Optimizing Ambulances To-hospital Transports in New York City

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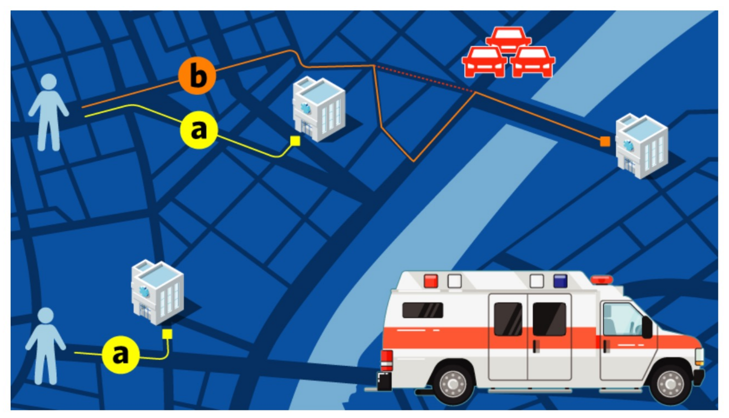
Motivation

- Estimates of ambulance route travel times are used in emergency medical service dispatch decisions.
- Ambulances are dispatched based on predetermined hospital suggestion patterns which are constructed using ambulance route travel times.
- Patterns are fed into the EMS Computer Aided Dispatch system and from the pattern and based on the incident location, the system assigns the closest appropriate hospital to the patient.
- Estimated travel times are needed for hospitals load balancing optimization algorithm.



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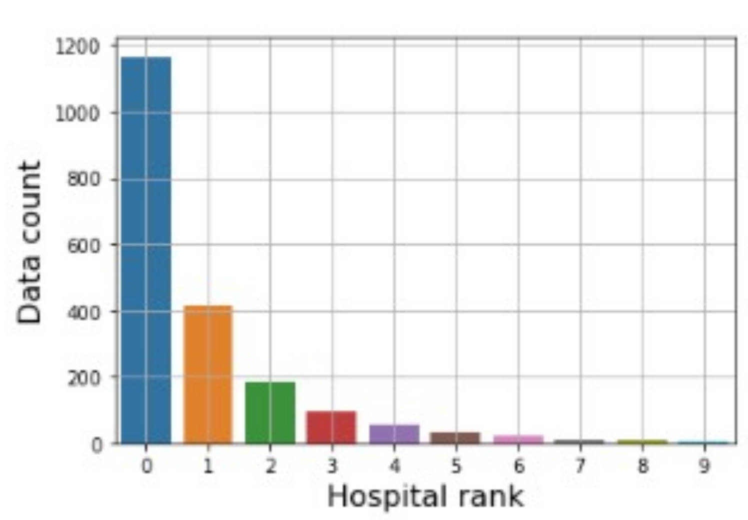
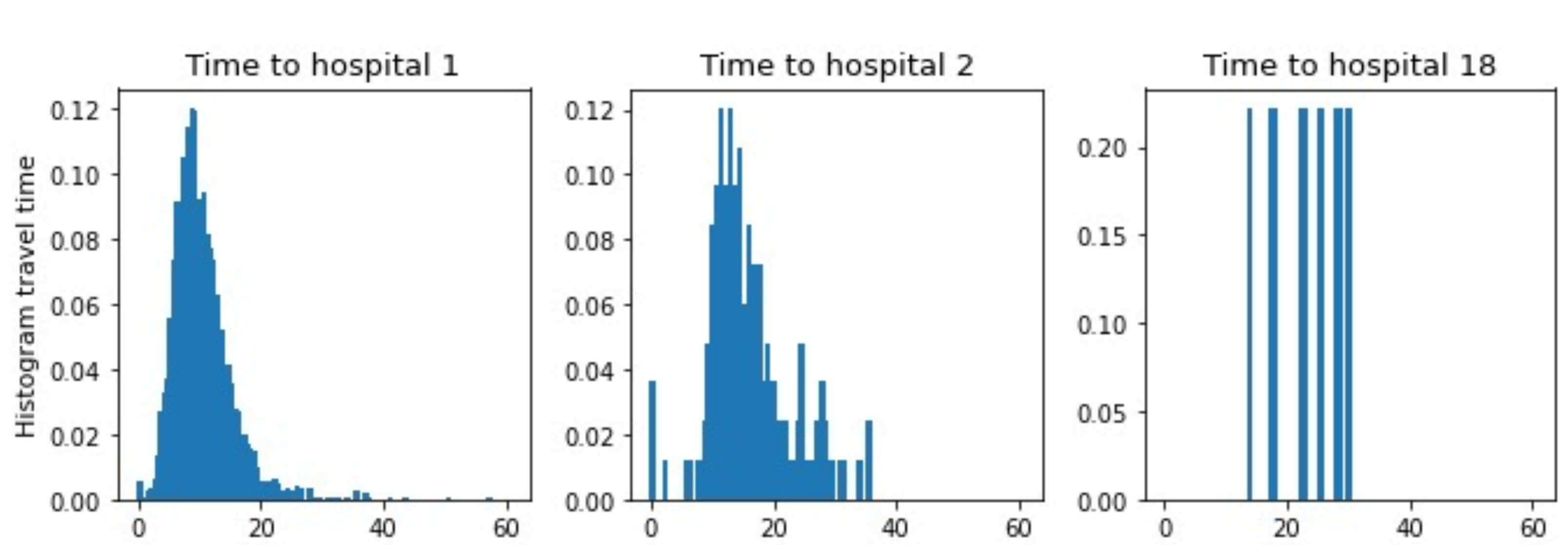
Data Sources

- We incorporate two sources of historical data sets:
  1. City-wide road segment speed profiles constructed using city-owned vehicles telematics data provided by New York City Department of Citywide Administrative Service. The speed profiles are fed into the Network Analysis model in ArcMap by the FDNY team to calculate the shortest path travel times for every origin-destination pair.
  2. Historical ambulance route travel times provided by FDNY
- Origin-destination travel times correspond to travel times from every atom (FDNY divides the city into 2,388 geographical polygons named atoms) to every hospital (71 unique EM).
- The latter data set is available for a limited range of atom-to-hospital pairs, while the former data set is not representative of ambulance behavior.





Method: Ambulance Travel Time

Calibration Model

- A linear relationship between ambulance travel times and road network travel times is observed. We build a linear model with zero-mean Gaussian noise ϵ_i with variance σ_i^2 to account for the epistemic uncertainty that arises from averaging travel time from a limited number of data points, we quantify this uncertainty using Bayesian bootstrapping.

$$y_i = f(x_i) + \epsilon_i; \forall i \in [1, \dots, n]$$
$$\epsilon_i \sim \mathcal{N}(0, \sigma_i^2)$$

- y_i is ambulance travel time and x_i is network analysis travel time for route i.

Gaussian Process Regression

- Ambulance travel times are predicted by heteroscedastic Gaussian process regression model with linear calibration of network estimates as mean function $m(x)$ and white noise kernel as covariance function $k(x, x')$.

$$f(\mathbf{x}; \theta) \sim \mathcal{GP}(m(\mathbf{x}), k(\mathbf{x}, \mathbf{x}')),$$
$$m(\mathbf{x}) = w_0 + w_1 \mathbf{x},$$
$$k(\mathbf{x}, \mathbf{x}') = \sigma_f^2 I$$

- The parameters of the model, $\theta = (w_0, w_1, \sigma_f^2)$ are estimated by maximizing the marginal likelihood.

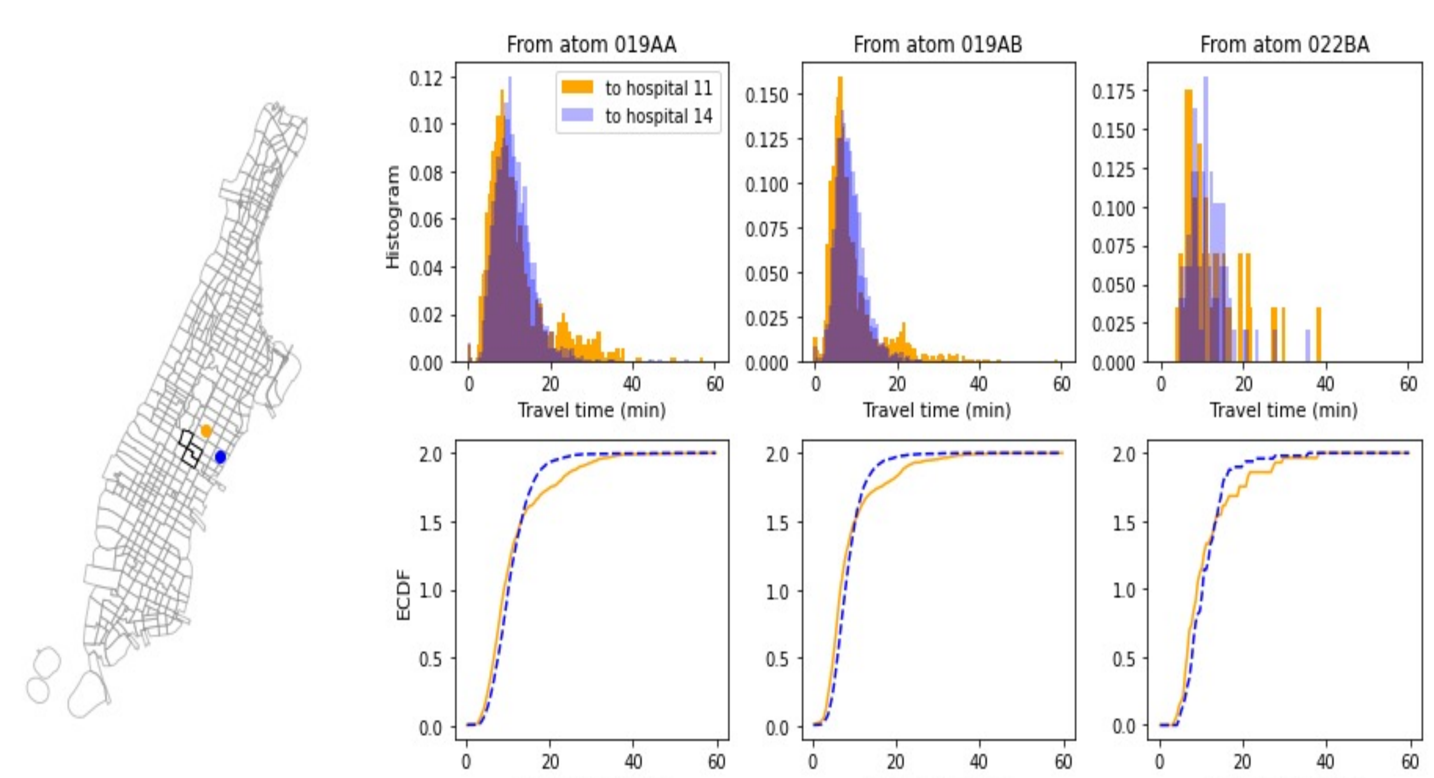
Method: Hospital Suggestion Pattern

Probabilistic Decision Rule

- To create the pattern, for each atom, hospital choices are ranked based on comparing the travel times from that atom to all hospitals.
- Hospital ranking is based on to which more patients will arrive faster.

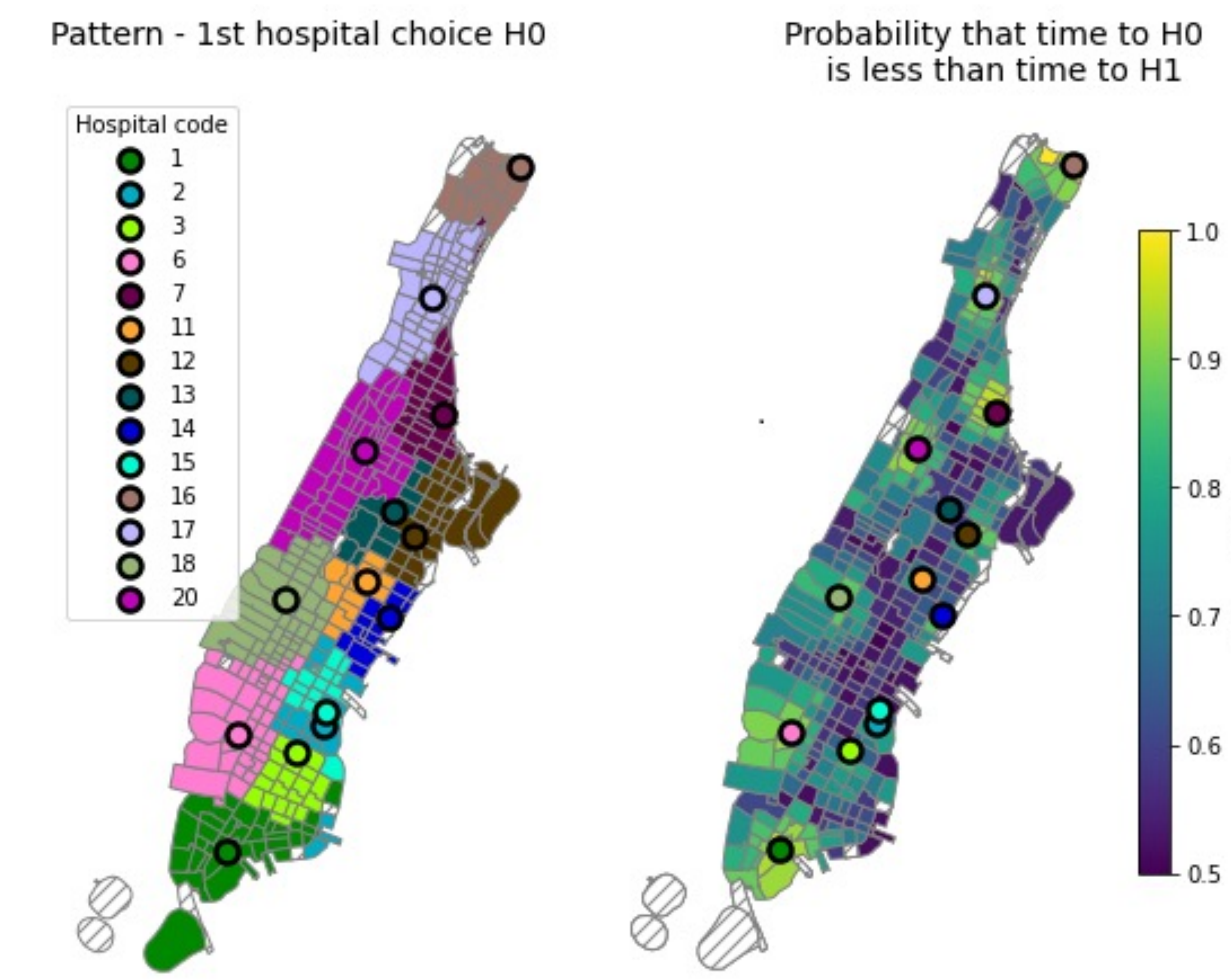
$$P(T_i \le T_j) > 0.5 \Rightarrow \text{hospital i is closer than hospital j}$$

- Ambulance historical data is sparse and for atom-to-hospital pairs with a small amount of data the decision is less reliable.

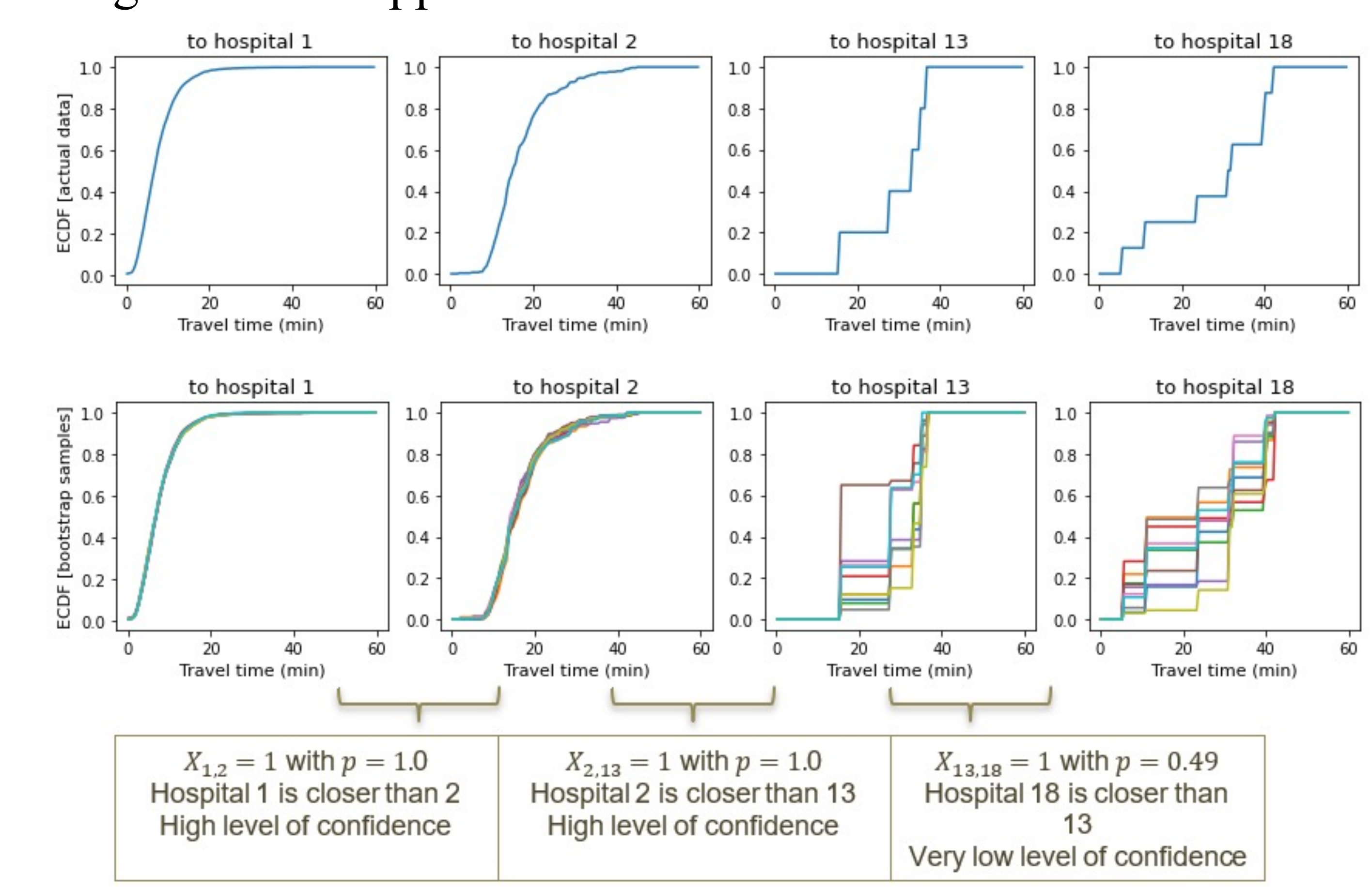


- Bayesian bootstrapping is used to quantify level of confidence in ranking two hospitals with ambulance transport data, i.e., creating slightly different version of dataset by re-weighting the data points; the confidence level will be the probability over the event:

$$\text{confidence level} = \frac{\#\text{ times hospital i is closer than hospital j}}{B}$$



- First, hospitals are ranked using calibrated network analysis travel times. If the rank is consistent with the rank derived from ambulance travel times, the decision is accepted. Otherwise, if level of confidence in ranking based on ambulance data is high the ranking will be swapped.



Conclusion

- With a focus on uncertainty quantification, we predicted atom-to-hospital ambulance travel times by integrating two sources of historical data.
- We proposed a data-driven pipeline to construct the hospital suggestion pattern accounting for our level of confidence in data sources.
- The constructed pattern was implemented in FDNY's CAD system and improved ambulances to-hospital transports travel times in NYC.

Acknowledgement

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