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Transportation Planning with Floods - Phase II

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16. Abstract

In the first year 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, which can help in making decisions for establishing evacuation centers and routing people outside the flood zone. We developed cyber tools and interfaces to recommend new routes in a flooding situation and used this tool to understand the impact of floods.

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Mid-America Transportation Center (MATC)

Nebraska Transportation Center (NTC)

Iowa Flood Center (IFC)

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Disclaimer

Abstract

In the second year of this project, our team was able to take our understanding of how floods impact travel times and road networks in Iowa to propose and evaluate new ideas for making decisions for establishing evacuation centers and routing people outside the flood zone. We developed cyber tools and interfaces to recommend new routes in a flooding situation in real time. We also completed a draft of a journal paper that summarizes our first two years of this project.

Chapter 1 Introduction: Using Flood and Road Maps for Better Evacuation Planning

In the first year of our research, we worked on connecting the flood maps developed by the Iowa Flood Center (IFC) with existing road networks. This helps us to understand which roads would not be usable after a flood. We then developed a tool to find paths on these maps to understand how transportation between locations changes after a flood. In the second year, we used this information for evacuation planning.

1.1 Evacuation Planning

The next step is to use the detailed data from our analysis to determine a more precise idea of evacuation center location subject to a set of potential constraints or limitations on the number of sites. We focus on evacuation centers as our location decision in this section, but a similar approach could be used for other location decisions related to flood events.

For evacuation centers, the locations need to be close to the citizens so they can quickly get to safety to be in safe locations. For cost reasons, cities or towns often want to have as few such facilities as possible. By combining street data with flood maps, we can use the understanding of what roads are flooded to develop a better site location. Many authors have used such data to eliminate locations that would be flooded. We go beyond that to consider the travel times that would occur after the flood. This is important because many of the citizens would not consider traveling to these evacuation locations until after the flood event has started. We presented a few different ways that this data can be used to make evacuation center locations. To understand the importance of incorporating the value of updated travel information, we compared the facility locations that are chosen to serve the population of a county with and without the updated travel time information. We solved these problems with integer programs using the Gurobi solver.

1.1.1 Parameters

For each of the presented models, we need several parameters. First, we need to understand how many citizens live in each grid of a county and represent this by *p_i for i in I* where *I* is the set of grid points. For our study of Johnson county, the population data was downloaded from Socioeconomic Data and Applications Center, an organization hosted by Columbia University. The data is in the form of shapefile, so we can easily import it into GIS software and get the population data for each point. Data for the United States is available at the website below: *http://sedac.ciesin.columbia.edu/data/set/usgrid-summary-file1-2010*.

Next, we need to decide several evacuation centers *f* that will be available to serve an area, and the capacity *c* of each evacuation center. It may not be feasible or necessary to set *c* strictly equal to the sum of the population divided by *f*. For example, this may not allow all of the residents from a particular point to be assigned to the same evacuation center. In our experiments, we set *c* based on equation 1.1, but we could model even more excess capacity to allow more flexibility but at higher costs.

$$c = \frac{\sum_{i \in I} p_i}{f} 1.1 \tag{1.1}$$

Last, we need a set of potential evacuation centers (*K*) and travel times using the roads network before the flood (*d_{ik}*) and after the flood ($\hat{d}$*_{ik}*). For simplicity, we will choose the set *K* from *I*. The values for *d_{ik}* and $\hat{d}$*_{ik}* come from the previous analytics.

1.1.2 Baseline Model

Our baseline uses the distances before the flood to assign customers to the *f* evacuation centers. We use the traditional objective of minimizing the sum of the travel time from the points to the assigned centers. The results for this model will provide a contrast to the results that come from using after-flood data.

For this model, we need two variables:

- $x_{ik} = 1$ if assign grid point i to grid point k for evacuation center, 0 otherwise
- $y_k = 1$ if open grid point k as an evacuation center, 0 otherwise

With the parameters, we present the following baseline model:

$$
\begin{array}{lll}
\min & \sum_{i\in I}\sum_{k\in K} p_i d_{ik} x_{ik} & \\
& \sum_{k\in K} x_{ik} = 1 & \forall i \in I \\
& \sum_{i\in I} p_i x_{ik} \le c y_k & \forall k \in K \\
& \sum_{k\in K} y_k = f & \\
& x_{ik} \le y_k & \forall i \in I, k \in K \\
& x_{ik}, y_k \text{ binary} &
\end{array}
$$

This model should always have a feasible solution since all points can reach all potential evacuation centers before a flood.

1.1.3 Flood Data - Model 1

When incorporating flood data, the challenge is how to set the value for *{d̂}_{ik}* when location *i* or *k* is flooded since travel between these points is not possible after a flood. First, we create the set {$\widehat{K}$_i} to be the subsets of set *K* that contain the locations in *K* that are reachable from *i* after a flood if location *i* is not flooded. But, we set the value of {d̂}_{ik}=d_{ik} and *{$\widehat{K}$_i}=K* for locations *i* where *i* is flooded in the flood map. The idea behind this assumption is that the population in locations that will flood will evacuate first and thus will likely travel when the flood is forecast and before it occurs. If we ignore the assignment decisions for the points *i* that are flooded, these locations will not be considered in the evacuation center location, and these locations should need an evacuation center most of all. We explore another option in Section 1.1.2.

The revised Flood Data Model 1 is:

$$
\begin{array}{lll}
\min & \sum_{i\in I}\sum_{k\in\hat{K}_i} p_i d_{ik} x_{ik} & \\
& \sum_{k\in\hat{K}_i} x_{ik} = 1 & \forall i \in I \\
& \sum_{i\in I} p_i x_{ik} \le c y_k & \forall k \in \hat{K}_i \\
& \sum_{k\in\hat{K}_i} y_k = f & \\
& x_{ik} \le y_k & \forall i \in I, k \in \hat{K}_i \\
& x_{ik}, y_k \text{ binary} &
\end{array}
$$

This model can be infeasible if there are more than *f* locations needed to reach all nodes in the graph when a flood occurs.

1.1.4 Flood Data - Model 2

We also can further modify the model to reflect that those in flooded locations are more likely to use these evacuation centers and should be prioritized in the location decision. We can modify the model in Section 1.1.3 in a few different ways to reflect this. One option is to change the *p_i* value for a node to reflect how close it is to a flood zone, or we can increase the importance placed on the *p_i* values for those nodes in a flood zone. Here, we will do the latter by multiplying the objective function by a constant a (where a > 1 for the flooded locations. For this model, we only need to change the objective function as in equation 1.2.

$$\min \sum_{i\in I}\sum_{k\in\hat{K}_i} \alpha_i p_i \hat{d}_{ik} x_{ik} \tag{1.2}$$

Here, we set *a_i* = *a* if location *i* is flooded, *a_i* = 1 otherwise.

1.1.5 Results

First, we present the results for the baseline model for Johnson County which has 122,139 citizens. We consider 4 evacuation centers. The results are presented in figure 1.1. The four dark shapes represent the locations of the evacuation centers and the colored shapes represent the nodes allocated to each center. The assignment overlays Google earth picture of

Johnson County. This model was solved using Gurobi optimization software. It took 1522 seconds to solve (within a 1% gap).

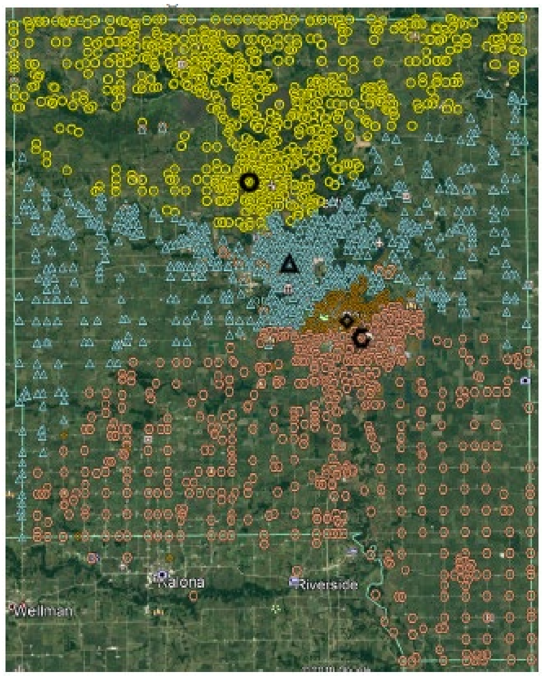

Figure 1.1 Baseline: Assignment of Grid Points to Evacuation Centers

Next, we evaluate the changes from using Flood Model 1 for Johnson County with the 100 and 500-year flood map. The 100-year flood map results are presented in figure 1.2. This problem solved in Gurobi in 3230 seconds (within a gap of 1%).

Both figures 1.2 and 1.3 are quite similar to each other but have significant differences when compared to figure 1.1. An obvious change is in the assignment of grid points to the evacuation center indicated by a circle. The assigned grid points are designated with pink circles. In figure 1.1, many are on the west side of the Iowa River, but many of these become assigned to the evacuation center indicated by a triangle in figure 1.2. This is due to the increased difficulty in traveling after the flood. Similarly, the grid points assigned to the evacuation center indicated by a triangle are spread west and east of the river in in figure 1.1. But in figure 1.2, the blue triangles are primarily to the west of the river.

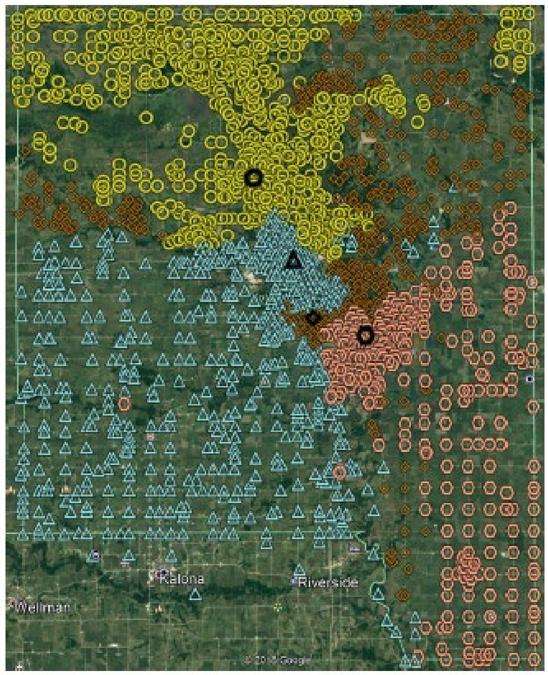

Figure 1.2 Model 1: Assignment of Grid Points to Evacuation Centers after 100 Year Flood in Johnson County

Next, we evaluate the results for Flood Model 2 for Johnson County for the 100- and 500-year flood map with $a=3$. The 100-year flood map results are in figure 1.4. This problem solved in Gurobi in 22,267 seconds. The objective makes these problems much harder to solve, so we use a 5% gap on these.

The 500-year flood map results are in figure 1.5. This problem solved in Gurobi in 13101 seconds (again with a 5% gap).

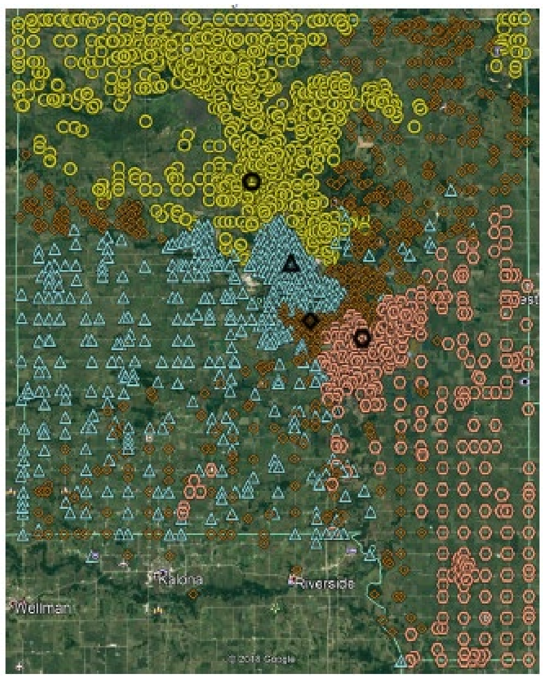

Figure 1.3 Model 1: Assignment of Grid Points to Evacuation Centers after 500 Year Flood in Johnson County

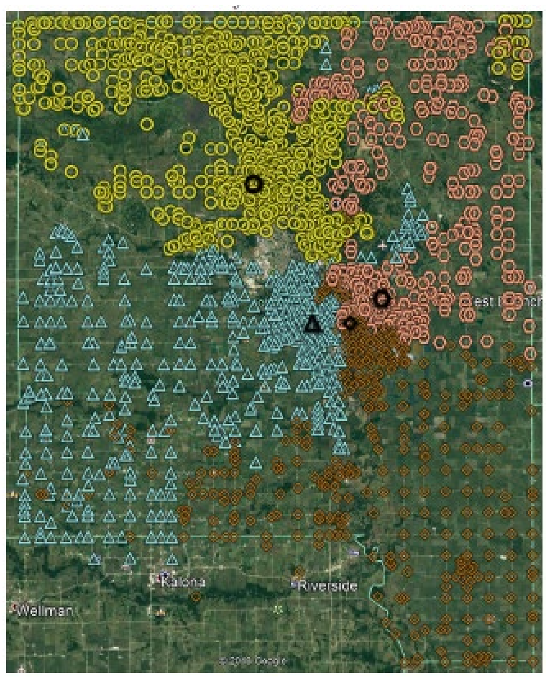

Figure 1.4 Model 2: Assignment of Grid Points to Evacuation Centers after 100 Year Flood in Johnson County

For Model 2, figures 1.4 and 1.5 mainly flip the choice of which locations serve as the evacuation center indicated by circles (pink) and diamonds (brown). In comparing figures 1.3 and 1.5, we see interesting differences. First the brown diamonds on the upper left side of 3, which are flooded locations, change assignment in figure 1.5. Similarly, the brown diamonds spread out on the bottom left of figure 1.3 are no longer west of the river in figure 1.5. Overall, figures 1.4 and 1.5 have a more intuitive look to the allocation decisions.

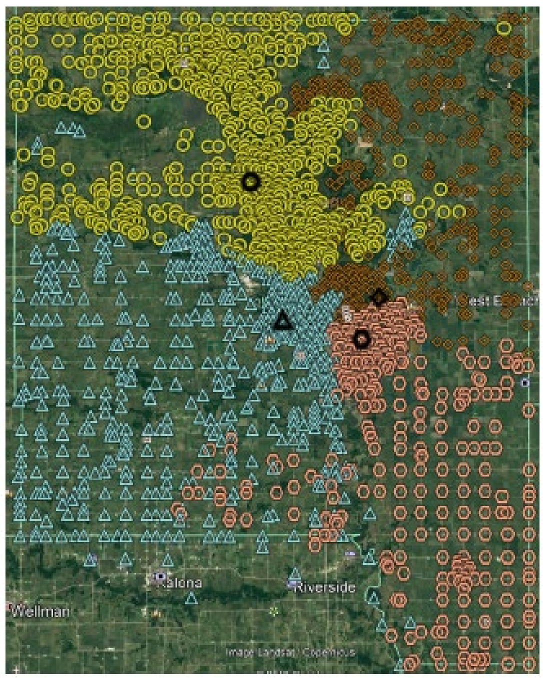

Figure 1.5 Model 2: Assignment of Grid Points to Evacuation Centers after 500 Year Flood in Johnson County

1.2 Real Time Flood Routing

We developed a web application for real-time routing (fig. 1.6) purposes to support decision making. The system integrates flood maps and road network datasets to a map environment (fig. 1.7), and allows users to get the directions from Point A to Point B before and after flood events. The system allows decision makers to open and close roads before flooding, and enable and disable roads based on flood information. The system runs entirely on the client side, and does not require server-side processing on the routing or data analysis.

Figure 1.6 Client-side routing algorithm interface

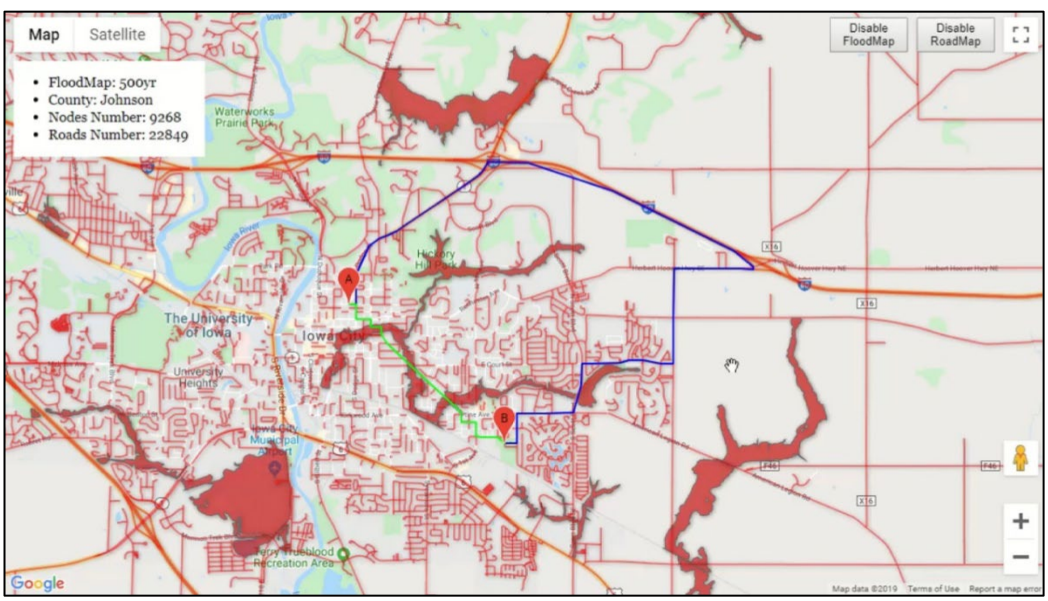

Figure 1.7 Real-time decision support system interface on web systems

Chapter 2 Conclusions

In the second year of this project, we focused on understanding of how floods impact travel times and road networks in Iowa to propose and evaluate new ideas for making decisions for establishing evacuation centers and routing people outside the flood zone. We developed cyber tools and interfaces to recommend new routes in a flooding situation in real time. We also completed a draft of a journal paper that summarizes our first two years of this project. We hope to have the paper submitted to a quality journal by March 1, 2020.