

# Dynamic Model Generation for Agent-based Emergency Response Simulation

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**Abstract:** Planned emergency responses have historically sufficed for small, local events such as building fires and traffic accidents; however, larger, more widespread events that affect the area's infrastructure are generally too dynamic and unpredictable for an established response plan to be effective in reducing casualties. The Pennsylvania Dynamic Discrete Disaster Decision Support System (PA-D4S2) provides methods for simulation of stress on city infrastructure as a result of a large scale event, such as an improvised explosive device detonation or bridge collapse, events where a large number of casualties and damage to city infrastructure will result. In this presentation, we propose a method for dynamically generating models of cities based on area of study extent, road network, average traffic, and emergency response location data. The model provides a base for conducting agent-based simulation of emergency response in the other areas of work within the PA-D4S2 project.

## 1. Introduction

Large-scale emergencies such as hurricanes, earthquakes, and terrorist attacks have caused tremendous loss of life. Recent events include the earthquakes in Haiti and Chile and hurricanes in the Gulf of Mexico. Unfortunately, every event is unique with regards to the circumstances it causes (i.e. which infrastructures are impaired or rendered inactive), and some happen without warning. Preparedness helps for events which can be somewhat predicted (e.g. when/where a hurricane will fall); however, response to unforeseen events is variable with each event that arises. In order to build better response to these unpredictable events, simulations are generally used to make responders and planners aware of what may happen, so they can take appropriate actions if and when the circumstance should arise.

Simulating disaster response and management is based on numerous factors. The more variables considered, the longer it takes to manifest results. As such, simplifications and assumptions are generally made in order to provide a useful model that can produce results quickly. Being that disaster response is a very geographically oriented problem; we have identified using a simplified road network as a means to reduce complexities in a city's model. This paper will discuss the methods used to produce this road network for agent-based simulations.

The remainder of this paper is organized as follows: Section 2 provides background information and impetus for this research. Section 3 discusses the methodologies used to produce the

simplified model. Section 4 provides examples from several cities' models. Section 5 concludes and discusses future research.

## **2. Background and Related Work**

The Center for National Preparedness (CNP) at the University of Pittsburgh has been developing an advanced integrated simulation system to simulate the response to emergencies. This simulation system, we call the Dynamic Discrete Disaster Simulation System (D4S2), is a core component of our overarching approach which we call the Pittsburgh Framework for Emergency Preparedness and Response. The central aim of D4S2 is to create a rapidly deployable simulation platform that produces actionable (i.e. informs situational awareness) results in reasonable time frames. While our initial focus has been on emergency response, we recognize that the framework has wider applicability in areas such as: urban and regional planning, military operations, etc.

D4S2 seamlessly integrates the ArcGIS 9.2 geographic information system (GIS), discrete event simulation, a custom built rule based decision modeling system and a control interface that mirrors an emergency operations center. The model's geo-database contains over 100 layers of geographic, asset and other geo-referenced information. The simulation model is built dynamically from the geo-database and situational data about the event allowing us to create any number, type and size of emergency events. The decision model contains rules that codify standards, training, best practices, exercises and research on first responders, emergency managers, dispatchers, the public, terrorists, other actors and environmental factors. Each component informs the others continuously of decisions, status changes, and other situational variables that have changed as the event(s) unfold. The model provides a circumstance independent laboratory for testing how the type and scale of an event, situational variables and command decisions affect responders' efficiency and effectiveness in dealing with disasters.

The development of the prototype model for D4S2 was reported in an earlier ESRI paper "Embedding GIS in Disaster Simulation". Pittsburgh was used as the base city for the development and validation of the overall model. The figure below shows one typical result from a simulation run modeling an IED explosion in the West End area of Pittsburgh.

### **Agent Based Simulation:**

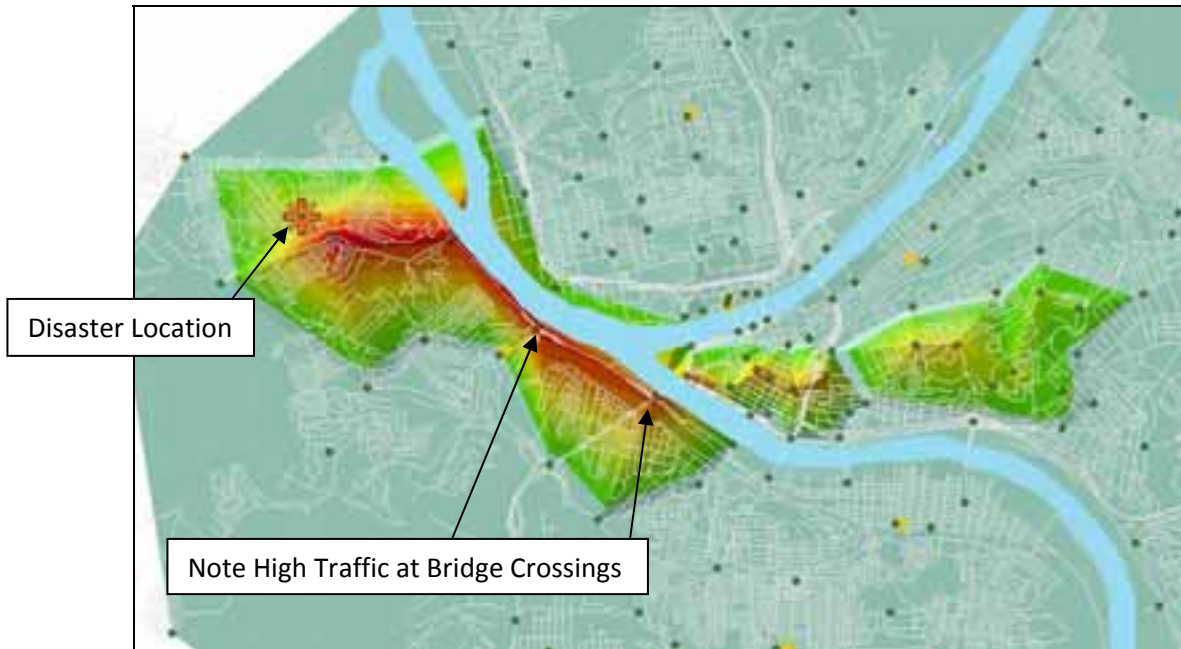


Figure 1: Pittsburgh Model, Colors Indicate Traffic Congestion

As one can see from this map, the disaster creates congestion throughout the city, with a majority of the congestion resulting on the west side of the Ohio River, specifically at the bridges and tunnels that allow responders to cross the river. They must do so in order to reach the Oakland area, where most of the hospital capacity resides.

This paper reports two efforts to enhance the model, the extension of the D4S2 model to other cities and the automation of the model building process. Work that was done in support of the PA-D4S2 project includes gathering of emergency responder locations in seventeen of the largest cities in Pennsylvania. To the authors' knowledge, no central repository exists for this information. All data on these locations was gathered through various resources including web, print, and expert knowledge.

### 3. Methodologies

This section details the methodologies for generating the models for use with agent-based simulation techniques for disaster response.

#### 3.1 Base Data Source Requirements

An encompassing road network is the first data requirement for first approximation nodes to be constructed. This network generally includes much more data than the area of study. Two attributes are required in this encompassing road network, traffic count and an attribute for localization of the road segments. These attributes are used for dynamic extraction of the road

network that the model will utilize. Traffic count attributes will be used to select roads that are heavily used in an area, assumed to be important roads in the daily flow of traffic. The encompassing road network used in this research was the PA State Roads data available at the Pennsylvania Spatial Data Access (PASDA).<sup>1</sup> This data set includes a CUR\_AADT attribute which is a value for the Current Average Annual Daily Traffic, which was used for the traffic count. The localization attribute is the CITY\_CODE attribute, which relates each road segment to a Pennsylvania city.

This method of first approximation node generation is node-centric. As such, a second initial data source is required, points of interest (POIs). The POIs will be used to dynamically determine the pertinent roads as well as to visually determine the user approximated area road network. The POI sets used in this research are the emergency responder locations, including fire stations, police stations, EMTs, and hospital locations.

### *3.2 Extraction of Base Data Sets*

To generate all area road network intersections, two processing steps are taken. First, the user visually determines a bounding box within the encompassing road network that will include all POIs for the area of study as well as the region wished to be included in the model. This yields a user approximated area road network. Then, from this approximate road network, all intersections are determined dynamically. This can be a time and resource consuming process, so the smaller, approximated road network is used for reduced computation. This intersection data set provides the initial geometry for the model. See Figure 2.



Figure 2: Bounding Box Selection of Local Roads and Intersection Determination

The localized road network is generated dynamically based on a relevant attribute in the encompassing road network data set. Actual size of this data set will vary for different applications, but the localized road network is significantly smaller than the encompassing road network yet large enough to contain the user approximated area road network. Initial topology is provided by this localized road network.

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<sup>1</sup> <http://www.pasda.psu.edu/>

### 3.3 Extraction of Pertinent Road Network

The pertinent road network is roads that are both high in daily traffic as well as within a proximity threshold to the POIs. High daily traffic will indicate roads in the area that are used heavily by the local citizens, therefore making those roads important to the larger area. Roads below the traffic level threshold will be removed as these will be less important to the area as a whole, considered minor roads. Also, being that this method is a node-centric generalization, roads' proximity to POIs is considered. So, pertinent roads will be preferably both high in daily traffic and close to POIs; however, meeting the thresholds of just either proximity or traffic suffices as well.

### 3.4 Generation of Pertinent Intersections

Pertinent intersections are generated by conducting a spatial intersect of the pertinent road network from 3.3 with the area road network intersections that were extracted in 3.2. A simple intersect operation will yield a large number of intersections, so a proximity tolerance is associated with this intersect operation. This tolerance level will provide the necessary generalization by combining nearby intersections to one position. See Figure 3. The red roads indicate the high traffic streets, the blue points represent all intersections in the selected area, and the green pentagons represent the generalized intersections.

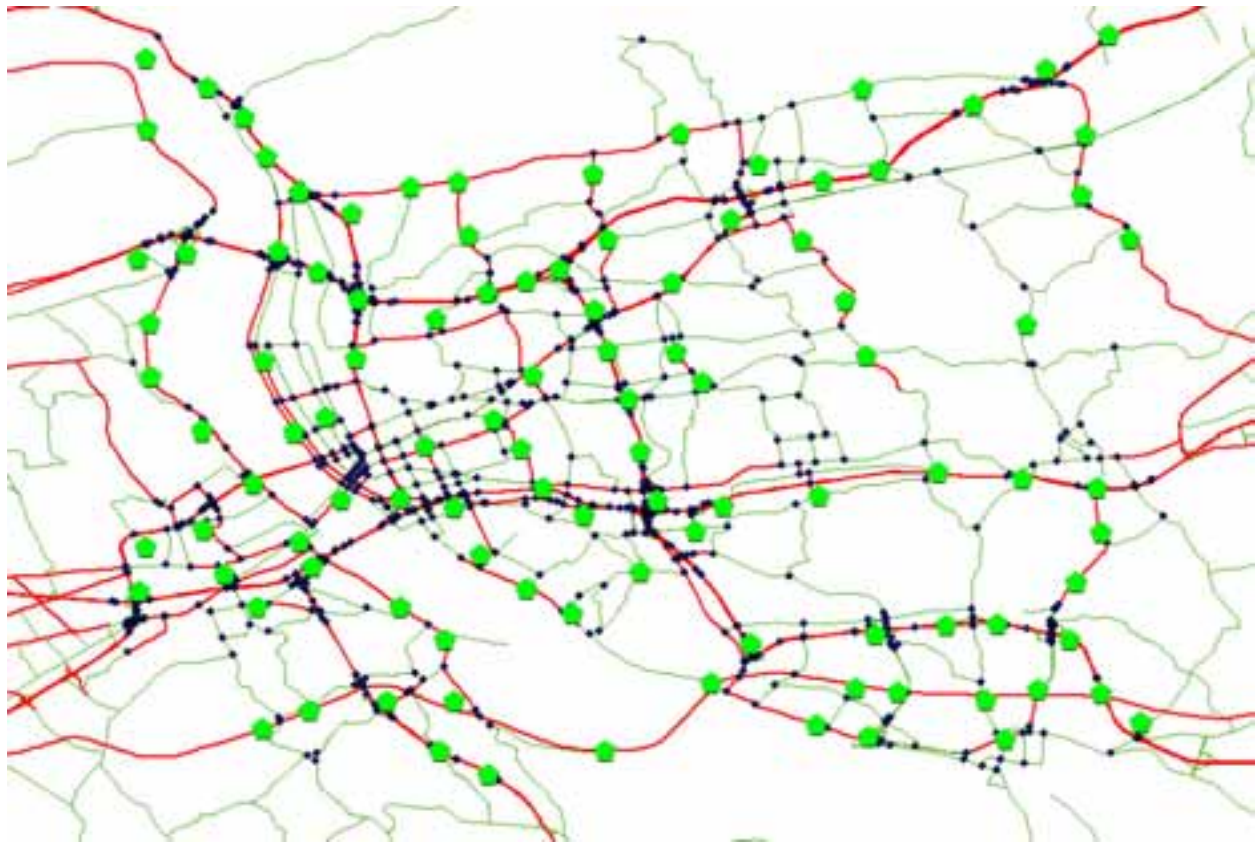


Figure 3: First Approximation Nodes (Green Pentagons)

Increasing the tolerance level will result in fewer uniquely positioned intersections. Conversely, decreasing the tolerance level will result in a higher number of uniquely positioned intersections. The tolerance level should be adjusted according to the application's requirements for the desired number of first approximation nodes. Once the intersect operation is completed, removal of the duplicated intersections based on position is required. After duplicates are removed, the data set becomes the first approximation nodes, thus providing the geometry for the final model.

### *3.5 Voronoi Diagram of First Approximation Nodes Intersect with Road Network*

While the nodes provide the geometry for the final model, topology must be reconstructed for this new geometry in order to provide a road-network-like model. This method of topology reconstruction uses the original road network from Section 3.2. We first create a Voronoi diagram of the node data set. This creates polygons around each node that contain all points that are closest to each node. These polygons are then used in a spatial intersect between the polygons and the original road network. Figure 4 depicts the result of the intersect operation. The triangles indicate the intersection of the polygon edge with the road network. These points are then used in the topology reconstruction step.

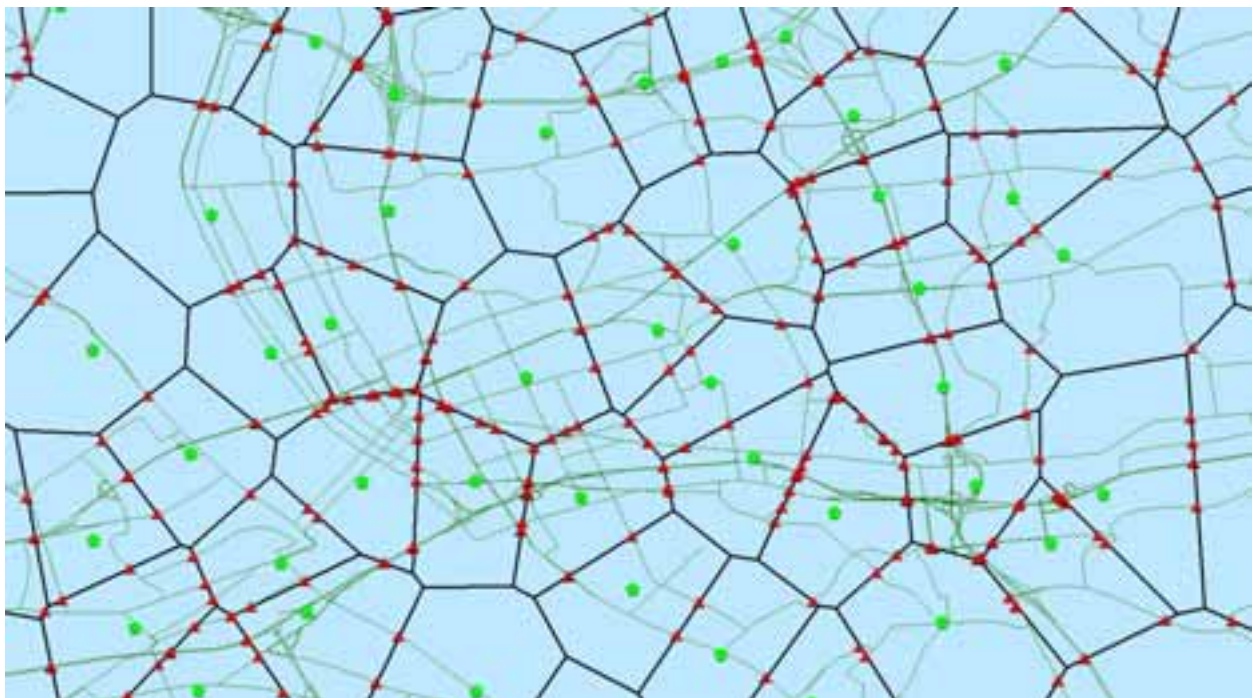


Figure 4: Voronoi Diagram Intersect with Road Network

### *3.6 Reconstruction of Topology*

#### *3.6.1 Conceptual Triangular Relation*

In order to generate the connectivity between each node, a method was developed to compare the nodes to one another using the Voronoi polygons. The points generated from the spatial intersect of the Voronoi polygons and the original road network contain an id which matches back to the id of the polygon, and node, that it is a part of. Since these polygons are laid on top of each other, when a street intersected an edge of a Voronoi polygon, it would intersect the neighboring polygon at the same point, resulting in two points being placed on this spot at the same latitude and longitude. By comparing the latitude and longitudes of the points generated by the intersect, we are able to determine which polygons, and therefore nodes, are adjacent.

Just because two nodes are adjacent, it is not accurate to assume that they are connected by a road. To examine the possible connectivity of adjacent nodes, we form a triangle using the location of the two nodes and the shared intersection point of the polygons as its points. We base our logical operations to determine connectivity off of the angles of these triangles. For us to ascertain these angles, we must determine the geodetic distance of each side of the triangle. This information supplies us with everything we need for the law of cosines to calculate each angle of the triangle. The logical operations that we developed are based off of the angle formed by the geodetic distance of the first node to the shared intersection point and the geodetic distance of the second node to the shared intersection point. Figure 5 highlights the conceptual triangle generated and the angle of consideration for one point along the intersecting Voronoi polygon line. The average geodetic distance (DistBetweenNodes) between two nodes for all adjacent nodes is a value that is also considered when determining connectivity.

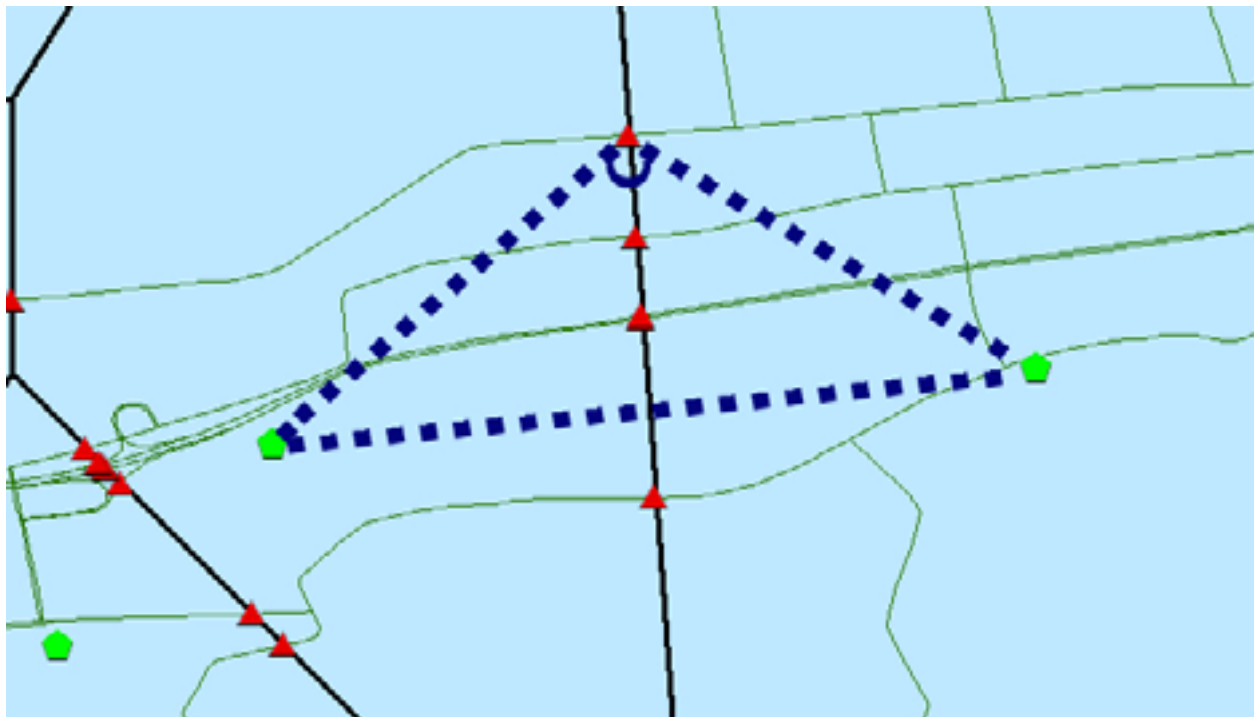


Figure 5: Conceptual Triangle & Angle of Consideration

### 3.6.2 Connectivity Categories & Logical Operations

The categories of possible connectivity are “Acute Connection”, “Obtuse Connection”, and “Flat Line Connection”. The simplest connection, “Flat Line Connection”, is valid if the angle of consideration is greater than or equal to  $170^\circ$  and the geodetic distance between the two nodes is less than the DistBetweenNodes value. The latter consideration is to try to rule out situations where node A may be adjacent to nodes B and C and have a possible flat line connection to both, but node C is much further away from A than B. The connections should move through the closest nodes first rather than jumping around from node to node. In this case, node A should connect to node B rather than node C, because the geodetic distance between node A and C would be greater than the average node distance. In order for an “Obtuse Connection” to be valid, the angle of consideration must be greater than  $90^\circ$  and the height of the triangle must be less than the DistBetweenNodes value or the geodetic distance between the two nodes divided by the DistBetweenNodes value is close to 1. An “Acute Connection” requires the angle of consideration to be less than  $90^\circ$  and the height of the triangle to be less than the DistBetweenNodes value to be a valid connection. If any of these three connections are valid, then it is assumed that there is a road connection between the two nodes in question. Visual examination of the results generated by this method show that most nodes are reconnected correctly.

The loss of road network data inherent in this process is mostly overcome by the methods outlined in this section, but the reconstruction of the topology of the area is still without speed limits for the road network. Since we are using a simplified road network for the model, we assume a slower speed between nodes to compensate for geometric and topological simplification. Connections that are on highways are assumed to have a speed of 45 mph, while all other connections are assumed to have a speed of 25 mph. Of course emergency vehicles may exceed these speeds where possible, this slower speed should also take into account navigating through traffic around the area.

### 3.7 Map-Matching Emergency Locations

With a reconnected road network generated using a Voronoi diagram, nodes, and the existing road network, the remaining information that must be linked to the reconnected road network is the emergency locations pertinent to the selected location. Using the Voronoi diagram, we link the emergency location to the node whose polygon they are within. Figure 6 shows the emergency location in relation to the node and its polygon. While the node itself and the emergency location may not be on the same street, the extent of the Voronoi polygons is small enough that the node and the emergency location would not be very far apart and the emergency responders would know the area well enough to make it from the node to the emergency location.



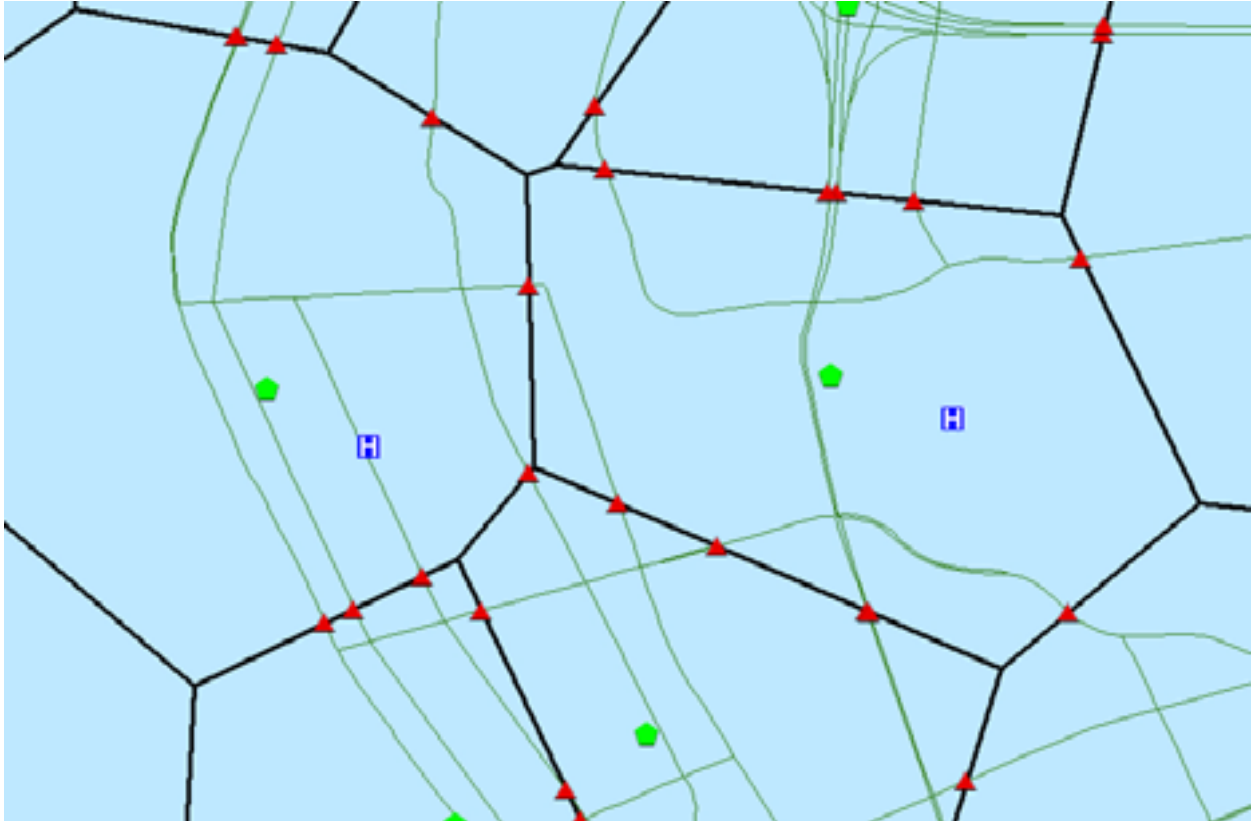


Figure 6: Emergency Location Map-Matching

#### 4. Example Models and Simulations

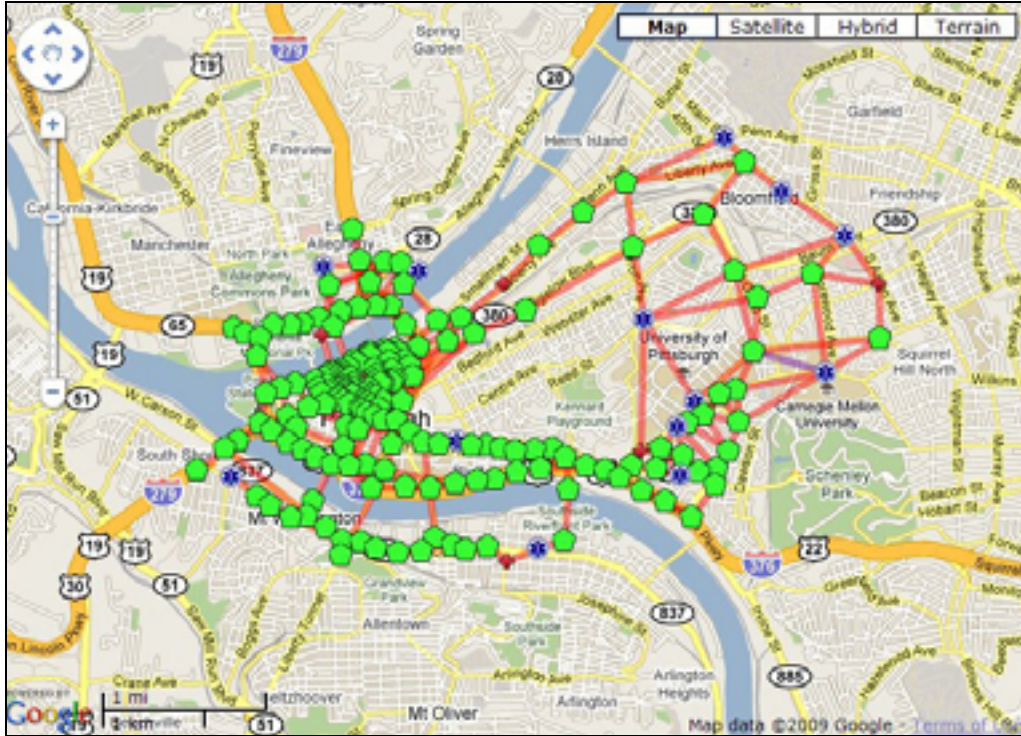
This section details four of the city models created using the methodology described in Section 3. Each city's model has a unique characteristic about it, which will be discussed shortly. Making models of these various cities helped us to identify the various issues associated with those characteristics.

The first new city for which a model was created was Johnstown, Pennsylvania. Johnstown is located in a predominantly rural area of Pennsylvania. The model included the "downtown" area of Johnstown as well as the rural, surrounding areas. This model was representative of model generation for dominantly rural areas.

The second city's model built was for Harrisburg, Pennsylvania. Harrisburg is the state's capital with a small urban area and largely suburban, surrounding areas. This model was representative of model generation for a small urban area with large suburban areas.

The third model is the Wilkes-Barre Scranton model this model is unique because it encompasses two relatively close cities.

During our development, it was announced that the 2009 G20 Conference was to be held in Pittsburgh. We therefore revisited the Pittsburgh model focusing on an emergency at the conference center. The figures below show the resultant G20 model and a zoom on the Oakland area.



G20 Model



Oakland Zoom

Table 1 displays relevant parameters used and resulting model info for each of the four cities. The model building techniques developed produced city models that were of manageable size in terms of number of nodes.

City	CUR_AADT	Intersect Tolerance (miles)	Approximate Model Extent (miles)	Final Node Count
Johnstown	2500	0.5	32	101
Harrisburg	10000	0.35	15	104
Wilkes-Barre/Scranton	7500	0.5	36	108
Pittsburgh G20	15000	0.05	5	202

Table 1: City Model Generation Parameters and Resulting Model Info

## 5. Conclusion and Future Work

The next phases of the project involve validating the models developed and exploring the model size to quality of results relationship. We are also expanding our model portfolio to the seventeen target cities in Pennsylvania. We will be analyzing the commonalities and differences in response structures across these cities.

As stated in Section 2, no central repository or clearinghouse for emergency responder locations exists. As the data was gathered for Pennsylvania responder locations, these were all logged into a database housed at the Center for National Preparedness. We have gone on to construct a web service that is used internally for delivering this information to other projects which also require this data. Work will be continued on this web service to standardize the data and establish formal protocols. We intend to explore making this a public-facing service so others can use the data we have collected as well; however, since this data is rather sensitive with regards to national security, detailed talks with the State will be conducted to discuss how and if this should be made a secure, public resource.