When disaster strikes: Statistical modeling of hurricane evacuation patterns in VA utilizing cellular mobility data

Mistrust in the government: Assessing the impact of governmental relations on evacuation rates for low income, high risk communities in Hampton Roads, VA

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Systems Engineering

By
Zachery Key

November 1, 2021

Technical Team Members:
Andrea Parrish, Connor Snavely, Gabby Bunch, Jamal Williams

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISORS

Rider Foley, Department of Engineering and Society

Dr. Majid Shaifee-Jodd, Department of Environment and Systems Engineering

Every year natural disasters claim the lives of tens of thousands of people and cause billions of dollars in damage. In 2019 alone, the US saw more than $130 billion dollars of damages to infrastructure and lost upwards of 12,000 lives to hurricanes, fires, flooding and tornadoes and other extreme weather events (Deng, 2021). Virginia is no exception; in 2003 Hurricane Isabel inundated the state with over 20 inches of rain in some localities, claiming 32 lives and causing 80% of the state to lose power. In 2016 Hurricane Matthew dropped a foot of rain in less than 48 hours and caused more than 260,000 people to lose power in the commonwealth (VDEM, 2021).

Current Hurricane evacuation techniques rely on a complex sequence of events that begin with an extreme weather forecast issued to the state governments by the NWS and culminate in localities issuing an evacuation order (Figure 1). Because modeling the uncertainty of a hurricane strike is an inverse function of time, governing bodies must decide early on whether to risk the lofty expenditures of a false alarm or wait and risk endangering lives. The decision to evacuate is not an easy one: the cost of premature evacuations in the US totals more than $10 billion dollars per year and repeat offenses can cost local governments their credibility (Reigner, 2008). Although most individuals report evacuation preparation times of less than 6 hours, many are hesitant to leave unless they have personally witnessed the evacuation order or have a high level of confidence in the authority of the messenger (Lindell, 2020). Furthermore, the government must be cautious of the order in which it issues evacuation mandates to avoid overwhelming inland transportation routes (Nakanishi, Wise, Suenaga, & Manley, 2020).

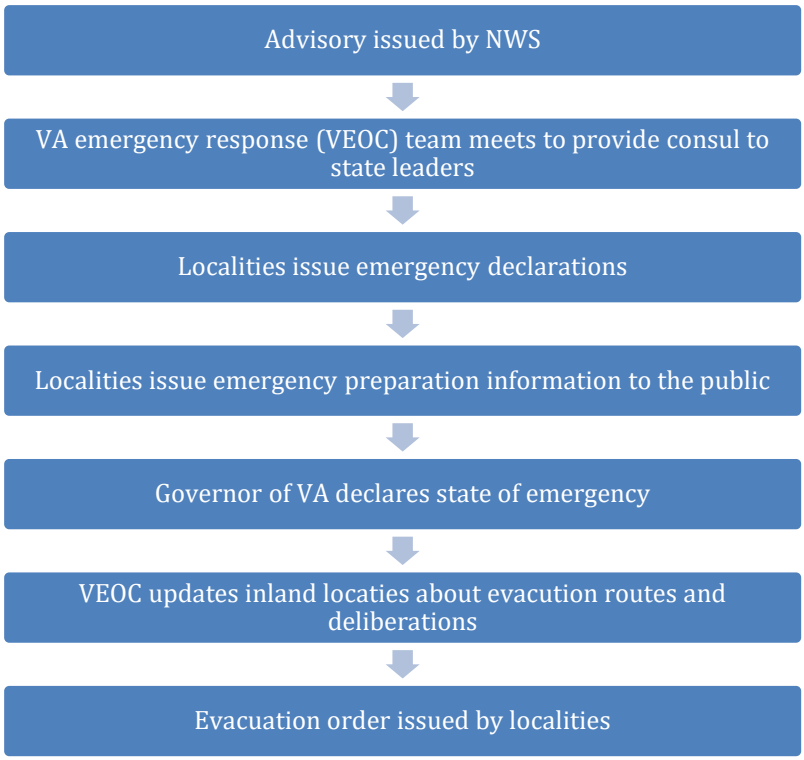

Figure 1. Hurricane Evacuation Order of Events (VDEM, 2010)

Despite the advances in forecasting technology, emergency evacuation orders are only acted on by fewer than 10% of the endangered population (Deng, 2021). Prior research has proven that there is a significant difference in the demographic makeup of the populations that evacuate (predominantly mid-to high income white families) and those who shelter in place (predominantly low-income, minority families) (Behr, 2020). A large number of factors (health concerns, family size, pets, etc.) play into the decision on whether to seek shelter locally or to evacuate and (because they are personal decisions) are uncontrollable by the government (Figure 2). To increase adherence to emergency policy measures, I seek to understand what sort of governmental policy factors are resulting in a reduced rate of evacuation from Hampton Roads.

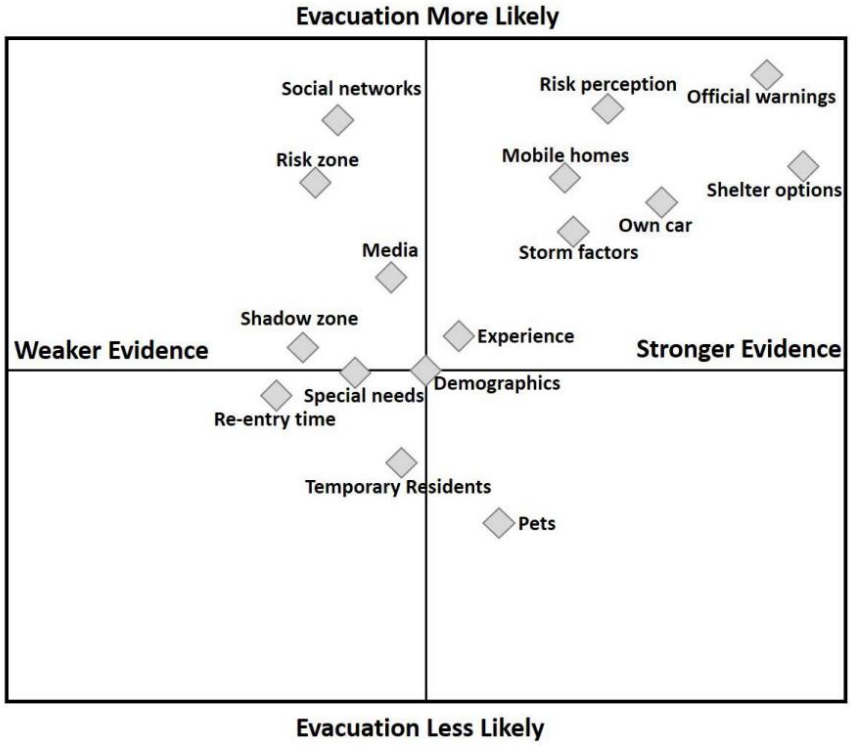

Figure 2. Factors Influencing Decision to Evacuate (Bowser, 2008)

Technical Project

In the technical portion of this report, my capstone team and I will be working closely with the Virginia Department of Emergency Management (VDEM) as hurricane evacuation procedure consultants. In addition to conducting interviews and gathering survey data, we will be drawing upon findings from prior art focused on the historical evacuation behaviour of communities with high social vulnerability (Smith, 2020). We shall have several final deliverables for this project: a deployable evacuation dashboard depicting the net flow of evacuees away from the evacuation site, a collection of data visualizations depicting the distribution of emergency evacuation resources amongst particular communities and a written report detailing the policy analytics process and the corresponding conclusions on which community outreach programs to deploy.

We will be operating primarily in Python, utilizing packages such as MovingPandas or Mobilkit to produce descriptive models of evacuation behaviour (Figure 3). Census data shall be collected on a county and block level for the state of Virginia and mobility data shall be purchased from a mobility data service provider (Cuebiq) on the county or census block level. Our team will be analyzing Hurricane Matthew mobility data in order to 1.) identify communities with similar evacuation behaviours and 2.) model mobility patterns of these communities before, during and after the hurricane evacuation order (Yabe, 2021). We will then cross validate the cell phone mobility data with geographic data collected from tweets in that region in accordance with the methods established by Martin (Martin, 2020). Two distinct and dissimilar "communities" of interest shall be identified from the mobility data (a community is defined as a finite geographically enclosed region that shares common socioeconomic characteristics and exhibits similar evacuation behaviour). The two residential "communities" with the highest disparity in evacuation rates will be considered in our study and labeled group A (high evac. rate) and group B (low evac. rate) accordingly. We will then conduct statistical tests to see if there are any significant demographic predictors of evacuation likelihood in terms of income, education, age, household size and race (Cahyanto, 2014).

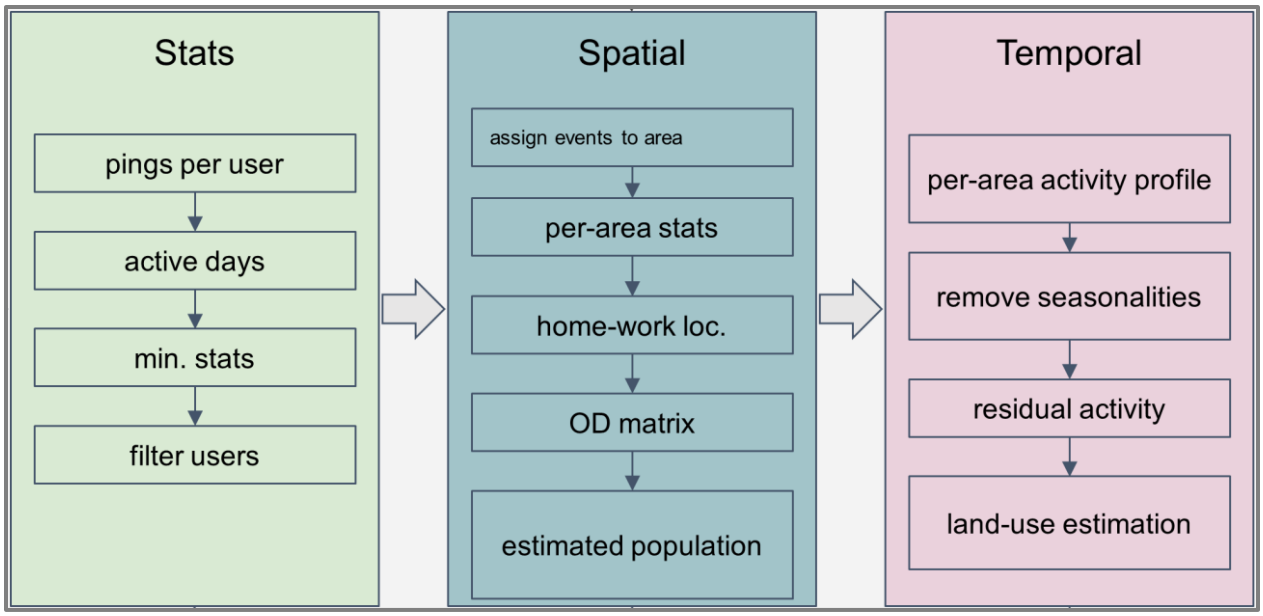

Figure 3. Analytic Capabilities of Mobilkit (Ubaldi, 2021)

To gain a deeper understanding of the attitudes of the people impacted by hurricane events in VA, we will perform sentiment analysis of responses to twitter posts made by the local government containing information about hurricanes, evacuations or policy related to the two (Zavattaro, 2015). Our team will utilize this information to gain insight to the distrust and frustration (negative sentiment) that is currently expressed towards the government in Hampton Roads, VA as well as to identify the structure and syntax of messages that are more positively recieved (Lamb, 2011). The insights gathered in the sentiment analysis will be used to construct survey questions directed toward residents in group(s) A & B, addressing topics such as trust in the government and concerns with the current evacuation system. This will build upon prior research methods that have identified frustrations with the evacuation system by isolating the causes of discontentment, allowing for the design of more elegant community-backed solutions.

STS Project

This section explores the relationship between the Hampton Roads community and its government through the technological medium of evacuation policy. I seek to increase transparency in the evacuation process by exploring the social agenda embedded in the current communication channels that disperse information (Dimaggio, 2004). Following Star's definition of infrastructure as "a relational property, not some thing stripped of use" I will characterize policy as the relational construction between citizens and their government containing the properties of embeddedness, transparency and visibility upon breakdown (Star & Ruhleder, 1996, p. 113; Star 1999). In the context of my project, emergency evacuation policy can be likened to a socially constructed technology that is embedded in the particular community in which it was created. Similarly, by applying the property of transparency to policy I can evaluate the degree to which the general public understands and comprehends the individual components of evacuation policy. Finally, I will assess the problems inherent in the current evacuation policy (low zone awareness, low evacuation rates) by evaluating the inefficiencies of the communication systems (social media, television, etc.) that disperse information about evacuation preparation and procedure. Arriving to a deeper understanding of the problem, I will restructure the decomposed system to arrive to my goal of insuring equal access to evacuation resources for everyone.

Research Question and Methods

I plan on investigating the discrepancy between the evacuation behavior of particular communities to devise community-customized programs that increase community engagement in an effort to improve the relationship between the government and localities (Wells, 2013). Data

shall be collected from surveys including a range of questions that explore community member's opinions on (presently) highly functioning components as well as potential improvements to the current evacuation situation. By exploring the feedback of community members from group A and group B, I can propose custom evacuation plans that distinguish where and how the government in Hampton Roads should focus its resources to aid in the steps involved in hurricane evacuation.

In accordance to Star's Infrastructure theory of technology, I will be exploring the differences in perception of transparency of the evacuation process between focus groups A&B, the government and emergency managers. I hypothesize that group A will have a fairly high level of trust in the government and consider the evacuation process more transparent and understandable than group B. I also hypothesize that the local government and emergency managers will overestimate the level of confidence that their constituents have in them to provide adequate support during a hurricane evacuation.

I will collect evidence for my project by combining prior research with interviews of project managers, government employees and community residents. Recent research efforts have observed that very few people are evacuating from endangered regions, suggesting a flaw in the government's current implementation of evacuation protocol. There is clearly a divide between the desired response to an evacuation order (100% adherence to evacuation orders) and the actual result of an evacuation order (>10% adherence to evacuation orders) that suggests a systemic breakdown. This disparity in expected and actual behavior is only made clear in the absence of a functioning system, leading me to believe that the government may have excluded some communities in the design of evacuation policy by employing a "one-size-fits-all approach" to evacuation protocol (Smith, 2020).

Conclusion

Low evacuation rates place higher levels of stress on emergency responders and result in an increased likelihood of injury or death from the damages inflicted from a natural disaster (Kruger, 2020). As a means to reduce the number of injuries and deaths from disaster situations, we aim to increase evacuation compliance in the state of Virginia by identifying and engaging with at risk communities to collaboratively construct education and outreach programs. We seek to provide the local government with the insights gained from our geographic evacuation modeling to inform them of where resources can best be distributed to increase evacuation compliance. Utilizing the same modeling methods mentioned before, we shall construct an evacuation visualization dashboard to quantify the performance of our recommendations following the next disaster evacuation. Finally, we shall synthesize the findings from our interviews to provide a series of recommendations to the local government about community engagement programs to improve the trust and increase the legitimacy of the relationship between low evacuation neighborhoods and their authority figures.

Sources Cited

Behr, J., Diaz, R., Yusuf, W., Giles, B., Lawsure, K., & McLeod, G. (2021). COVID-19 Evacuation and Sheltering Risk Perception Study. ODU Digital Commons. Retrieved 12 October 2021, from https://digitalcommons.odu.edu/odurc-presentations/28/

Bowser, G., & Cutter, S. (2015, October 26). Stay or Go? Examining Decision Making and Behavior in Hurricane Evacuations, Environment: Science and Policy for Sustainable Development, 57:6, 28-41, DOI: 10.1080/00139157.2015.1089145

Cahyanto, I., Pennington-Gray, L., Thapa, B., Srinivasan, S., Villegas, J., Matyas, C., & Kiousis, S. (2014). An empirical evaluation of the determinants of Tourist's Hurricane Evacuation

Commonwealth of Virginia Emergency Operations Plan. (2010, July). Commonwealth of Virginia Emergency Operations Plan. Division of Legislative Automated Systems . Retrieved October 19, 2021, from http://services.dlas.virginia.gov/User_db/frmView.aspx?ViewId=3060&s=22.

Deng, H., Aldrich, D. P., Danziger, M. M., Gao, J., Phillips, N. E., Cornelius, S. P., & Wang, Q. R. (2021, June 15). High-resolution human mobility data reveal race and wealth disparities in disaster evacuation patterns. Nature News. Retrieved October 12, 2021, from https://www.nature.com/articles/s41599-021-00824-8.

Dimaggio, P., Hargittai, E., Celeste, C., & Shafer, S. (2004, December 1). Digital inequality: From unequal access to differentiated use. Northwestern Scholars. Retrieved October 26, 2021, from https://www.scholars.northwestern.edu/en/publications/digital-inequality-from-unequal-access-to-differentiated-use.

Horowitz, D. L. (1993). Democracy in divided societies. Journal of Democracy, 4(4), 18–38. https://doi.org/10.1353/jod.1993.0054

Kruger, J., Smith, M. J., Chen, B., Paetznick, B., Bradley, B. M., Abraha, R., Logan, M., Chang, E. R., Sunshine, G., & Romero-Steiner, S. (2020). Hurricane evacuation laws in eight Southern U.S. Coastal States — December 2018. MMWR. Morbidity and Mortality Weekly Report, 69(36), 1233–1237. https://doi.org/10.15585/mmwr.mm6936a1

Lamb, S., Walton, D., Mora, K., & Thomas, J. (2011, November 10). Effect of authoritative information and message characteristics on evacuation and shadow evacuation in a simulated flood event: Natural hazards review: Vol 13, no 4. Natural Hazards Review.

Retrieved October 17, 2021, from https://ascelibrary.org/doi/10.1061/%28ASCE%29NH.1527-6996.0000070

Lindell, M. K., Sorensen, J. H., Baker, E. J., & Lehman, W. P. (2020, July 8). Community response to hurricane threat: Estimates of household evacuation preparation time distributions. ScienceDirect.com. Retrieved October 17, 2021, from https://www.sciencedirect.com/science/article/abs/pii/S1361920920306441?via%3Dihub.

Martín, Y., Cutter, S. L., & Li, Z. (2020, January 23). Bridging Twitter and survey data for evacuation assessment of Hurricane Matthew and Hurricane Irma. Natural Hazards Review. Retrieved October 12, 2021, from https://ascelibrary.org/doi/10.1061/%28ASCE%29NH.1527-6996.0000354.

Nakanishi, H., Wise, S., Suenaga, Y., & Manley, E. (2020). Simulating emergencies with transport outcomes Sim (SETOSim): Application of an agent-based decision support tool to community evacuation planning. International Journal of Disaster Risk Reduction, 101657.

Regnier, E., Arora, P., Pedraza-Martinez, A. J., Regnier, E. D., & McLay, L. A. (2008, January 1). Public evacuation decisions and hurricane track uncertainty. The Institute for Operations Research and Management Science. Retrieved October 12, 2021, from https://pubsonline.informs.org/doi/abs/10.1287/mnsc.1070.0764.

Riley, J. (1990). American Democracy and Majority Rule. *Nomos*, *32*, 267–307. http://www.jstor.org/stable/24219413

Smith, M. (2021). Social Vulnerability and Hurricane Evacuation Behavior in Hampton Roads, VA: Emergency Management Stakeholders' Perceptions of Low-to-Moderate Income Households in a Social Construction Paradigm. ODU Digital Commons. Retrieved 12 October 2021, from https://digitalcommons.odu.edu/publicservice_etds/44/

Star, Susan Leigh. (1999). The Ethnography of Infrastructure. American Behavioral Scientist, 43(3), 377–391. https://doi.org/10.1177/00027649921955326

Star, R.L. & Ruhleder, K. (1996). Steps toward an ecology of infrastructure: Design and Access for large information spaces. Information Systems Research, 7(1), 11-134.

Virginia Department of Emergency Management (VDEM). (2021, September). Hurricane Evacuation Guide. Virginia Department of Emergency Management. Retrieved October

26, 2021, from https://www.vaemergency.gov/wp-content/uploads/2021/09/Hurricane-Evacuation-Guide-COVID-19-Edit.pdf.

Ubaldi, E., Yabe, T., Jones, N. K. W., Khan, M. F., Ukkusuri, S. V., & Strano, E. (2021, July 29). Mobilkit: A python toolkit for urban resilience and disaster risk management analytics using high frequency human mobility data. arXiv.org. Retrieved October 12, 2021, from https://arxiv.org/abs/2107.14297v1

Wells, K. B., Tang, J., Lizaola, E., Jones, F., Brown, A., Stayton, A., Williams, M., Chandra, A., Eisenman, D., Fogleman, S., & Plough, A. (2013). Applying community engagement to disaster planning: Developing the vision and design for the Los Angeles County Community Disaster Resilience Initiative. American Journal of Public Health, 103(7), 1172–1180. https://doi.org/10.2105/ajph.2013.301407

Yabe, T., Jones, N. K. W., Rao, P. S. C., Gonzalez, M. C., & Ukkusuri, S. V. (2021, August 5). Mobile phone location data for disasters: A review from natural hazards and epidemics. arXiv.org. Retrieved October 12, 2021, from https://arxiv.org/abs/2108.02849

Zavattaro, S. M., French, P. E., & Mohanty, S. D. (2015, April 27). A sentiment analysis of U.S. Local Government Tweets: The connection between tone and citizen involvement. Government Information Quarterly. Retrieved October 26, 2021, from https://www.sciencedirect.com/science/article/pii/S0740624X15000337.