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Transportation Planning with Floods - Phase III-V

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MATC

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16. Abstract In the early years of this project, our team was able to develop a good understanding of how floods impact travel times and roads in Iowa. The analysis allows us to understand what areas will be more or less accessible after floods. We used this information during these phases of the grant to understand what roads would be good candidates for mitigation, given both their propensity to flood as well as the access they provide for citizens to health care facilities during a flood. We have also worked on an interactive web platform for users to evaluate flood scenarios and their impact on transportation.		
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Abstract

In the early years of this project, our team was able to develop a good understanding of how floods impact travel times and roads in Iowa. The analysis allows us to understand what areas will be more or less accessible after floods. We used this information during these phases of the grant to understand what roads would be good candidates for mitigation, given both their propensity to flood as well as the access they provide for citizens to health care facilities during a flood. We have also worked on an interactive web platform for users to evaluate flood scenarios and their impact on transportation.

Chapter 1 Identifying Candidates for Mitigation

With knowledge of city infrastructure and historical flood behavior, we have developed a decision support tool to predict which roads can be used after a forecasted flood event and can provide reliable delivery paths to use after a flood. We can use the detailed information available from the flood and road maps, as well as different techniques for reducing flood impact to identify what mitigation choices would be the most helpful for improving transportation to hospitals when a flood event occurs.

1.1 Creating the Data Instances

To develop our current decision support tool, we use OpenStreetMaps to collect information about the roads in Johnson County, Iowa. We use historical information about 100-year and 500-year flood levels from the Iowa Flood Center to understand the level of flooding in different parts of the county.

We have added to this knowledge by including information about flood mitigation options that could be used at different locations within the network. Each option would have a cost, based on the type of road and number of lanes involved, and would offer the potential to prevent certain links from being flooded.

1.2 Mitigation Analysis

We can optimize the choice of mitigation options given budget limitations. The optimization analysis focuses on different objectives such as minimizing the number of citizens who would not have access to the rest of the county or reducing the impact on the average travel times between locations in a county. Such optimization problems are typically modeled as integer programs, as we did here, so we can solve them exactly using commercial integer programming solvers that evaluate the different options. We examine several locations within Iowa in this study, such as Charles City, Fort Dodge, Keokuk, and Coralville.

We started with smaller cities, then worked on improving the model's efficiency. These improvements come in the form of removing roads for consideration for mitigation as well as determining which sets of roads in the graphs can be merged without impacting solution quality. The improvements developed correspond to changing both the model's build-time and its solution-time.

1.3 Results and Discussions

We visualize the solutions on ArcGIS. The visualization is designed to better understand the optimal location of mitigated roads and investigate the optimal solutions.

We generated 80 instances of the problem for each city based on combinations of (available budget, hospitals' total capacity, covered percentage of the total population, and the number of hospitals).

In evaluating our results, we define a parameter, B, which represents the budget required to mitigate all roads likely to flood in each scenario. We found results for Coralville such as:

- A mitigation budget equal to 15% of B will be enough to improve the performance of Coralville's transportation network up to its fully functional status for getting to hospitals.
- The set of upgraded roads for Coralville always includes eight vulnerable roads that are needed to create connectivity to the network.
- With the same total capacity as Coralville's HCFs, we can have a much better objective value if the capacity is more evenly distributed among the networks.

For Coralville, it would be helpful to have a large hospital (i.e., more capacity) on the north side of the network (we note that one recently started construction.)

Chapter 2 Web-Based Decision Platform

Transportation systems can be significantly affected by flooding, leading to physical damage and subsequent adverse impacts such as increased journey distance to essential services. Even though flooding is a frequently recurring phenomenon that can affect thousands of people per event, there are limited accessible online tools available for analyzing and visualizing flood risk for routing and emergency activities. Existing tools are generally based on complicated models and are not easily accessible to non-expert users. Therefore, the challenge is to develop an efficient and meaningful way of communicating flood conditions on transport networks to various stakeholders, including the public, to minimize the adverse impacts for those groups.

In this study, we developed a web application that uses theoretical graph methods and the latest web technologies and standards to assist in describing flood events in terms of operational constraints and provide analytical methods to support mobility and mitigation decisions during these events. The framework is designed to be user-friendly, enabling non-expert users to access information about road status, shortest paths to critical amenities, location-allocation, and service coverage.

The study area includes the following two communities in the State of Iowa, Cedar Rapids and Charles City, which were used to test the application's functionality and explore the outcomes. Our research demonstrates that flooding can significantly affect bridge operation, routing from locations to critical amenities, arbitrary point to point routing, planning for emergency facility placement, and service area analyses. The introduced framework is capable of solving complex flood-related tasks and providing an understandable representation of transportation vulnerability, enhancing mitigation strategies. Therefore, this web application provides a valuable tool for stakeholders to make informed decisions during flood events.

2.1 Web-Based Routing Engine During Flooding

The main objective of our framework is to provide operational and analytical methods that can be used by experts and laypeople for routing during flooding, eliminating the need for complex software and skilled analysts. We understand that dealing with complicated data processing and analysis software can be time-consuming and frustrating for non-experts, which is why our system is designed to be user-friendly and straightforward. Our web application development involves integrating spatial and non-spatial data with programming languages, including Python for the back-end server and JavaScript for the client-side. The following sections provide a detailed description of both server-side and client-side development, including each component's technical specifications and functionalities.

2.2 Server Side

The back-end server is the system's backbone and is responsible for managing and providing services to support the front-end users. It plays a crucial role in data processing and storage and handles various functions and tasks that are accessible by the client-side. Data for the framework was collected from multiple sources and serves as inputs for the system's methods. The PostgreSQL database, with PostGIS spatial extensions, was used to store spatial and aspatial information, including pre-computed shortest paths and flood extents. Methods supporting the framework functionality are handled by a custom application programming interface (API) enabled by an Asynchronous Server Gateway Interface (ASGI, 2018). We use the FastAPI framework with API services provided by ASGI. The NGINX webserver (Reese, 2008) provides load-balancing and proxy services for front-end requests. To expedite the sharing of geographical data on the map, we linked the PostgreSQL database to GeoServer, an open-source server, that provides a platform to serve and publish geospatial data (geoserver.org, 2023). The use of GeoServer allows the system to share geographic data quickly and efficiently with the front-end users.

2.3 Client Side

Hyper Text Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript were used to build the web interface. Leaflet (Agafonkin, 2022), a free-source JavaScript library, is employed to display spatial data (e.g., vector) into interactive maps. The entry webpage for the framework provides access to the main functionality of the framework through an intuitive and user-friendly design. This features a map based on OpenStreetMap and Mapbox-compatible map tiles, with map scale and zoom controls to allow users to navigate and zoom in/out of the map easily. The system provides the user with the ability to define the geospatial area of interest and the scenario (e.g. no flood or flood events) they want to examine.

The system offers five main functions that the user can interact with. The first is road assessment under flood return period scenarios, which enables users to visualize open and closed roads under various flood conditions as well as bridges in the study area. The system provides a summary panel that lists the total length and quantity of the impacted segments for the user's convenience. This allows users to quickly assess which roads and bridges are affected by a flood event. In addition, the road conditions can be explored by visualizing the closed and open routes based on river flood stages. The system provides users with information on the flood extent linked with each flood stage. Additionally, the current and 10-day flood river levels within the study area are integrated into the map, enabling users to learn in advance about the condition of the road. This feature is important because it allows users to plan their travel routes and avoid flooded areas during a flood event.

The third function is accessibility analysis, which provides users with the shortest path length from a defined location to critical amenities, including fire departments, police stations, and hospitals, before and after a flooding event. The system generates the shortest paths and allows users to hover over each path to display relevant information such as distance. This feature is important because it lets users plan their travel routes and avoid flooded areas during an emergency. Also, we have created a point-to-point routing function that empowers users to effortlessly discover the shortest path between any two locations on the map within the communities under study. Our map interface displays two markers representing the origin and destination points. Users can manipulate these markers, allowing them to explore different locations and observe the corresponding outcomes. As they adjust the markers, the system dynamically updates the displayed route, along with the associated travel distance, considering the potential effects of flooding.

The fifth function is facility allocation, which helps users to identify the best locations for emergency sites (e.g., food and medical supplies) based on the input parameter (number of required facilities). The system displays the optimal locations, demand points belonging to each location, and mean distance on the map. This feature is useful for emergency response planning as it enables users to identify the most appropriate locations for emergency facilities while minimizing travel distance for demand points. The last function is the service coverage, which displays the routes that users can reach from a defined location within a certain travel distance. This feature is useful for users who need to travel within a specific area, such as first responders, during an emergency.

The system's main web page offers a range of functions that enable users to visualize and analyze the impact of flooding on roads and bridges, plan travel routes, and identify the best locations for emergency facilities. Figure 2.1 illustrates the overall development of the system, including both server and client-side components.

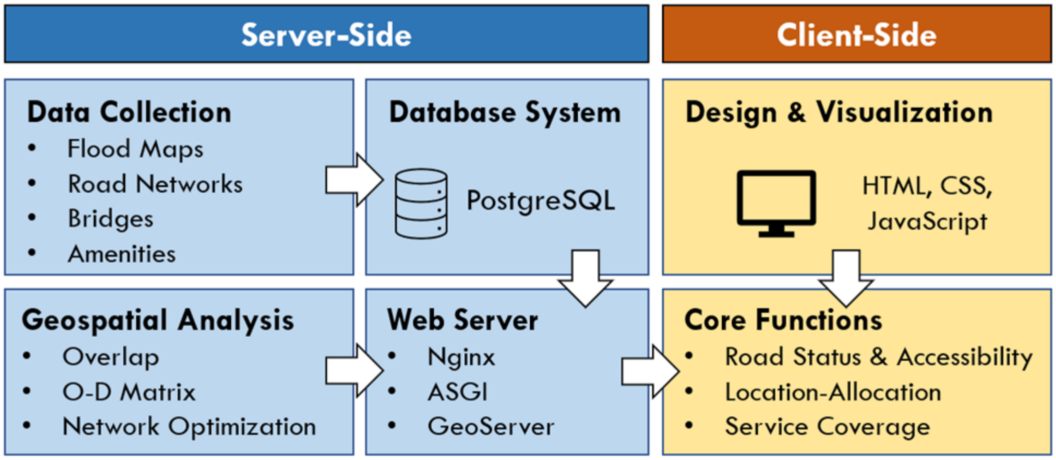

Figure 2.1 A flowchart illustrating web-based application development.

2.4 Research Outcomes and Findings

This research presents a web-based framework for routing and allocating emergency facilities during flood scenarios. The framework employs various spatial and optimization methods, including graph theory and facility location optimization. We have incorporated two Iowa communities, namely Cedar Rapids and Charles City, into the framework to thoroughly evaluate the system's functions before and after flood events and visualize the outcomes on an interactive map. The system enables users to examine flooded routes and shortest paths to critical amenities, point-to-point routing and perform location-allocation and service area analysis. The findings indicate that inundated routes significantly impact the accessibility to critical amenities, as well as the location-allocation and service areas. The developed web application facilitates access to information for decision-makers, including citizens and emergency responders, enabling them to respond appropriately to flooding irrespective of their technical knowledge.

Furthermore, the system visualizes the results on the map within seconds without the need for complicated systems, such as GIS, which may impede non-technical users. The framework's functionalities can help communities increase awareness of flood impacts on road networks, navigate around flooded routes, determine optimal locations for emergency services, and identify evacuation routes.

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