CSE 6730

Group 14: Cheting Meng, Hana Herndon,

Xiyu Pan, Yuchen Wang, Zefang Chen

March 29, 2023

Project Checkpoint 1: Preliminary Progress Report

GT GitHub link: https://github.gatech.edu/ywang4119/CSE6730-Project

1. Abstract

Flooding is a frequent disaster in urban areas. It disrupts the urban transportation network, blocks portions of the roads, and results in longer travel times for residents and service vehicles. The primary approach to predict the travel time in prior studies is to simulate individual vehicle movement on disrupted road networks based on the fastest routing analysis. However, this approach implicitly assumes free-flow transportation and does not effectively model the movement of other vehicles as well as the macro-level traffic flows. To create a more effective travel model for residential vehicles, this study creates an improved traffic simulation in SUMO. First, the inundation depth is determined from hydrodynamic inundation models and the resulting road blockage is calculated. Next, the capacity of these roads is determined and used in a macroscopic traffic simulation across a large road network. This traffic simulation is used to determine the increase in travel time across the road network during flooding events.

2. Description of the system being studied

This project studies the integrated system of urban transportation and flooding. The inundation caused by flooding will likely cut off some road segments in the city and impact the transportation on the disrupted road network. This section describes the major components of the system being studied, as well as the dataset being used and the preliminary analysis to represent the system status.

2.1. Road network:

The City of Virginia Beach (VB), Virginia, will be used as the study system. The city's road network data was obtained from the open data portal of VB (https://gis.data.vbgoc.com/). The dataset consists of over 20,000 road segments. It was split at all the intersections, and a polygon of the road surface shape represents each road segment. Roads are assigned to be cut off and removed from the traffic simulation based on the flood inundation depth (below).

2.2. Transportation flows

To simulate the transportation at the macro level, the population density and the travel patterns (e.g., moving between the residential areas to business districts at peak times should be considered. The transportation flows are defined by origin-destination matrices.

2.3. Flood and road disruption:

Predicting the inundation is a prerequisite for obtaining the status of the road network at the time of flooding. The results from the study by Loftis et al. (2018) were used in the present simulation. Loftis et al. (2018) produced 24 inundation maps for each hour at 10/09/2016 UTC with the depth of water featuring the impact of Hurricane Matthew in VB. The inundation map for 10:00-11:00 UTC was used for the road disruption estimation in the present study because the impact of inundation reaches its maximum during this period.

3. Conceptual model of the system

Assessing and predicting the impact of the flooding inundation on transportation as well as the cascading effects is critical for taking mitigation measures. A system is developed conceptually step by step in this section to predict and measure the level of impact in advance of flooding incidents.

Input: Input dataset includes the road network, population density and business density, and the inundation map of the city.

Inundation analysis: To obtain the direct impact of inundation on road network, the inundation is mapped onto the road network to determine the road disruption. The inundation area was overlayed on the road segments and the maximum inundation depth was used at the degree of inundation for the road segment. Figure 1 illustrates the inundation depth on the road segments. To eliminate the influence of outliers, only inundation below 6 ft was plotted. The darkness of the color suggests the depth of inundation, and the darkest color indicates an inundation of 6 ft. The roads in the city's central area were inundated to varying degrees. Roads are assumed to be impassable if the inundation exceeded 25cm (0.82ft), according to a study by Yu et al. (2020). Impassable roads were taken off the whole road network. The updated road networks are then used in the macroscopic traffic analysis.

Figure 1. Inundation depth on the road network, City of Virginia Beach, VA. The darkest color indicates an inundation depth of 6 ft.

Traffic flow estimation: Before performing the simulation, the Origin-Destination (OD) traffic flows must be pre-defined. The city is discretized into many cells using a mesh grid. The residential density and business density could be used to calculate the destination distribution in the city during morning and evening peak times. The estimates are represented by OD matrix, each element of which is the volume of a traffic flow from one cell to another.

Simulation: To model the transportation in the disrupted road network, we will use Simulation of Urban MObility (SUMO), an open-source road traffic simulation package developed by the Institute of Transportation Systems at the German Aerospace Center. SUMO has been widely used in various research projects related to traffic management and has proven to be a reliable tool for modeling complex traffic scenarios (Costa et al. 2020). In this model, the roads are represented by edges and nodes with different capacities and directions. Edges are directed segments that have one or more lanes and a speed limit associated with them. Nodes are junctions that connect edges and can have traffic lights or priority rules to regulate the traffic flow. The SUMO network of edges and nodes can be automatically generated by importing the Virginia Beach road network.

Experiments and system output: We will create different versions of the network by modifying the properties of the segments that could be blocked by floods, such as their capacity, speed limit, and accessibility. We then compared the performance of the network under normal and disrupted conditions, using different indicators such as travel time, delay, and congestion. The results of our simulations provide useful insights for designing and implementing effective traffic management strategies in case of natural hazards.

4. Platforms of development

This project is based on Python. Different packages and software are used for each step of the analysis. For inundation analysis, rasterio and geopandas are used for mapping the raster-based inundation map onto the road network. Traffic flow analysis is based on pandas, the simulation majorly relies on the API of SUMO as well as its user interface for visualization. Matplotlib and Plotly is used to do the visualization for all analysis as needed.

5. Literature review

Our group intends to conduct further research on traffic modeling and simulation, with a specific focus on the impact of flooding on the roadway system. By employing numerical analysis, this study aims to uncover new understandings of the system's behaviors during flooding, devise optimization insights, and help increase the roadway system's overall resilience.

Some studies focused on simulating the movement of emergency service vehicles (e.g., emergency medical services, fire rescues, police dispatches) on the individual level to measure the impact of inundation on road networks and emergency services relying on transportation. Coles et al. (2017) study is one of the most typical in this direction. They obtained the flooding areas and the inundation depth from hydrodynamic models and set a threshold to identify the roads the flooding would disrupt. A micro-scale and individual-level traffic simulation was conducted with the disrupted road network and pre-defined network connectivity rules, including speed limit, turn restriction, and one-way traffic. A quickest routing analysis could be conducted based on the traveling speed in the simulation and suggest the traveling time increase due to the disruption. The following studies attempted to improve the rules defined in the simulation. Koch et al. (2020) developed an agent-based simulation model for ambulance moving with more accurate behaviors, where ambulances would respond to randomly generated calls and return to emergency medical service stations after delivering the patient to the hospital. Yin et al. (2020) emphasized the temporal variance of traffic status and emergency service demands and proposed a scenario-based approach. Four scenarios, including midnight, night, day, and morning and evening peak, were designed to tune the parameters in the simulation. Yu et al. (2020) designed different scenarios for three groups of vulnerable populations in the U.K., including the elderly, young children, and people with terrible health, who have different demographical distributions and levels of demands.

Other studies have investigated how the road network for the general population is impacted after a disaster. He et al. (2012) created a discrete-time model of the traffic disruption of the collapse of the I-35W Mississippi River Bridge in Minneapolis, Minnesota. They proposed the prediction-correction model, which is crucial for disruption simulations as drivers react differently under irregular circumstances. A minimization optimizing constraint was set upon the computation of the drivers' predictions that will be corrected through travel cost iteratively after each time unit as the disruption takes place. This allows the modeling of driving behavior to consider both past experiences and anticipations of traffic conditions. Their comparison results between simulations and empirical data showed greater capability from the prediction-correction model to capture recovery characteristics of unexpected disruptions.

The transportation disruption simulation during flood incidents has also been extensively studied. Li et al. (2018) developed a model to capture the traffic disruption in urban areas during pluvial flash floods (PFFs), which are low-frequency but high-disruption floods. Their road network model consisted of roads, links, and crosses with link direction constraints that will be blocked once the flooding exceeds 30cm. The BPR model, which describes the relationship between volume and travel time, and the A* algorithm, which is a heuristic optimization of the Dijkstra algorithm, were used to assign trip paths. To augment the actual travel data, the researchers used a random distribution to complement trips in their simulation. Improvements can be made upon practical calibration of the BPR model's parameters and increasing its scale for better travel data validation across the entire city. Shahdani et al. (2022) employed the mesoscopic simulation technique to identify traffic disruptions during flood events and used the Santarém, Portugal flood as a case study. The researchers evaluated the functionality of the transportation network before and after the infrastructure failed from flooding using static and dynamic traffic models. The model incorporated the road network geometry, trip paths, road closures, and speed limitations to evaluate the redistribution of travel time and vehicle volume during the flood. The impact of flooding on transportation networks was assessed by analyzing the changes in traffic data (i.e., travel time, travel distance, and street speeds) under normal and flooded situations, Costa et al. (2020) used SUMO to model traffic through a network of partially blocked roads after an earthquake to determine the increased travel time and distance for drivers. In their model, the roads are represented by nodes and edges with different capacities and directions. They determine the capacity of each edge, or road, by calculating how much debris would fall on the road after the earthquake. This work is novel because they study the impact of partially closed and fully closed roads on the transportation network, while most studies only study the impact of fully closed roads after a disaster. Hou et al. (2022) also studied how partially closing roads in a transportation network impacts mobility for the general population. Because current models do not consider the decreased capacity of partially closed roads, the calculated updated travel time is inaccurate and does not represent traffic flow after a disaster. They use a cellular automata model to model this behavior and determine an accurate travel time function.

In addition to understanding the transportation disruption behavior after disasters, engineers must optimize the transportation strategies after disasters for rapid and safe evacuation. Accordingly, Escribano-Macias et al. (2020) developed a pre-planning model that is based on a hybrid simulation-optimization method to optimize evacuation response strategies by demand staging and signal phasing. The evacuation policies were evaluated by a dynamic traffic assignment model to incorporate congestion, queuing, and vehicle spillback. The study employed derivative-free optimization algorithms to identify optimal evacuation strategies based on a benchmark dataset and examined the impacts of different network conditions on evacuation efficiency by varying the number of activated paths and frequency of departure. The simulation results indicated that combining departure time scheduling with signal phasing is an effective approach to enhance evacuation efficiency.

Cited Literature:

Alam, M., & Habib, M. (2020). Modeling Traffic Disruptions during Mass Evacuation. Procedia Computer Science. 170, 506-513. https://doi.org/10.1016/j.procs.2020.03.115

Coles, D., Yu, D., Wilby, R. L., Green, D., & Herring, Z. (2017). Beyond 'flood hotspots': Modelling emergency service accessibility during flooding in York, UK. Journal of Hydrology, 546, 419–436. https://doi.org/10.1016/j.jhydrol.2016.12.013

Costa, C., Figeuiredo, R., Silva, V., & Bazzurro, O. (2020). Application of open tools and datasets to probabilistic modeling of road traffic disruptions due to earthquake damage. Earthquake Engineering & Structural Dynamics. 49(12), 1236-1255. https://doi.org/10.1002/eqe.3288

Escribano-Macias, J., Angeloudis, P., & Han, K. (2020). Optimal design of Rapid evacuation strategies in constrained urban transport networks. Transportmetrica A: Transport Science, 16(3), 1079-1110. https://doi.org/10.1080/23249935.2020.1725179

He, X., Liu, H. X. (2012). Modeling the day-to-day traffic evolution process after an unexpected network disruption. Transportation Research Part B: Methodological. Volume 46, Issue 1 https://doi.org/10.1016/j.trb.2011.07.012

Hou, G., Chen, S., & Bao, Y. (2022). Development of travel time functions for disrupted urban arterials with microscopic traffic simulation. Physica A: Statistical Mechanics and its Applications. 593, 126961. https://doi.org/10.1016/j.physa.2022.126961

Koch, Z., Yuan, M., & Bristow, E. (2020). Emergency Response after Disaster Strikes: Agent-Based Simulation of Ambulances in New Windsor, NY. Journal of Infrastructure Systems, 26(3), 06020001. https://doi.org/10.1061/(asce)is.1943-555x.0000565

Li, M., Huang, Q., Wang, L., Yin, J., & Wang, J. (2018). Modeling the traffic disruption caused by Pluvial Flash Flood on the intra-urban road network. Transactions in GIS. Volume 22, Issue 1 https://doi.org/10.1111/tgis.12311

Shahdani, F., Santamaria-Ariza, M., Sousa, H., Coelho, M., & Matos, J. (2022). Assessing Flood Indirect Impacts on Road Transport Networks Applying Mesoscopic Traffic Modelling: The Case Study of Santarém, Portugal. Applied Sciences, 12(6), 3076. https://doi.org/10.3390/app12063076

Yin, J., Yu, D., & Liao, B. (2020). A city-scale assessment of emergency response accessibility to vulnerable populations and facilities under normal and pluvial flood conditions for Shanghai, China. Environment and Planning B: Urban Analytics and City Science, 0(0), 239980832097130. https://doi.org/10.1177/2399808320971304

Yu, D., Yin, J., Wilby, R. L., Lane, S. N., Aerts, J. C. J. H., Lin, N., Liu, M., Yuan, H., Chen, J., Prudhomme, C., Guan, M., Baruch, A., Johnson, C. W. D., Tang, X., Yu, L., & Xu, S. (2020). Disruption of emergency response to vulnerable populations during floods. Nature Sustainability, 3(9), 728–736. https://doi.org/10.1038/s41893-020-0516-7