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Learning from traffic data collected before, during and after a hurricane

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ABSTRACT

Hurricanes harm people and damage property through extreme wind speeds and flooding associated with heavy rains and storm surge. One of the most effective and widely used tactics to protect people from hurricanes is evacuation. Improved knowledge of the behavior of communities before, during and after an evacuation can better support emergency planning and operations, and thus help make evacuations safer and more efficient. The objective of this work is to identify ways to use traffic data to better understand evacuation behavior and to explore ways to integrate traffic data into evacuation planning and response. Traffic data collected in Delaware before, during and after Hurricane Irene in August 2011 using automated traffic recorders are assembled and analyzed. The analysis shows that a significant number of residents and visitors evacuated from the beach communities and the evacuation patterns are very similar to the traffic patterns experienced on summer weekends. These insights suggest that this type of analysis may also be of value for other events in other communities.

1. Introduction

1.1. Motivation

Experiences over the past two decades provide clear evidence of the destructive power of hurricanes, also known as cyclones and typhoons. These experiences demonstrate the importance of developing strategies to prepare for and mitigate the impacts of hurricanes. Hurricanes harm people and damage property through extreme wind speeds and flooding associated with heavy rains and storm surge. Hurricanes are a major problem in the U.S. and around the world. Hurricanes cause about $10 billion in damages in the U.S. each year [1]. Beyond recurring yearly losses, hurricanes also have the potential to cause catastrophic loss. For example, in 1970, a typhoon caused one of the largest catastrophes in world history, killing over 300,000 people in Bangladesh. More recently, in 2005, Hurricane Katrina caused $108 billion in damage and killed 1200 people on the Gulf Coast of the U.S [2]. Hurricanes have been and will continue to be a cause for concern as population centers in coastal areas around the world continue to grow [3].

One of the most effective and widely used tactics to protect people from hurricanes is evacuation [3]. Evacuation allows people to escape the hazards of extreme wind and flooding. In an evacuation, residents and visitors of hazardous areas leave before they are exposed to negative consequences. Evacuations are especially feasible for hurricanes as advance warnings allow large populations to leave at risk areas before the hurricane arrives. While evacuations hold the potential to protect the public, they may put evacuees at unnecessary risk, and certainly cost government, industry and private citizens' time and money. Improved knowledge of the behavior of communities before, during and after an evacuation can better support emergency planning and operations, and thus help make evacuations safer and more efficient.

As lead time in issuing hurricane warnings to threatened populations increases with improvements in hurricane monitoring and mass communication technology, the social and organizational features of integrated warning systems become paramount as key factors in saving lives and reducing damages to property. Even if the public understands hurricane forecasts, their trust in the reliability and accuracy of these forecasts, and in the sources that provide such information, may significantly impact their behavior and response [4,5]. For example, public confidence and trust in the sources that provide such information (e.g., hurricane forecasts and warnings) has an impact on their perception of risk [6,7]. However, trust in institutions is a variable entity, often a function of minority status and power [5] that at times is undermined by mass media accounts that convey inaccurate, biased, and exaggerated information [8–11]. Sufficient lead time, moreover, should allow the public to take appropriate action. Previous research has shown that one of the most significant problems with weather forecasts is how the information is presented and communicated to end-user communities (e.g., government agencies, emergency management organizations, industry, and to the general population; see Refs. [4,12–14]). It is noteworthy, however, that even forecasts of severe weather events that attempt to solve these problems may fail to elicit appropriate protective action (horizontal evacuation,

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vertical evacuation, shuttering, securing roofs, stockpiling food, having a generator, alternate means of communicating etc.) given that an individual's response to forecasts and warnings is often impacted by factors that have little to do with the technical features of weather forecasts, such as the individual's social class, education, gender, race, ethnicity, cultural background, and previous experiences with weather events.

Given the different perceptions of events, access to and response to information, and alternative actions, we know very little about who actually evacuates and when, if a hurricane warning is issued, and when the evacuees return. This lack of information is a problem for both planning for and responding to hurricanes.

1.2. Objective

Traditionally, emergency management agencies perform the majority of evacuation planning and operations, but recently transportation departments are becoming increasingly involved [3]. This provides an opportunity for new improvements to evacuation planning and operations. Specifically, increased participation of Departments of Transportation (DOTs) benefits evacuation operations by involving transportation professionals and utilizing intelligent transportation systems (ITS). Transportation professionals and ITS provide access to real-time collection and analysis of traffic data that can be used to inform the planning process and enhance the efficiency of response operations.

The objective of this work is to identify ways to use traffic data to better understand evacuation behavior and to explore ways to integrate traffic data into evacuation planning and response. This involves examining traffic data collected in Delaware before, during and after Hurricane Irene in August 2011. Analysis of this data is performed and the usefulness of this type of data is then discussed. The use of traffic data will ultimately allow governments to better plan and execute evacuations.

1.3. Related work

While a great deal of research focuses on evacuations in general and hurricane evacuations in particular [15–17], relatively few studies make use of traffic data. Many evacuation studies instead rely on surveys. For example, Kang et al. [18] compared hypothesized household behavior with actual behavior during a hurricane. Other studies have used traffic data to support their data collected from phone interviews. For example, Dow and Cutter reviewed data from Hurricane Floyd [15]. A notable use of traffic data is the analysis of the 2005 Hurricane Katrina evacuation in Louisiana by Wolshon [17,19,20]. Traffic data analyses have also been undertaken for other types of disasters. In Japan, traffic data provided insight into the impact and recovery from the 1995 Kobe earthquake [21]. Other studies use travel demand and traffic models to plan evacuation routes [22,23] and some recognition has been given to the importance of integrating behavioral information with the models [24].

Among state DOTs monitoring and usage of traffic data are far more common. Across the country, states have been working on developing and implementing ITS systems using inductive loop traffic counters and closed circuit television to monitor real-time travel conditions [25]. In hurricane-prone areas, state plans identify these technologies as an important resource [26]. Florida has a statewide web based system to monitor traffic data for hurricane response and parts of Texas use real-time data for hurricane response as well [27].

In Delaware, the area examined in this study, the use of real-time data for hurricane evacuation is not standard practice as it is in states that regularly experience hurricanes. Delaware like other states with some hurricane risk does, however, have planning documents to address hurricane hazards. In Delaware, consultants have worked with Delaware Department of Transportation and Delaware Emergency Management Agency to develop all hazards evacuation plans [28–30]. The Army Corps of Engineers has also developed a Hurricane Evacuation Study to inform hurricane evacuation planning for the entire Delmarva Peninsula, which includes Delaware as well as parts of Maryland and Virginia. This study also defines behavioral assumptions for the Delmarva Peninsula [31].

2. Data and data analysis

2.1. Context for the data

Delaware is an Atlantic coastal state. While Delaware is the second smallest state (under 2000 square miles or about 5000 square kilometers) and has a population of about 900,000, vacationers swell the population of the beach communities each summer. The state is situated on the Delmarva Peninsula, a narrow body of land bordered by Chesapeake Bay to the west and Delaware Bay and the Atlantic Ocean to the east. The state of Delaware is bordered by Pennsylvania to the north and Maryland to the west and south. The Chesapeake–Delaware canal crosses northern Delaware providing a shorter shipping route between Baltimore and Philadelphia. The majority of the population is clustered in northern Delaware away from the ocean. State Route 1 and US 13 are the primary north–south routes. State Route 1 is a multi-lane limited access toll road in northern Delaware. Along the Atlantic Ocean, the beach communities are developed with a dense local street network. Most access is from the north with limited access to the west, and to the south via the Chesapeake Bay Bridge and Tunnel. This geography means that there is limited access to the beach communities. During severe weather, this may be compounded by closures at the bridges across the canal, and the Indian River Inlet in southern Delaware.

Although the state frequently experiences severe weather, tropical storms and hurricanes are less common in the area. In the five year period between 2005 and 2010, Delaware experienced 37 severe weather events, of which only one was a tropical storm [32]. Hurricane Irene in August 2011 was the first time Delaware experienced a hurricane evacuation.

This work uses data from Hurricane Irene to explore the usefulness of traffic data for modeling and understanding hurricane evacuations. Traffic data from Delaware before, during and after the 2011 Hurricane Irene are analyzed, and graphed to identify traffic patterns before, during and after the mandatory evacuation. This information is used to make some inference about the behavior of the population. To put this analysis further in context, the timeline of the event is reviewed.

On Thursday August 25, 2011, the National Weather Service issued a hurricane warning for coastal Delaware [33] and an hour later the governor issued an order for the immediate evacuation of all visitors in coastal areas effective at 6:00 PM, August 25th, local time. This evacuation order was amended Friday August 26th at 11:00 AM to include a mandatory evacuation for all residents within three-quarters of a mile (1.1 km) of major bodies of water. Delaware coastal residents had until 9:00 AM Saturday to evacuate [34]. In nearby Maryland, the timing and conditions of evacuations orders varied widely, as individual counties and municipalities made the determination of what kind of evacuation order to issue and when. Ocean City, Maryland, a coastal community bordering Delaware, pursued one of the most aggressive evacuations in the state, calling for a mandatory evacuation of all residents and visitors, requiring businesses to close, banning the sale of alcohol beginning Friday morning at midnight, restricting entry to only essential personnel and going door to door Friday to make sure everyone had left [35]. Irene was a category 1 hurricane as it passed just off the coast of the Delmarva Peninsula between 8 PM Saturday night, and 5 AM Sunday morning [33].

August is a busy time for the beach communities in southern Delaware. In addition to the residents there are the regular beachgoers