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Data-driven analysis on the effects of extreme weather elements on traffic volume in Atlanta, GA, USA

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ABSTRACT

Severe weather events pose a significant threat to transportation networks. This research analyzes and discusses the impact of precipitation, temperature, visibility and wind speed on hourly weekday traffic flow volume in Atlanta, Georgia. The study involves the following: determine weather variables that affect traffic volume, develop a machine learning technique to derive decision rules based on weather and traffic volume, and create a web-based decision support visualization tool using the analyzed results. The relationship between extreme weather events and traffic volume was investigated by comparing traffic volume between a base case scenario and an extreme weather scenario. Data from 48 Automatic Traffic Recorder (ATR) sites around Atlanta, GA, USA and hourly precipitation data from 4 climate measurement stations were used to conduct this study. The spatiotemporal relationships between traffic volume and weather variables were analyzed individually and evaluated using a non-parametric statistical test. A machine learning technique is applied to derive decision rules that result in reduction in traffic volume. Results show significant impacts on traffic volume from visibility, precipitation and temperature and helps in isolating hours in a typical weekday when such impacts are felt. A decision support tool was also developed to visualize traffic volume and weather interactions. The data-driven insights from this analysis is applicable to transportation planners, centralized traffic control rooms and urban infrastructure decision makers.

1. Introduction

The transportation sector is an important component for the economic development of an area. An efficient transportation network increases economic and social opportunities by improving accessibility to employment, markets, and additional investments. As population and the number of vehicles increases, congestion on road networks becomes more common. Traffic congestion accounts for over three billion hours of traffic delay annually in the US (*Press release - urban mobility information*, 2015).

Extreme weather events can adversely impact traffic volume (Cools, Moons, & Wets, 2010, Calvert & Snelder, n.d.). These weather events have negative effects on transportation network performance, travel speed, time, capacity, and volume (Bartlett, Lao, Zhao, & Sadek, 2013). The Federal Highway Administration (FHWA) provided a statistical report showing that severe weather events cause up to 22% of vehicle accidents. According to a 2015 Federal report (DoT, Nitch, Safety, & FLAP, 2015), more than 5897 deaths and 445,303 injuries occurred in the U.S. during a ten-year period because of extreme weather events. A better understanding of weather factors affecting traffic flow can eventually help both government and other infrastructure agencies to properly plan, design, and maintain road networks and thereby reduce the risk of fatalities.

This research investigates and analyzes the impact of four weather variables - precipitation, visibility, temperature and wind speed - on hourly traffic volume. The focus of the study was on the city of Atlanta, Georgia, USA. One of the main motivations for choosing Atlanta was it being the large urban city with a dense transportation network and its propensity to extreme weather hazards. NOAA climate normal reports show that Atlanta receives an average annual rainfall of 1262.63 mm (49.71 in.) which is 27% more than the average in other similarly-sized US cities (Arguez et al., 2012).

Two major data sets were used in this research. Traffic data for the state of Georgia, USA was provided by Transmetric LLC, a transportation data management firm located in Austin, Texas. The weather data was retrieved from the Integrated Surface Hourly (ISH) archives at the

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National Centers for Environmental Information and housed locally.

The impact of weather hazards on traffic volume was then studied by applying rigorous statistical and machine learning tests. A decision support tool was built to visualize the impacts of inclement weather events on transportation volume in Atlanta.

1.1. Problem description

This work focused on analyzing and examining the following research questions:

- Do precipitation, temperature, visibility and wind speed have a significant impact on hourly traffic volume in Atlanta?
- If so, does the impact have a specific pattern? Is the impact different based on different times of the day and volumes of precipitation, temperature, visibility and wind speed?
- Is it possible to statistically correlate these impacts?
- Is it possible to develop a machine learning model that can account for interdependent weather variables and predict impacts on hourly traffic volume?

1.2. Background and similar work

Previous studies examined relationships between weather events and traffic characteristics. A recent study by (Yuan-Qing & Jing, 2017) looked at the effect of rainfall on traffic flow on a freeway in Hainan province in China. Studies have shown that extreme weather conditions could lead to reduction in speed, travel time, road capacity, and volume. For instance, research from the Federal Highway Administration showed that light rainfall could reduce driving speed by 6–9% in several cities (Hranac et al., n.d.). This decrease in speed during extreme weather caused 3.5% more travel time compared to days (Stern, Shah, Goodwin, & Pisano, 2003) with normal weather conditions. Heavy rain has been reported to produce a 14–15% reduction in traffic speed and capacity (according to Agarwal, Maze, & Souleyrette (2005)), and heavy snow events have been reported to reduce the capacity of road networks by up to 28% (Agarwal et al., 2005).

Some studies investigating traffic behavior using weather variables have applied machine learning models to predict traffic characteristics in different weather conditions. These machine learning models could accurately classify which variables contributed to change in traffic behavior. For example, a study of the effect of traffic parameters on road hazards using a classification tree model identified hazardous situations on the freeways (Hasan, 2012). Results of this research showed that traffic flow and vehicle speed were the most important factors that influence traffic volume. Another study of the mixed effects of precipitation on traffic crashes used a machine learning technique to build a crash risk prediction model based on precipitation and snowfall. The study discovered that if precipitation increased by 10 mm, the fatal crash rate would increase about 3% (Eisenberg, 2004).

Previous research found decreases in traffic volume during different severe weather events. For example, an average winter storm event can reduce traffic volume by 29% (Knapp, Smithson, & Khattak, n.d.). Another urban study (Kwon, Fu, & Jiang, 2013) looked only at the impact of winter weather conditions on traffic volume and the study monitored just 2 locations over a 2 year period. A study used a probabilistic approach to find reductions in traffic volume during intense snow and rain events (Samba & Park, 2010). A study of hourly traffic volume and precipitation in Buffalo, NY, USA investigated relationships between traffic volume and precipitation by dividing traffic volume into two subgroups including 1) traffic volume during non-inclement weather (base case) and 2) inclement weather (inclement case) (Bartlett et al., 2013). This research applied a regression model to the dataset to create the predictive model under specific weather conditions. Results showed a significant correlation between hourly rainfall and traffic volume (Bartlett et al., 2013). Similarities between this study and that of (Bartlett et al., 2013) were the sub-grouping of scenarios between extreme and normal weather conditions. The differentiating factors were different cities with differing extreme weather thresholds, analyzing a more extensive network of traffic counters, differing statistical techniques and use of a machine learning model to derive rules. Similar to our work, Angel, Sando, Chimba, & Kwigizile (2014) explored the effect of rain on the traffic volume at 2 freeway sites in Florida and Dehman & Drakopoulos (2017) studied the effect of inclement weather on 15 freeway traffic counters in Milwaukee, Wisconsin. Factors that differentiated our work were the extensive statistical analysis, the deriving of thresholds and specific hours of affected traffic volume using predictive models and the decision support visualization tool.

Wind speed, temperature and visibility could also create hazardous driving environments and cause a decrease in traffic volume. A study of the effect of wind speed, temperature, precipitation and visibility on traffic capacity in Minnesota found that precipitation had the most severe impact on traffic capacity, reducing it by 19–28% (Agarwal et al., 2005). Cold temperatures and low visibilities had moderate impacts on the capacity, leading to a 10–12% decrease. However, wind speed did not have any noticeable effect on capacity reduction in Minnesota (Agarwal et al., 2005). Work such as Saha, Schramm, Nolan, & Hess (1994–2012) seek to provide a link between adverse weather conditions with fatal vehicle crashes in the United States by looking at the Fatality Analysis Reporting System (FARS) data set.

1.3. Outline

This work consists of three components. First, a statistical, data-intensive study is provided to analyze correlations between individual weather elements and traffic volume. Then, a machine learning model is discussed to predict changes in traffic volume based on weather conditions. Finally, a decision support tool is presented to visualize hourly traffic volume and its interaction with studied weather elements.

The paper is organized as follows: First, a background of prior research on this topic is provided. Also provided is a detailed description of the datasets, along with methodologies pertaining to data collection, storage and data processing. Secondly, the statistical experiments and computational results are provided. Thirdly, a discussion of the machine learning model and the development of the geo-visualization decision support tool (this includes programming methodologies used) is detailed. The last section provides conclusions and future work.

2. Study area and data processing

The focus area was the Atlanta Metropolitan Statistical Area (MSA) which has a dense network of traffic counting stations. Atlanta also happens to be an important business hub and one of the largest population centers in the southern U.S. According to the Georgia Department of Revenue, there are almost 3,000,000 personal passenger cars in the area with nearly 500,000 daily riders. Weather hazards can play a significant role in such a city.

The specific study area includes Cobb, Fulton, Dekalb, Henry and Clayton counties (see Fig. 1). The study area covered approximately 135 mile^2, containing latitudes between 33.4623° N and 34.0683° N and longitudes between 84.1462° W and 84.6059° W. Based on the NOAA 1981–2010 US Climate Normals dataset (Arguez et al., 2012), this area averages 113 days with rain and 1263 mm (49.7 in.) rainfall annually. The annual rainfall total is 27% larger than the average rainfall in other cities with similar size across the United States. Precipitation, visibility, wind speed and temperature data used was from the Integrated Surface Hourly (ISH) dataset (Smith et al. (2011)) of the National Centers of Environmental Information (NCEI). ISH is a large hourly data set spanning more than 2000 stations worldwide. Four weather measurement stations were available within the study area and reported regularly between 2010 and 2015 (see Fig. 1). The four weather stations included: KATL (Hartsfield-Jackson Atlanta