick	2
Concrete	236
Gravel	2
Not stated	1

Grand Total	**411**

Table A128 Work zone type

Work Zone Type	Number of Crashes
Intermittent or moving work	12
Lane closure	21
Not applicable	331
Other	32
Work on shoulder or median	15
Grand Total	**411**

Table A129 Roadway junction type

Roadway Junction Type	Number of Crashes
Crossover	1
Driveway	1
Four-way intersection	74
Not at junction	278
Not stated	11
Off-ramp	3
On-ramp	9
T-intersection	32
Traffic circle/roundabout	2
Grand Total	**411**

Table A130 First harmful event

First Harmful Event	Number of Crashes
Animal	1
Bridge pier or abutment	3
Bridge rail	15
Culvert	2
Ditch	10
Embankment	7
Fence	6
Guardrail end	4
Guardrail face	9
Highway traffic sign post	11
Jackknife	3
Light/luminaire support	10
Median barrier	22
Motor vehicle in transport	202
Other fixed object	5
Other non-collision	1
Other post, pole, or suppt	4
Overhead sign support	1
Overturn/rollover	65
Parked motor vehicle	8
Pedestrian	3
Tree	10
Utility pole	7
Work zone maint. equipment	2
Grand Total	**411**