Emergency Dispatch Optimization in Manhattan

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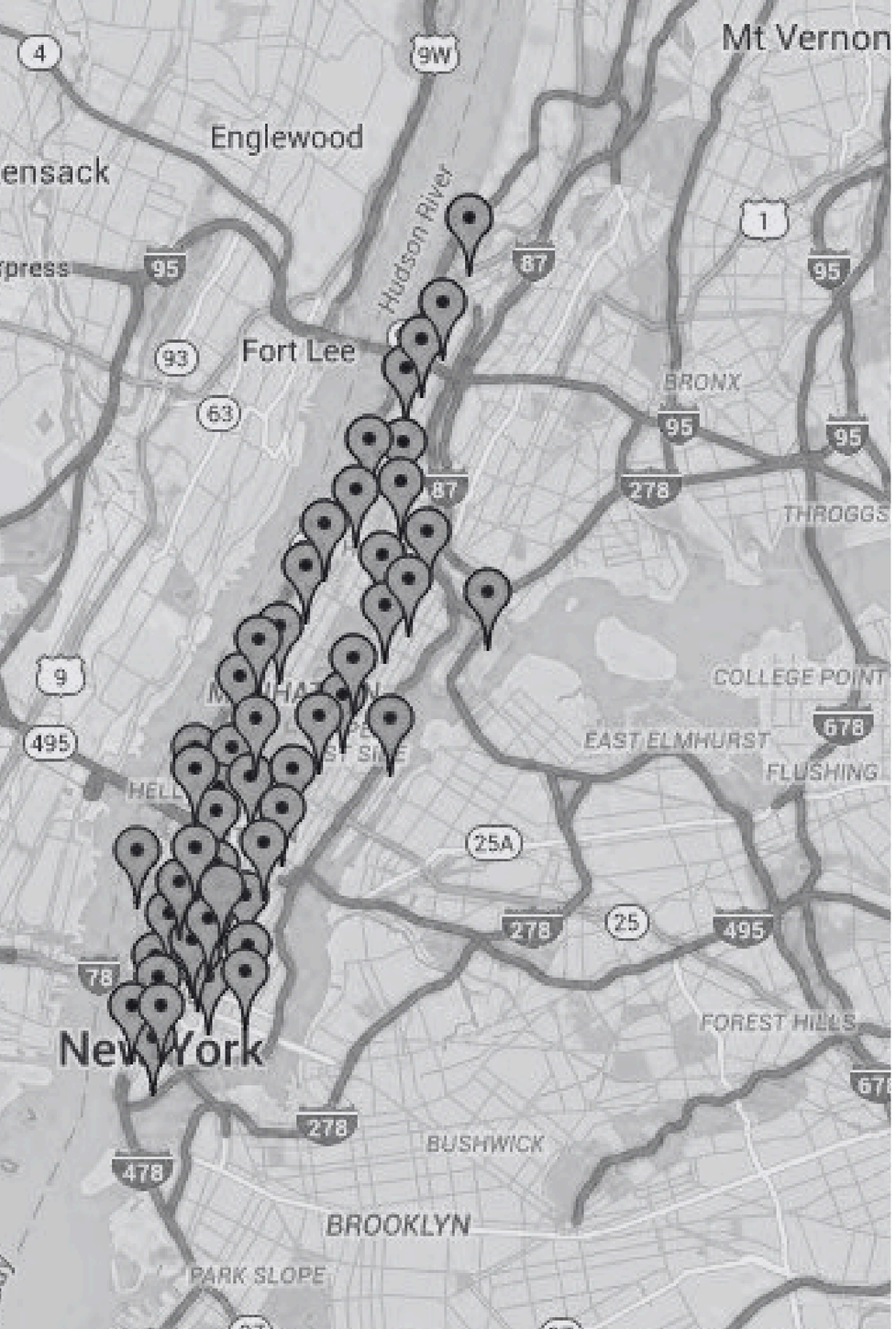


- Model Manhattan’s roads in a weighted graph
- Find and evaluate shortest path routes from fire stations to emergency locations
- Use different distance metrics

IN A GRAPH

A path of length n from starting point to end point modelled as u and v respectively, is a sequence of n edges $e(1)$, $e(2)$, ..., $e(n)$, such that there exists a sequence of vertices $x(0) = u$, $x(1)$, ..., $x(n-1)$, $x(n) = v$ where each edge $e(i)$ connects $x(i-1)$ to $x(i)$.

IN A WEIGHTED GRAPH

A shortest path is the path from u to v with minimal sum of edge weights.

A map as a graph

Graph Model

- Using OSMnx library to download directed graph of Manhattan map
- Edges are roads, nodes are intersections
- Firehouse dataset for latitudes and longitudes
- Mapped fire stations onto nodes of graph
- Selected 3 emergency locations
- Built-in edge attributes used for various distance measures to calculate shortest path lengths

DIJKSTRA's Algorithm

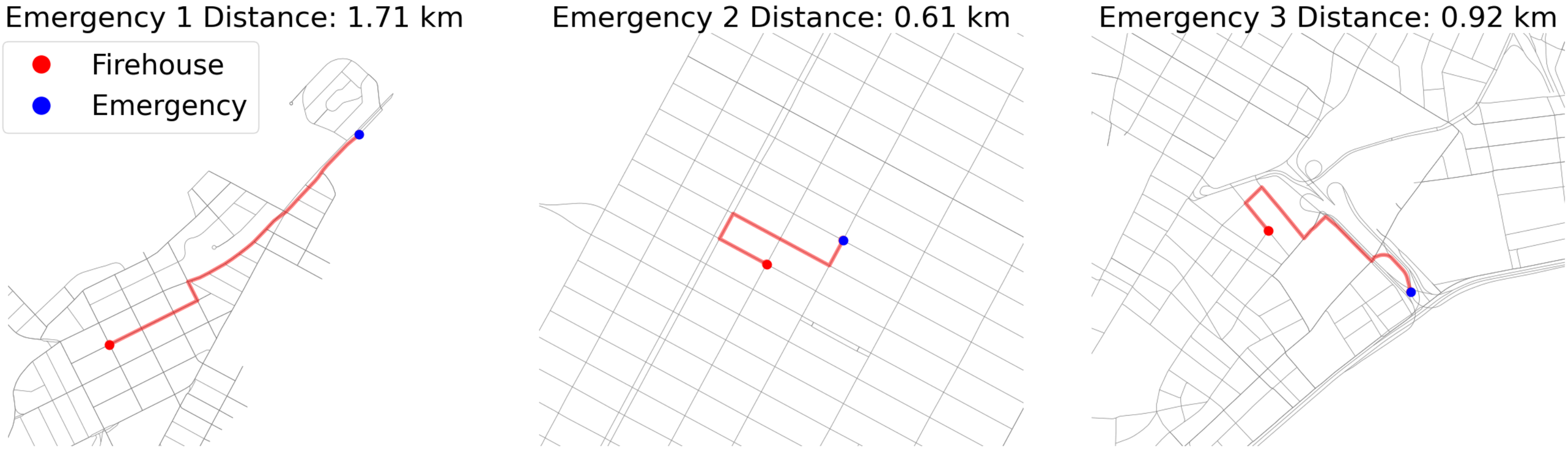
Finds the shortest path between a start node and all other nodes in the graph

1) The algorithm starts by labeling all vertices as "unvisited"
2) It iteratively selects the unvisited vertex with the smallest distance from the source
3) Then, neighbors of this vertex are visited and the distance is updated if a shorter path is found
4) The vertex is then marked as "visited"
5) This process repeats until all vertices are visited

Dijkstra's algorithm is guaranteed to find the global optimal shortest path.

Computation of the shortest path

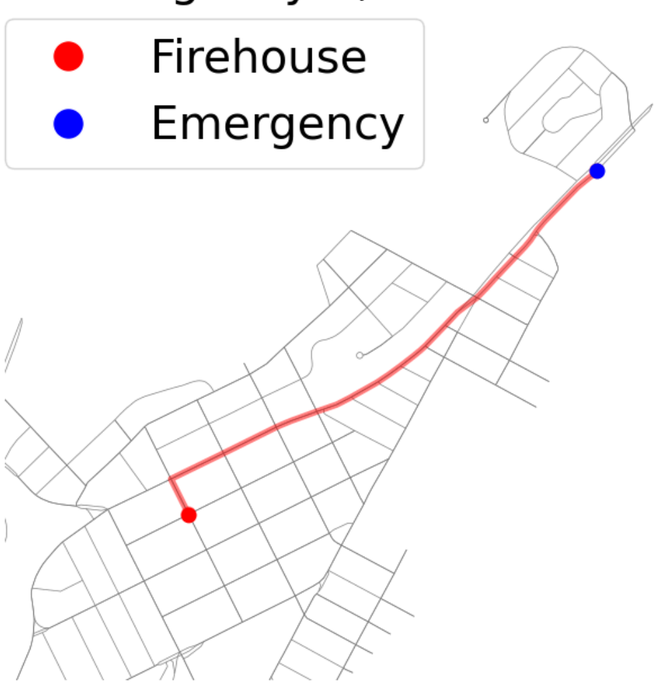
Closest Firehouse Route by Road Length



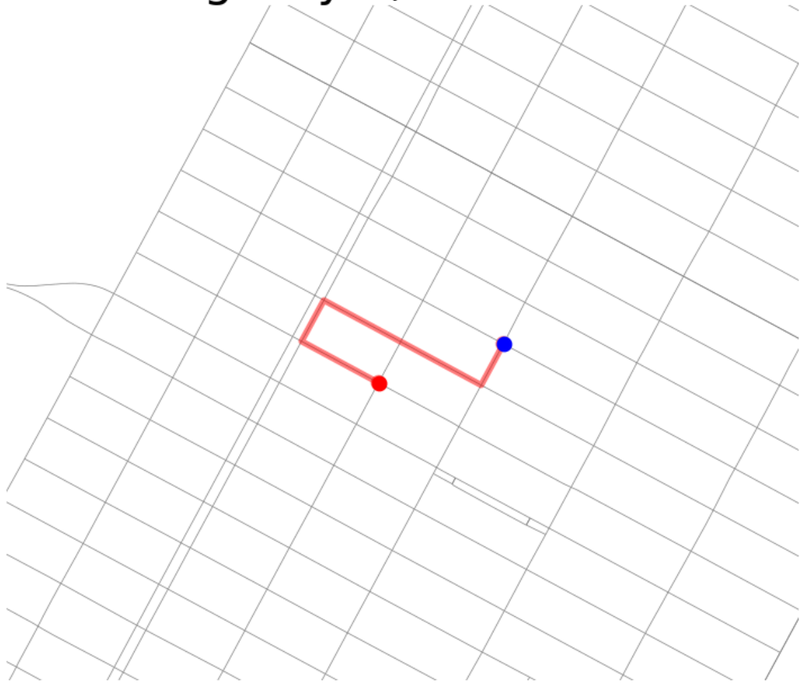
- Some paths look suboptimal → emergency 2
  - Due to OSMnx constrains (one way streets, pedestrian only zones)

Closest Firehouse Route by Travel Time

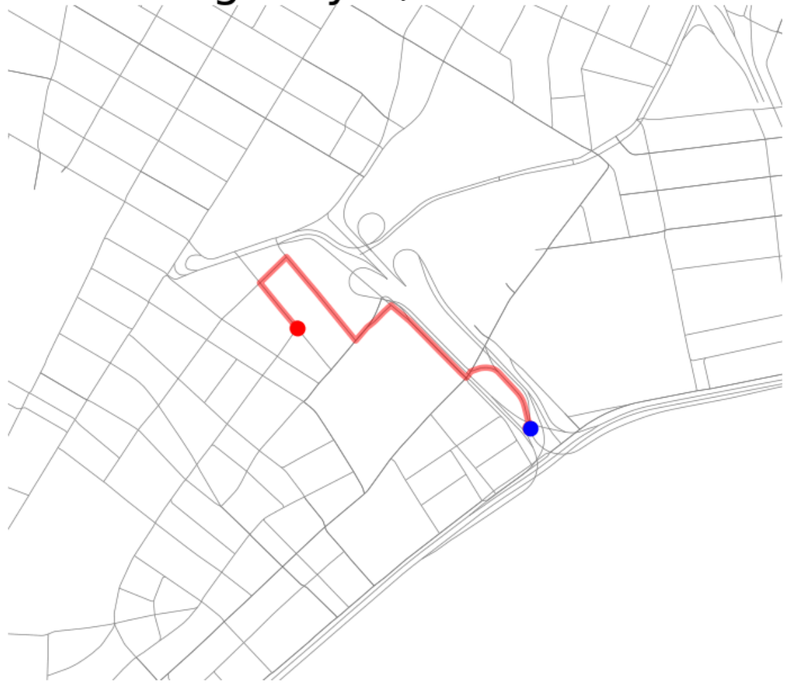
Emergency 1, Time: 158.64s



Emergency 2, Time: 56.44s

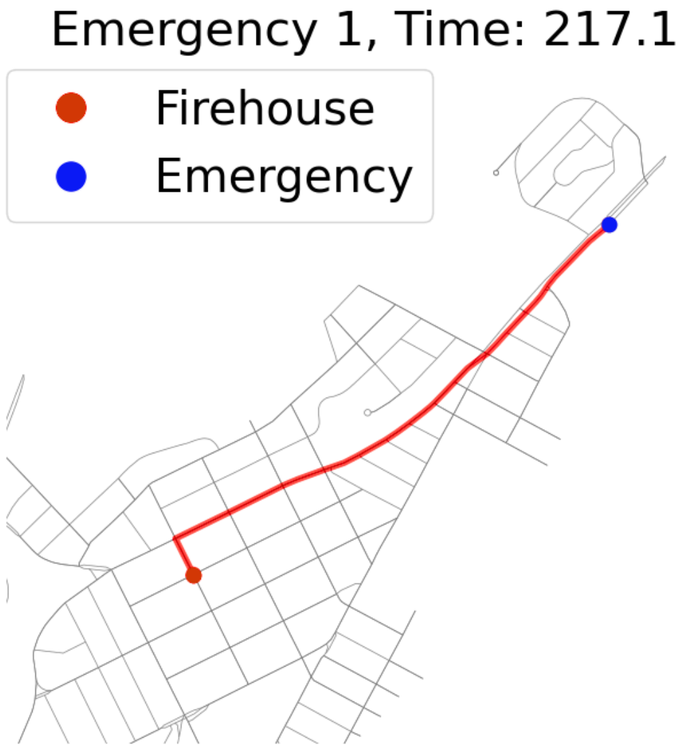


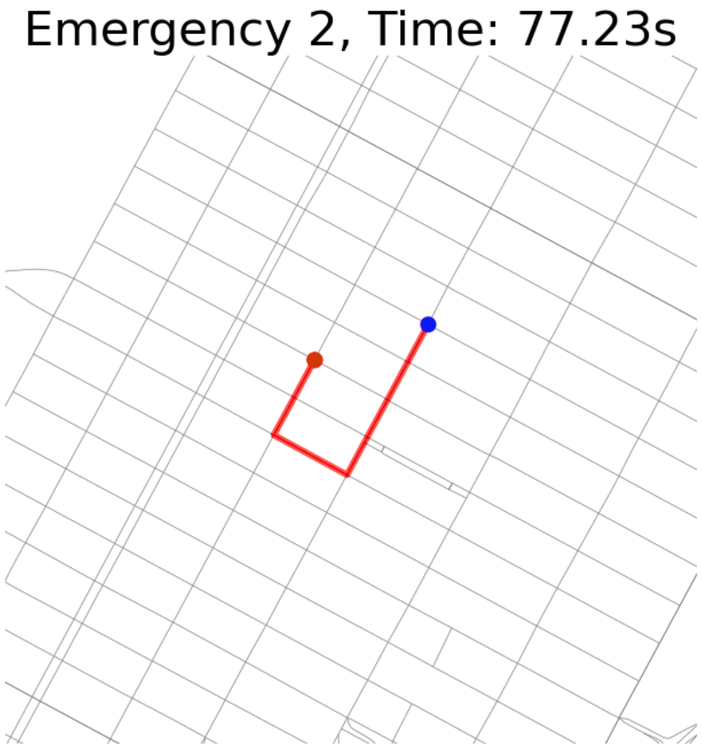
Emergency 3, Time: 98.4s

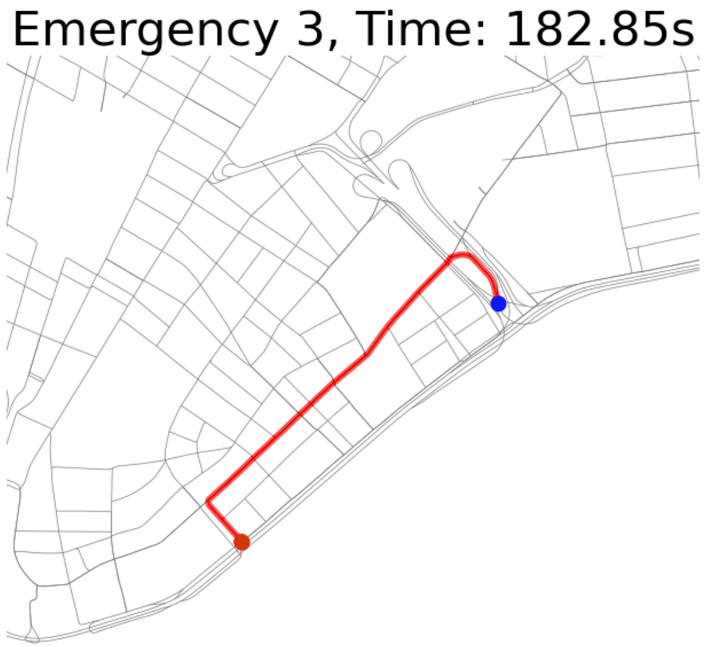


- Similar to road length, as road length and travel time are related
- Why did emergency 1 change?
  - Highway types of road length path: all primary, 4 tertiary
  - Highway types of travel time path: all primary, 1 tertiary
  - Primary is faster than tertiary

Closest Firehouse Route by Lane-Penalized Travel Time





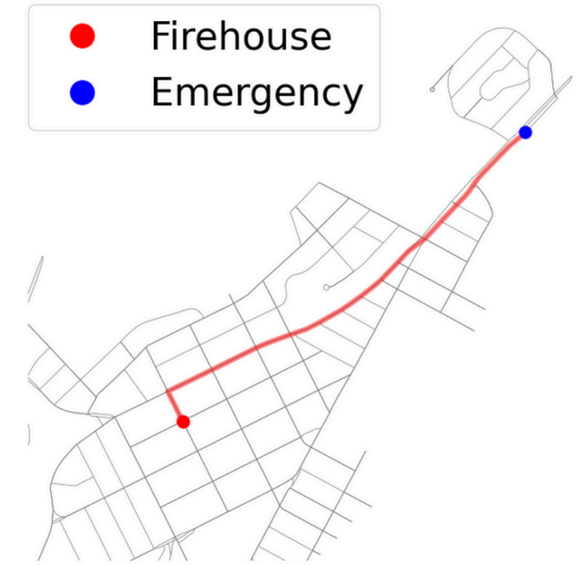


Closest firehouse changed

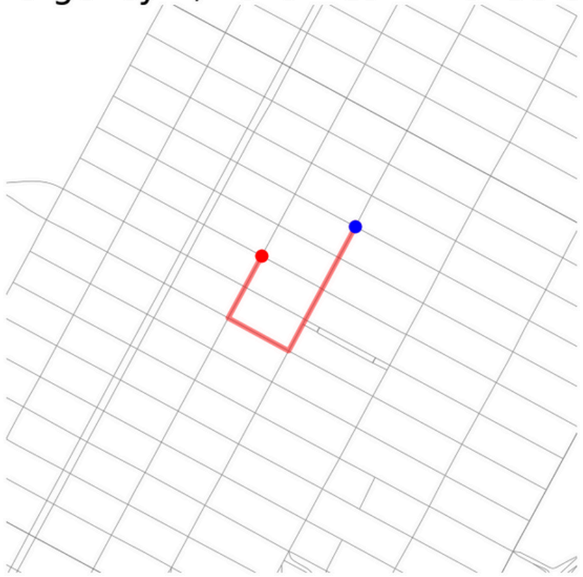
- Created a weight that penalized roads with less lanes → less space, harder to overtake, slower
- Average network number of lanes: 2.04
- Avgerage lanes in emergency 1 paths: 3.1 travel time, 3.1 penalized travel time
- Average lanes in emergency 2 paths: 2.1 travel time, 3.62 penalized travel time
- Average lanes in emergency 3 paths: 1.55 travel time, 3.14 penalized travel time

Closest Firehouse Route by Penalizing Small Roads

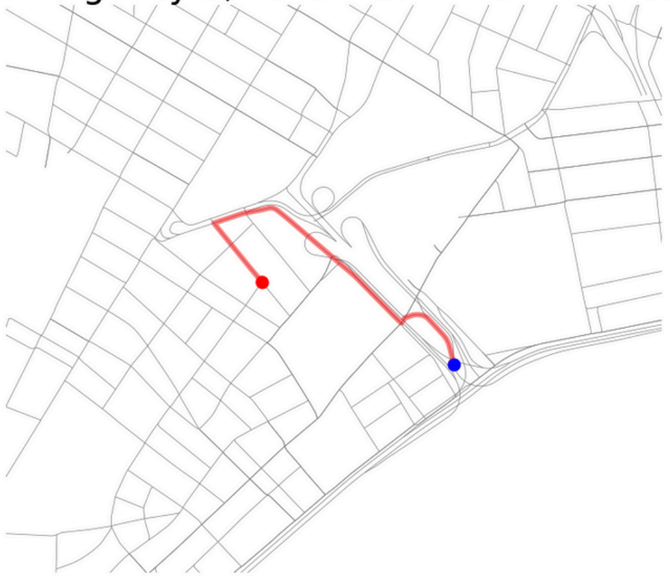
Emergency 1, Penalized Time: 226.79s



Emergency 2, Penalized Time: 86.04s

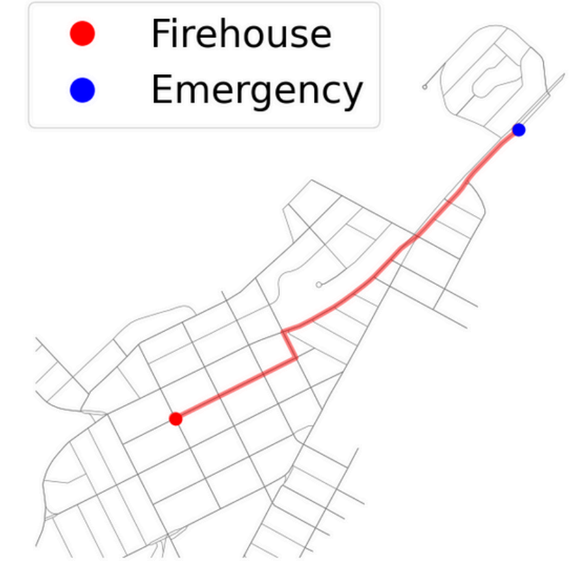


Emergency 3, Penalized Time: 165.18s

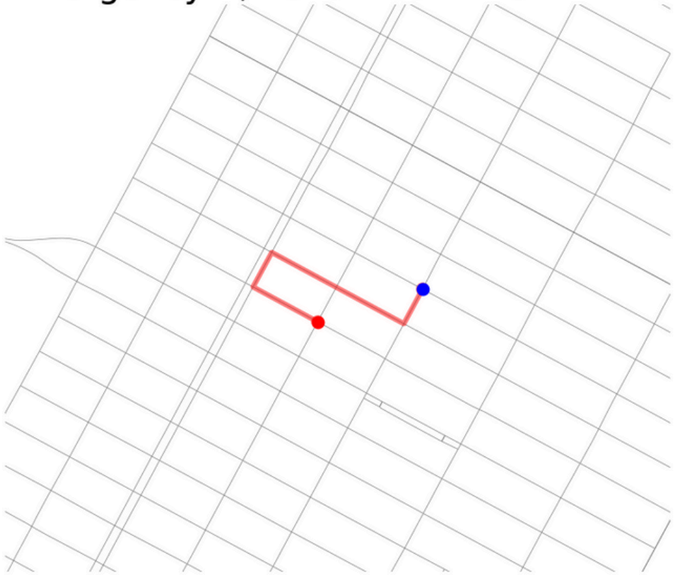


Closest Firehouse Route by Penalizing Large Roads

Emergency 1, Penalized Time: 265.97s



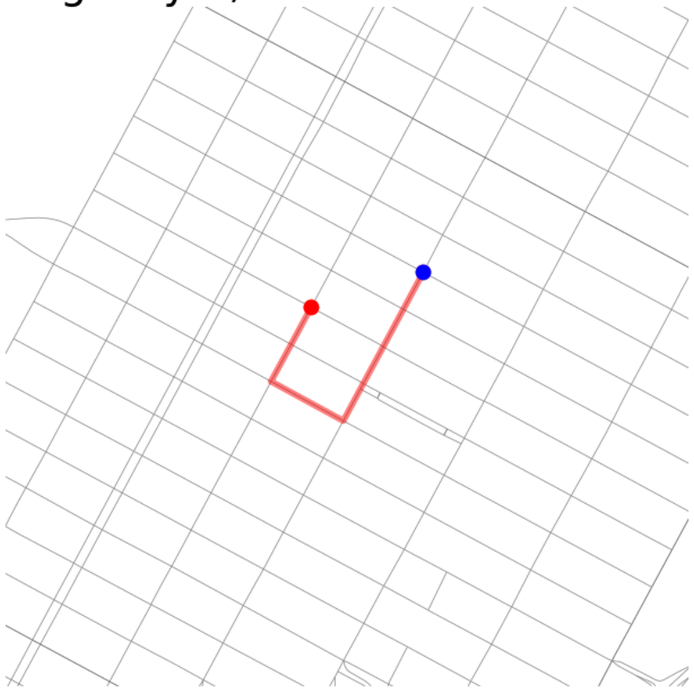
Emergency 2, Penalized Time: 72.12s



Emergency 3, Penalized Time: 136.75s

Firehouse Route by Penalizing Small Roads

Emergency 2, Penalized Time: 86.04s



5 primary, 2 secondary

2 turning points

Firehouse Route by Penalizing Large Roads

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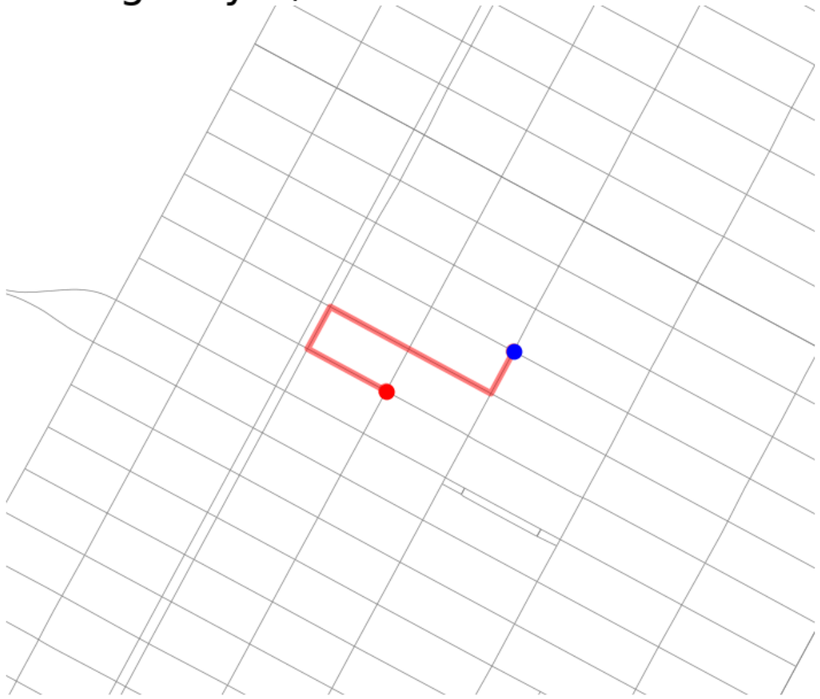

2 primary, 3 residential

3 turning points

Penalizing Small Roads

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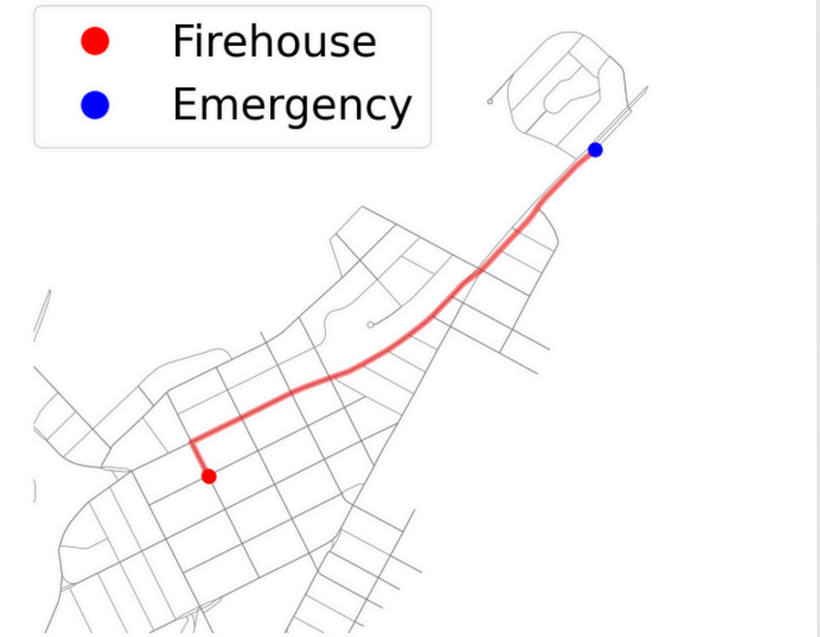

Penalizing Large Roads

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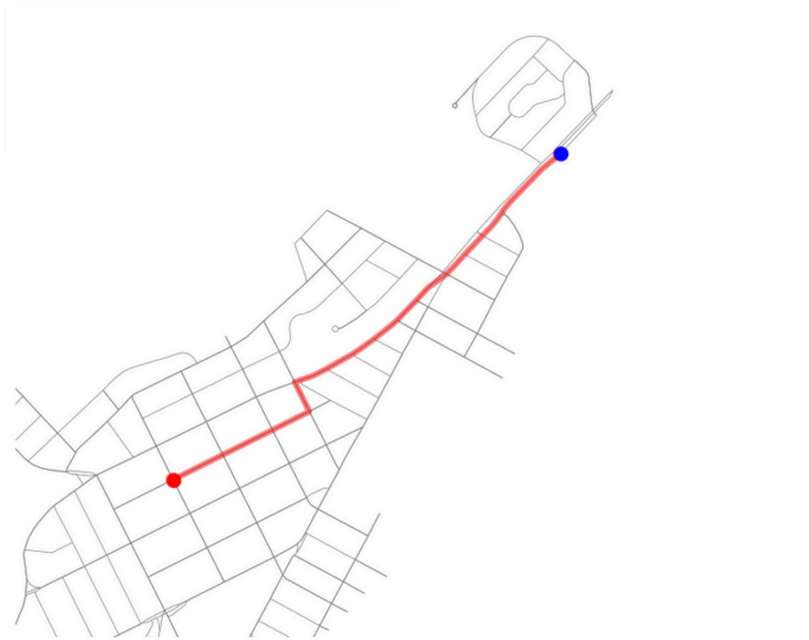
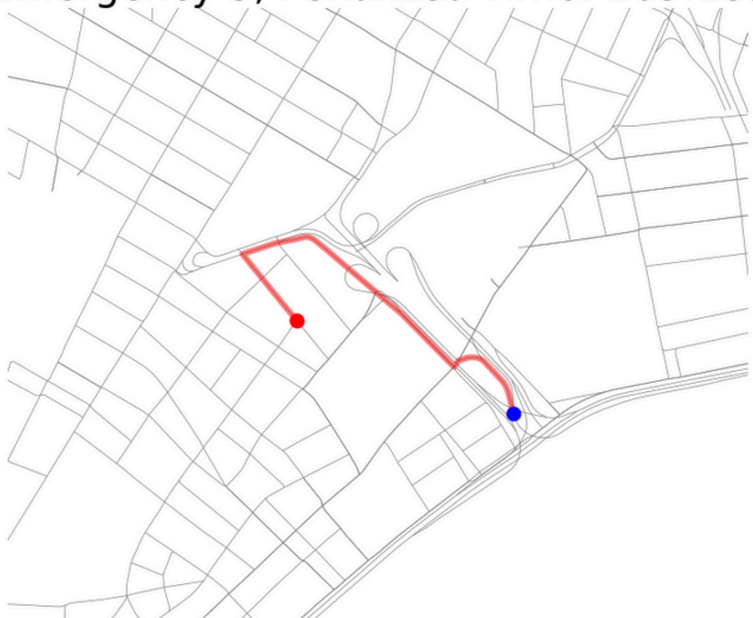
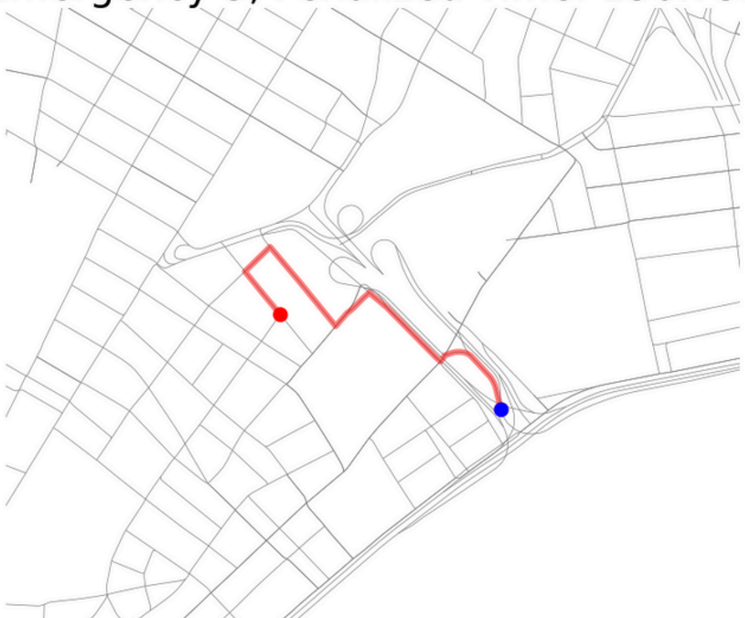


- Small: 1 tertiary, 16 primary
- Large: 4 tertiary, 13 primary

Emergency 3, Penalized Time: 165.18s



Emergency 3, Penalized Time: 136.75s



- Small: 1 unclassified, 1 residential, 5 secondary, 1 primary, 2 motorway links
- Large: 1 unclassified, 4 residential, 2 secondary, 1 primary, 2 motorway links

Conclusion & Assumptions

- Dispatch centers can select between identified routes based on priorities
- Assumptions:
  - Speed limit is met
  - OSMnx enforces one-way streets, pedestrian only zones
  - No real-time data of road construction or temporary closures
- Further investigation:
  - Removing constraints imposed by OSMnx
  - Time-dependent weights to simulate traffic conditions in various NYC zones