Accident Analysis and Prevention 121 (2018) 202–212

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Using spatial interpolation to determine impacts of annual snowfall on traffic crashes for limited access freeway segments

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ARTICLE INFO

Keywords:
Traffic safety
Crashes
Spatial interpolation
Kriging
Weather
Snow

ABSTRACT

Snowfall affects traffic safety by impacting vehicle performance, driver behavior, and the transportation infrastructure. Depending on intensity snowfall can reduce visibility, pavement friction performance, vehicle stability and maneuverability. Based on this premise, the objective of this study was to use spatial interpolation to analyze the effects of annual snowfall on crash occurrence at non-interchange freeway segment locations in Michigan. Using the geostatistical method of Ordinary Kriging, site specific historical snowfall values were estimated based on data obtained from a series of weather stations during the primary winter months (December, January, and February) for the years of 2004 through 2014 along Michigan's entire limited access freeway network. These weather data were spatially matched with historical crash data and roadway inventory data for each freeway segment. A Negative Binomial regression model was developed to quantify the effects of snowfall on crashes. Explanatory variables included annual average daily traffic, segment length, horizontal curvature, and snowfall. The results indicated that annual snowfall has a statistically significant positive effect on winter crashes for all types of crashes analyzed. With respect to vehicle type, crashes involving a truck or bus experienced the strongest relationship with annual snowfall. Considering crash severity, property damage crashes possessed a stronger relationship with snowfall as opposed to injury crashes.

1. Introduction

Inclement weather can influence crash occurrence in a transportation system. Nearly one-quarter of all crashes in the United States (US) are a result of adverse weather patterns (U.S. Department of Transportation Federal Highway Administration (FHWA, 2016). Among the various inclement weather conditions, existing literature suggests that the risk of crashes increases if precipitation is snow (Qiu and Nixon, 2008). The exposure to snow related events is particularly extensive in the US as more than 70% of the transportation network experiences some amount of snowfall (U.S. Department of Transportation Federal Highway Administration (FHWA, 2018). Depending on the intensity, these events impact all elements of the transportation system including vehicle performance, driver behavior, and infrastructure through reduced visibility, pavement friction performance, vehicle stability and maneuverability (Pisano et al., 2008; Liu, 2013; Leard and Roth, 2015).

Regions such as the Great Lake basin of the US are particularly risk susceptible to frequent severe snow events during winter months due to lake effect climatic conditions. These events can result in significant hazardous driving conditions due to a sudden onset of heavy snowfall, high wind speeds, and low temperature, the outcomes of which can replicate the high crash rates typically observed during the first snowfall of the season (DeVoir, 2004; Eisenberg and Warner, 2005; Banacos et al., 2014). Not surprisingly, although drivers in these regions are presumed accustomed to driving in snowy conditions, crash occurrence continues to be high (Andreescu and Frost, 1998). More recently, severe winter events have resulted in dramatic mega crashes such as the events of January 2015 in southwest Michigan, where extreme whiteout conditions led to a 193 car pile-up along Interstate 94 (I-94) resulting in loss of life, multiple injuries, and significant economic cost (Sell, 2016).

As a result of this catastrophic crash, research was undertaken to determine the effects of snowfall accumulation on safety performance for various vehicle type categories on the limited access freeway network in Michigan. The variable of snowfall accumulation was deemed appropriate as opposed to snowfall interval variables such as number of days with snow due to variability in snowfall amounts experienced across the Great Lakes region due to lake effect snow. While several studies have evaluated the effects of snowfall on crashes, particularly the effect on crash severity outcomes, there has been little consideration of the impacts across various vehicle types or various facility types,

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https://doi.org/10.1016/j.aap.2018.09.014
Received 11 February 2018; Received in revised form 5 September 2018; Accepted 14 September 2018

particularly limited access freeways. Accordingly, an investigation on these factors can provide revealing information which could prove useful to transportation agencies in implementing and prioritizing mechanism to minimize crashes due to inclement weather conditions.

2. Relevant literature

2.1. General snow effects

In regions like the Great Lakes basin of the US, snowfall is often the primary weather factor impacting traffic operations and safety. It is commonly recognized that greater snowfall results in an increase in the crash occurrence rate (Qiu and Nixon, 2008). In spite of this common understanding, the effects of snow among different vehicle types and crash severity outcomes may vary. Studies assessing the impact of snow on property damage only (PDO) crashes indicate that snowfall results in an increase in their incident rate (Eisenberg, 2004; Eisenberg and Warner, 2005; Bilionis, 2013). Comparatively, findings on the effects of injury or fatal accidents during snowy weather are less conclusive as accident rates may experience a small increase or even a reduction during days with snow versus those without snow (Fridstrom et al., 1995; Eisenberg, 2004; Eisenberg and Warner, 2005; Bilionis, 2013; Liu, 2013). Parallel variances can also be found among crashes involving commercial and non-commercial vehicles due to differences in travel behavior or physical characteristics. For example, drivers perceive severe snow events as dangerous and may avoid voluntary trips. However, commercial vehicle trips are often business related and thus less flexible in route and/or timing choice (Pisano et al., 2008).

A secondary noteworthy dimension on this topic relates to the area along the freeway on which these crashes occur. Specifically, interchange and non-interchange freeway segments are commonly treated separately in crash modeling as crash rates in the interchange areas are much higher than in non-interchange areas due to merging/diverging and associated speed change behavior (Kiattikomol, 2005). Given the distinctive traffic interaction characteristics, the effects of snowfall on interchange versus non-interchange freeway segment crashes may also vary.

2.2. Weather data spatial interpolation

A common barrier to assessing the impacts of snow on crashes is the data collection process of weather variables. Presently there is no practical method to explicitly measure such data continuously along an expansive freeway system. As a result snowfall data are commonly estimated from weather stations randomly distributed throughout the United States (Bostan et al., 2012). Each of these stations captures and reports weather conditions on a particular location over pre-established time periods. Because distances between stations may vary in magnitude of less than a mile to several miles, values reported by one station do not provide the level of accuracy required to estimate snowfall when applied at specific locations along a freeway. Weather patterns can also be localized in small geographic regions that experience relatively different snowfall amounts among each other or their surroundings due to lake-effect climatic conditions, wind patterns, or terrain. Thus, it is naive to average these values across a specific region (Leard and Roth, 2015).

To overcome these shortfalls weather data prediction models must incorporate the density and locations of weather stations to obtain accurate weather values on desired localities (Ashraf et al., 1997). Spatial interpolation is the procedure utilized in incorporating these variables to estimate weather related data at specific locations. Sluiter (2009) states that spatial interpolations methods can be grouped into three categories: deterministic, probabilistic, and other types; where deterministic methods produce continuous surfaces based on specific geometric characteristics of existing observations (i.e. nearest neighborhood, triangulation, Inverse Distance Weighting (IDW), splines, linear regression); probabilistic methods produce continuous surfaces based on statistical theory (i.e. Ordinary Kriging, Simple Kriging, Universal Kriging); and other types consist of a combination of deterministic and probabilistic methods.

Traditionally, deterministic methods have an extended history of use in predicting meteorological data. In recent trends however, probabilistic methods have become a more preferred approach in predicting weather values since they provide statistical reliability, consider the spatial correlation between observations, and allow for the inclusion of secondary explanatory variables (i.e. elevation) in improving the estimation on unknown locations (Mair and Fares, 2011). Not surprisingly, while more demanding to implement, several studies have found that probabilistic methods delivers superior estimates than their deterministic counterparts (Tabios and Salas, 1985; Ashraf et al., 1997; Goovaerts, 2000; Mair and Fares, 2011).

2.3. Crash modeling

Crash modeling entails estimating the average expected crash frequency of a particular site given its specific geometric, operational, and local conditions over a pre-defined time period (American Association of State Highway and Transportation Officials (AASHTO, 2010). Typically, these traffic crashes are assumed to be random occurrences in time and space (Bilionis, 2013; Zou et al., 2015), and have been presumed to follow a Poisson distribution (Lord and Mannering, 2010; Bilionis, 2013; Seeherman and Liu, 2015; Bilionis). In these cases, crash modeling has been conducted via Poisson regression (Lord and Mannering, 2010). The equivalency between the mean and the variance however is not always achieved as researchers have found that crashes often exhibit variances that exceed the mean, which is commonly referred to as over-dispersion. To account for this over-dispersion, crash modeling has been most often conducted by employing a Negative Binomial regression model (Lord and Mannering, 2010; Bilionis, 2013; Seeherman and Liu, 2015). The Negative Binomial model is an extension of the Poisson model which accounts for the over-dispersion in the data by including a gamma distributed error term with mean 1 and variance α^2 (Lord and Mannering, 2010).

3. Methodology

3.1. Objective and study framework

The objective of this study was to investigate the effects of snowfall quantities on non-interchange freeway crashes during winter periods in Michigan. For purposes of this study, non-interchange crashes were defined as crashes not associated with an interchange and which typically occur between two interchanges. The specific crash categories analyzed consisted of crashes occurring solely during the winter months of January, February, and December between 2004 and 2014, and included:

- All winter crashes – all winter season crashes
- Truck/bus winter crashes – winter season crashes involving at least one truck or bus
- Non-truck/bus winter crashes – winter season crashes involving no trucks or buses
- Injury winter crashes – winter season crashes where at least one injury or fatality was reported
- PDO winter crashes – winter season crashes involving only property damage

The 11-year winter period of 2004 and 2014 also represented the study time period of analysis. The months of January, February, and December were selected to represent the primary winter period in Michigan during which the majority of the annual snowfall amounts occur.