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Street-level Travel-time Estimation using sparse and coarse data

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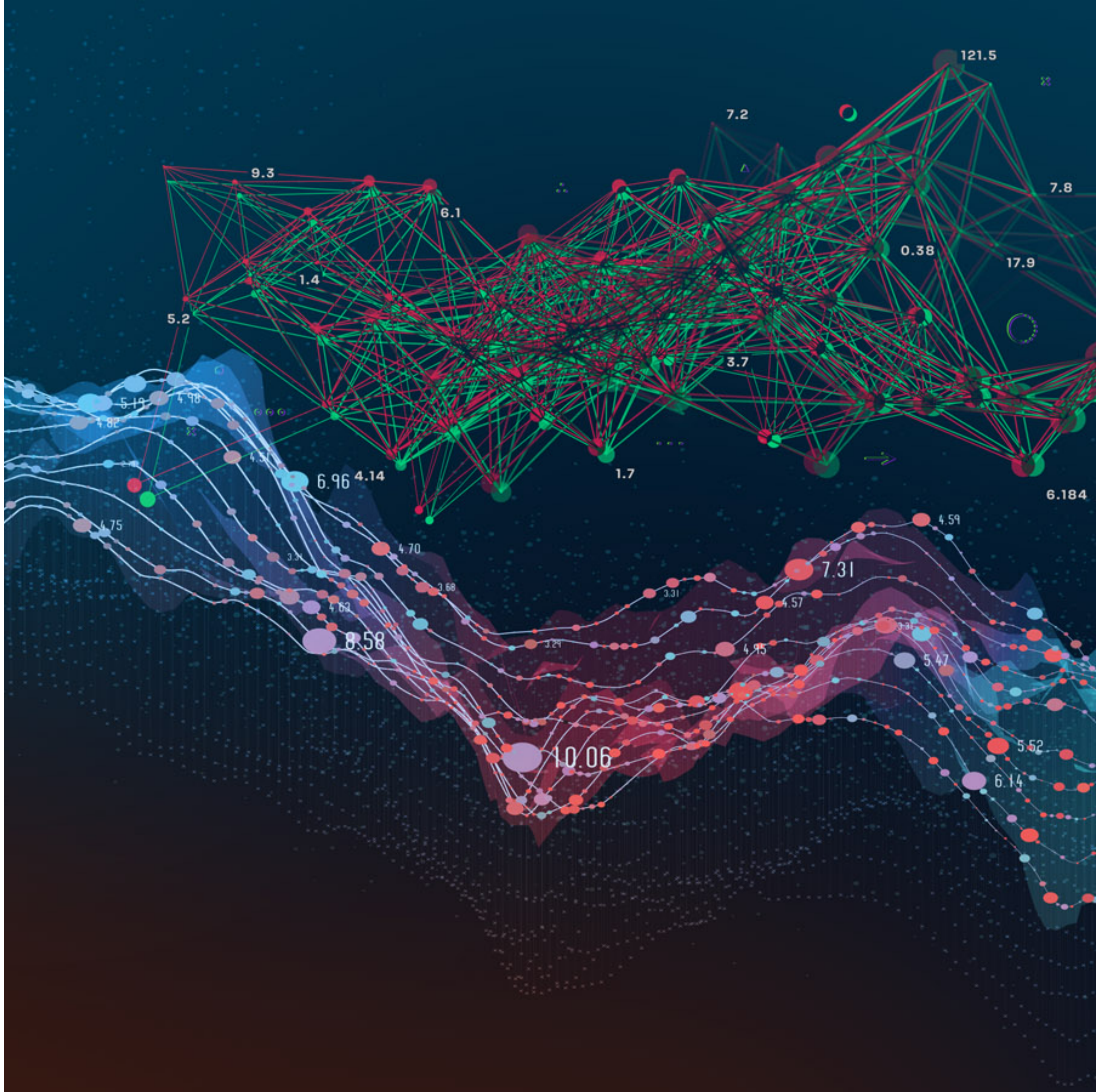


Goal

- Two major areas of traffic forecasting:
  - Demand modeling (number of trips between O-D pairs)
  - **Travel-time estimation** (travel time between O-D pairs)

- Due to data availability, there is more research on freeways than on **arterials**.
  - Many sources but **sparse**.

- **Goal:** Develop a method to leverage open (sparse) data sets to estimate arterial **street-level** travel times on a metropolitan road network.

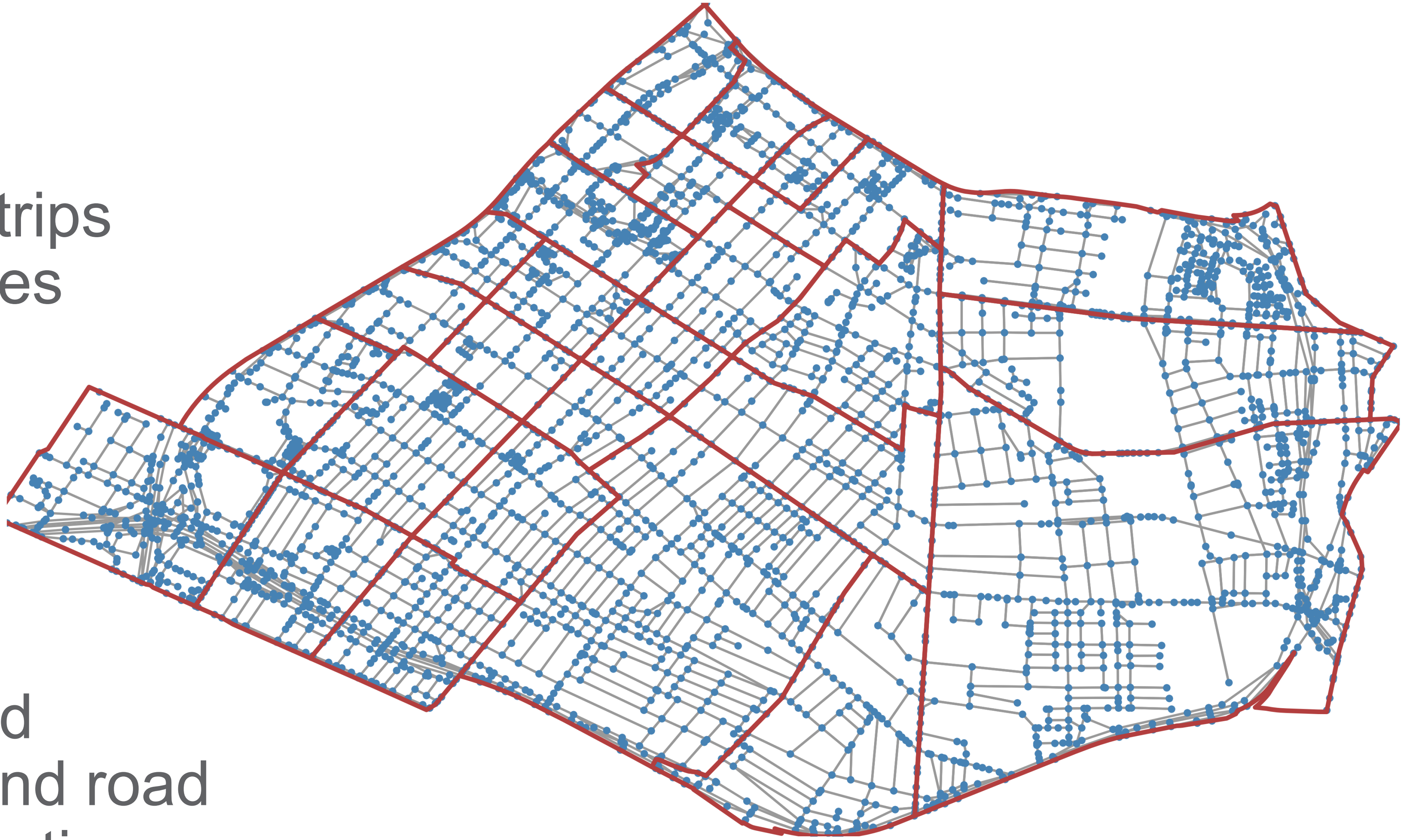
Data Sources

Uber Movement

- Summary statistics of Uber trips between traffic analysis zones (TAZ)
- movement.uber.com

OpenStreetMap

- Graph representation of road network with intersections and road segments represented as vertices and edges
- openstreetmap.org



Road network for 27 TAZs in downtown Los Angeles

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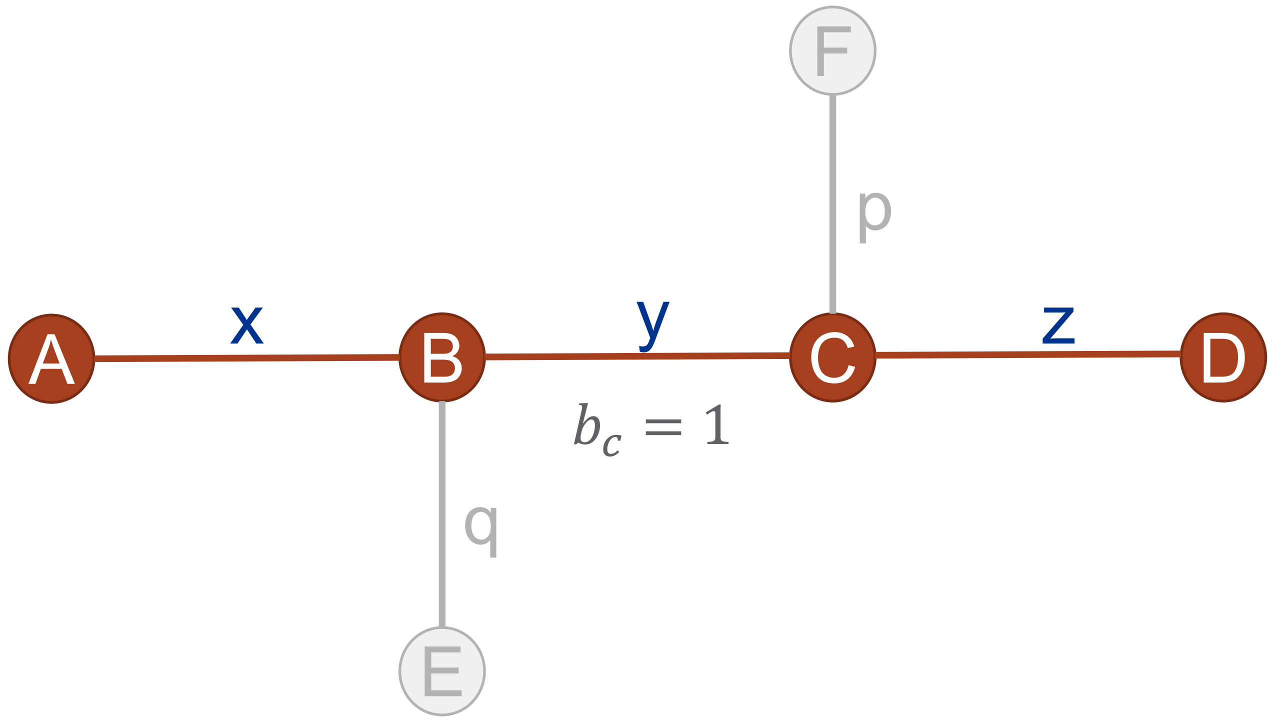
Edge Travel-time Estimation

	A	B	C	D	E	F
A				25		
B						
C						
D						6
E						13
F						



Solutions:

x = 12, y = 1, z = 12

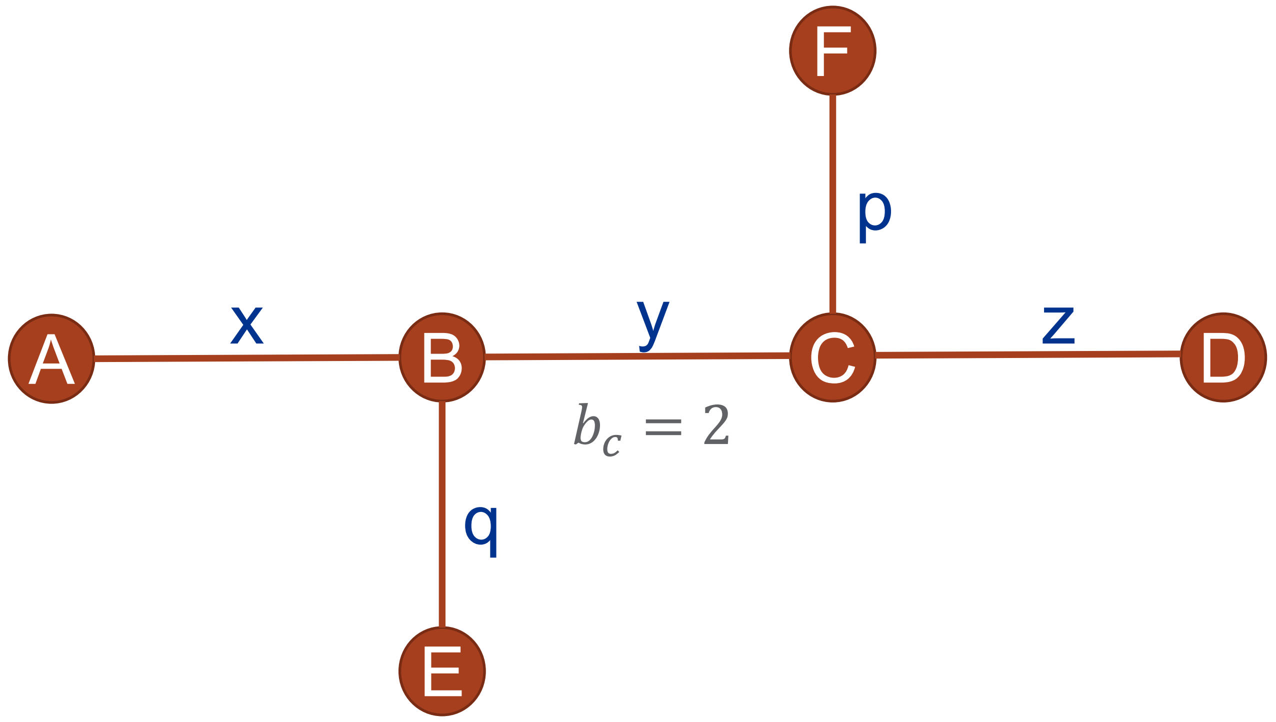
x = 1, y = 23, z = 1

y = [1, 23]

$$\begin{cases} x + y + z = 25 \\ p + z = 6 \\ q + y + p = 13 \end{cases}$$

Edge Travel-time Estimation

	A	B	C	D	E	F
A				25		
B						
C						
D						6
E						13
F						



Solutions:

$x = 12, y = 1, \quad z = 12$

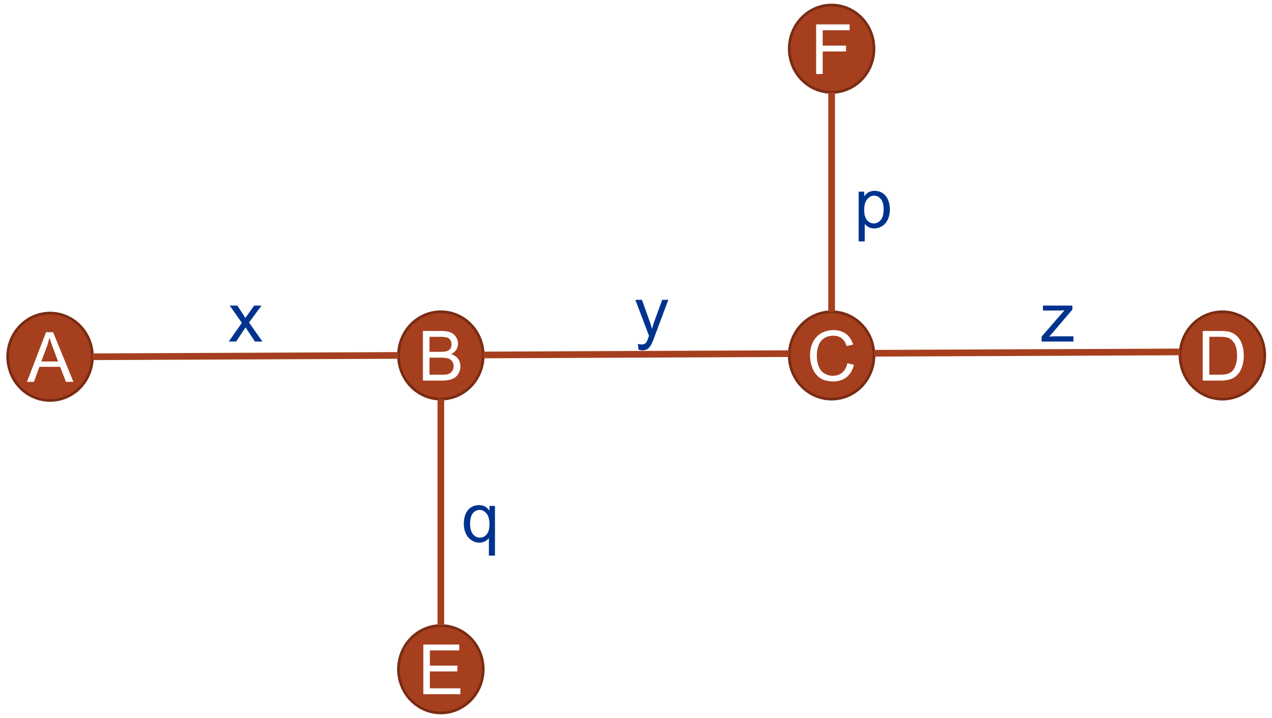
$q = 1, \quad y = 11, p = 1$

$y = [\,1, 11\,]$

$$\begin{cases} x + y + z = 25 \\ p + z = 6 \\ q + y + p = 13 \end{cases}$$

Edge Travel-time Estimation

	A	B	C	D	E	F
A		9	20	25	10	21
B			11	16	1	12
C				5	12	1
D					17	6
E						13
F						



Solution: x = 9, y = 11, z = 5, p = 1, q = 1

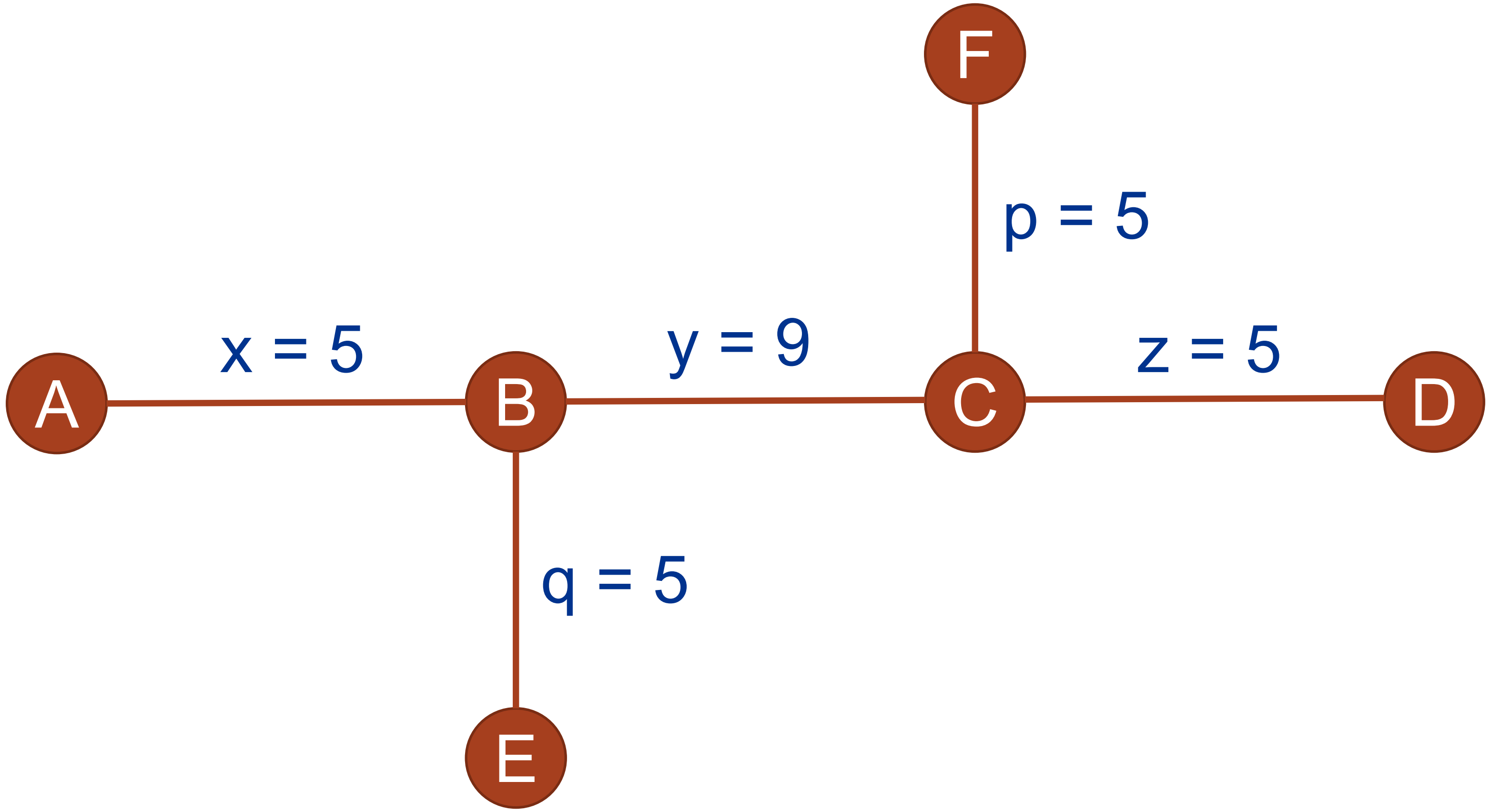
N ⟷ # of trips ⟷ # of equations

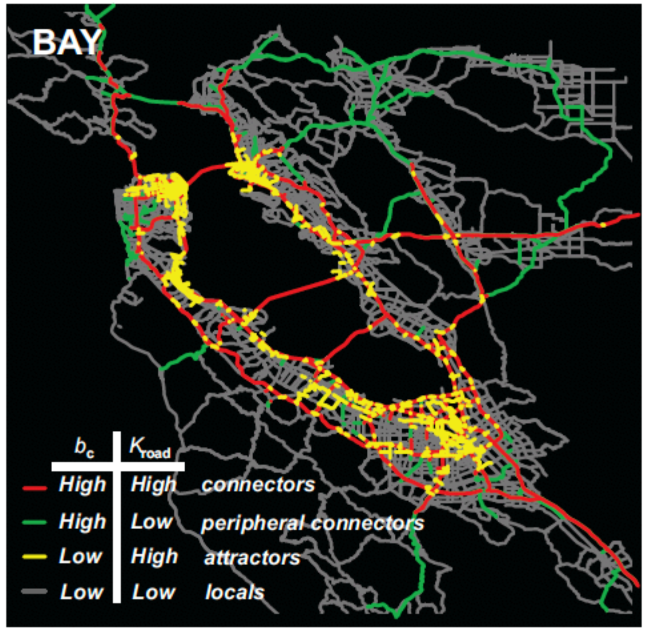
M ⟷ # of road segments ⟷ # of variables

$$\begin{cases} x + y + z = 25 \\ p + z = 6 \\ q + y + p = 13 \end{cases} \quad \longleftrightarrow \quad S^T t \approx y$$

Edge Betweenness (b_c) Centrality

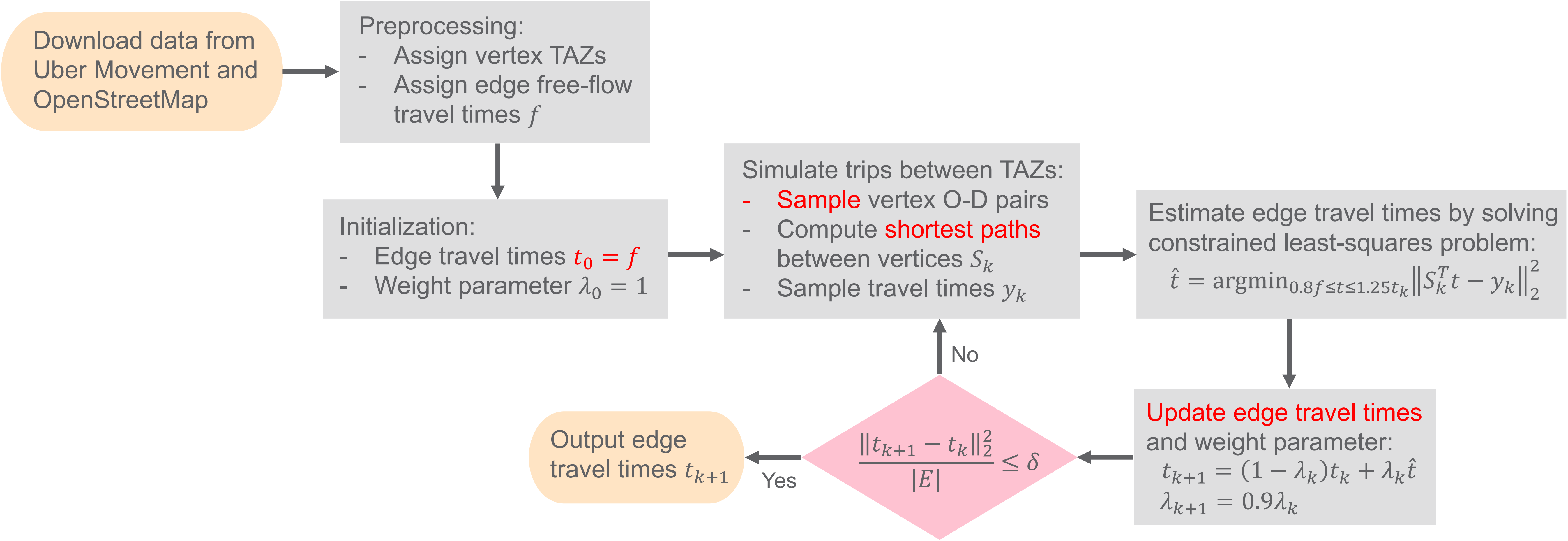
The betweenness of an edge is the number of shortest paths that go through it for all possible vertex O-D pairs.





Types of roads based on betweenness centrality (b_c) and degree (k_{road}). (Source: Wang et al. *Sci. Reports*, 2012, 2, 1001)

Project Workflow



Experimental Results

We estimated edge travel times for downtown LA graphs using

- Different times of day:
  - 3am = 507,449 TAZ O-D pairs
  - 6pm = 1,115,432 TAZ O-D pairs
- Different graph sizes:
  - 1-mile ($M = 7{,}138$), 2-mile ($M = 22{,}756$) and 3-mile radii ($M = 40{,}929$)
- Different number of sampled trips:
  - N = 1,000, 3,000, and 5,000

Error measured by $\epsilon_k = \sqrt{{}^1/_N \sum_{(i,j)\in\mathcal{U}_k} n_{ij}\left(\log g_{ij}(t_k) - \log G_{ij}\right)^2}$

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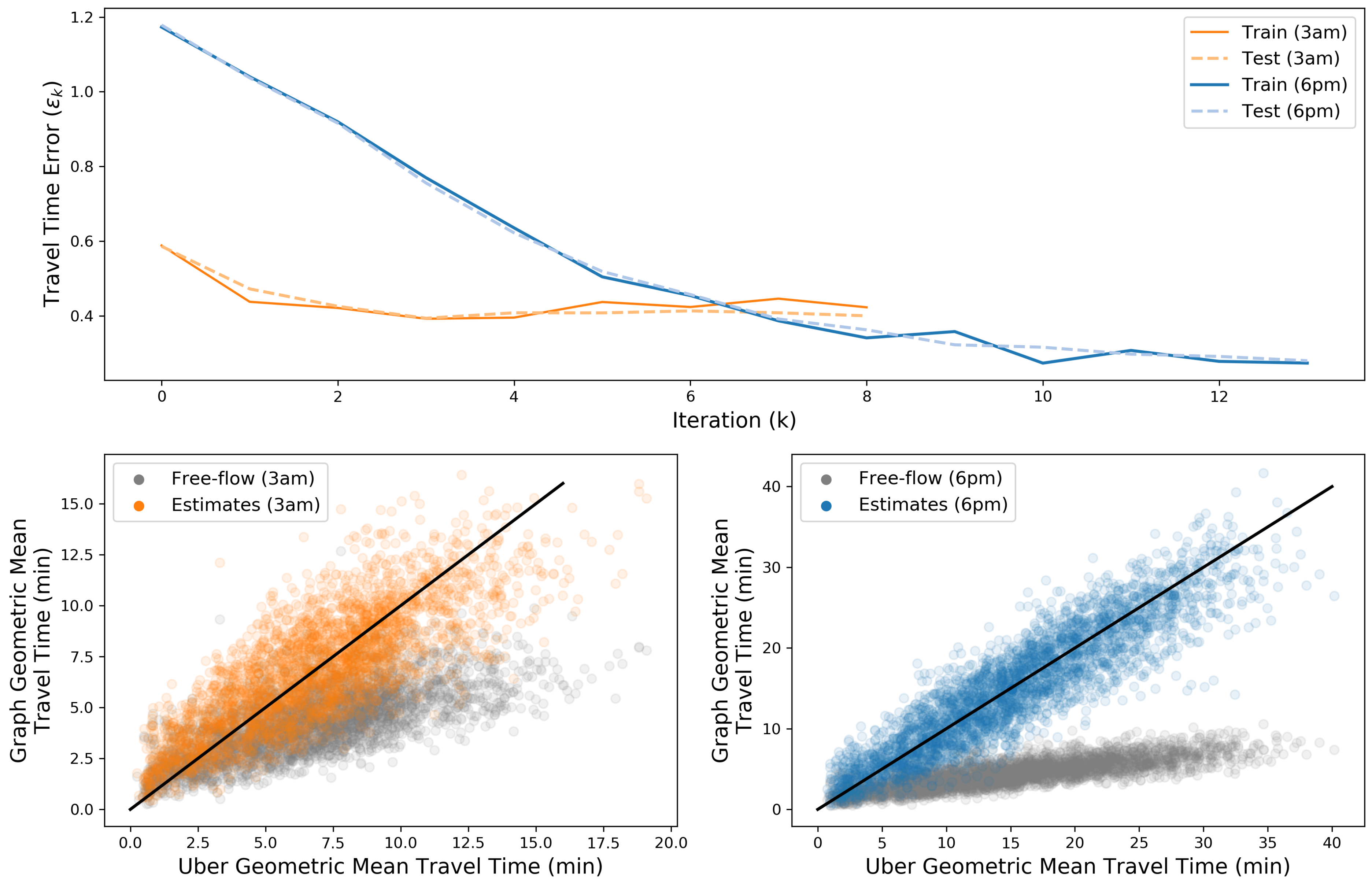
Experimental Results: Convergence



Initial Results on metro-scale estimation

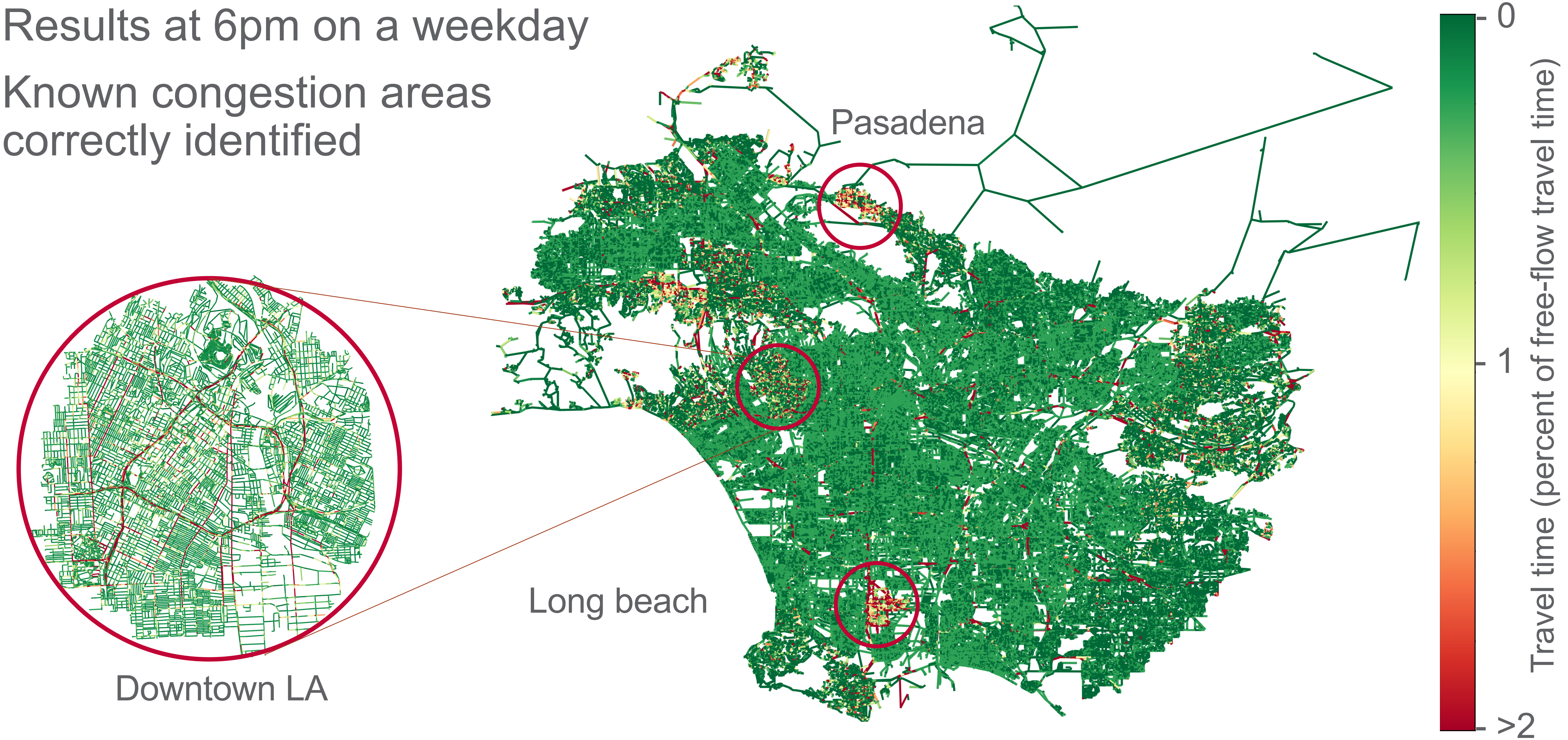
- LA and associated Metro Areas (160k intersections / 470k links – no sparsification):
  - Total coverage - Approx. 1200 sq. mi
  - 64 chunks @ approx. 20 sq. mi. per chunk
  - Total running time on a single (8-core) server node : 18.5 hours per hourly window
  - With 64-node cluster ~ Approx. 25 mins (including serial overhead)

- Seattle and associated Metro areas (/ 160k links – no sparsification)
  - Total coverage – Approx. 500 sq. mi
  - 16 chunks @ approx. 30 sq. mi per chunk
  - Total running time on a single (8-core) server node : 5.00 hours per hourly window
  - With 16-node cluster ~ Approx. 20 mins (including serial overhead)

- Current approach cannot be used to drive-down chunk sizes as it affects accuracy
  - Imposes a limit on scaling gains
  - Projections for a 64-node cluster (12K Processors) are of about 30 mins (including overhead)
  - Potential areas of performance improvement: Python code, constrained least squares solver

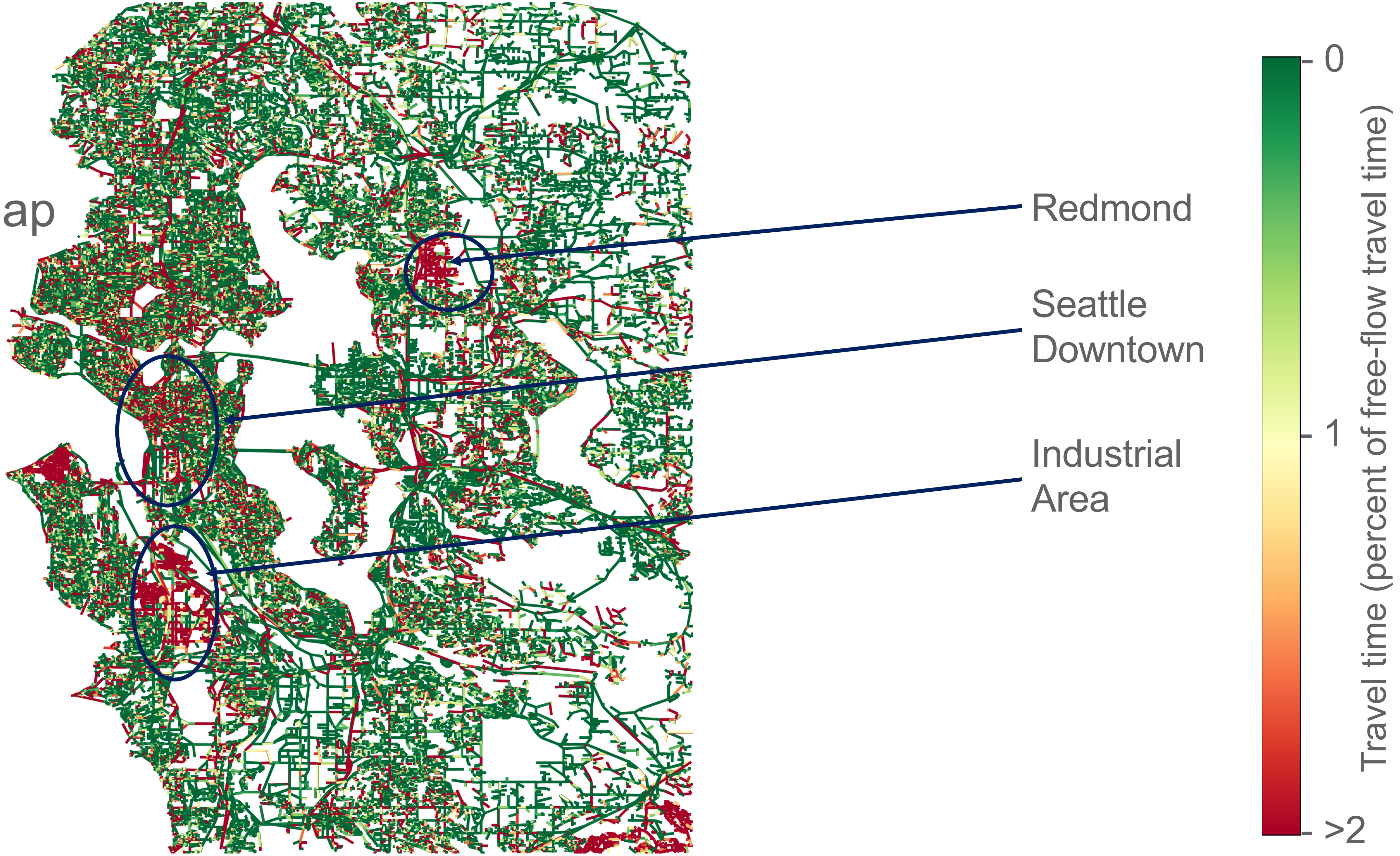
Visualization of congestion on LA metro-area map

- Results at 6pm on a weekday
- Known congestion areas correctly identified



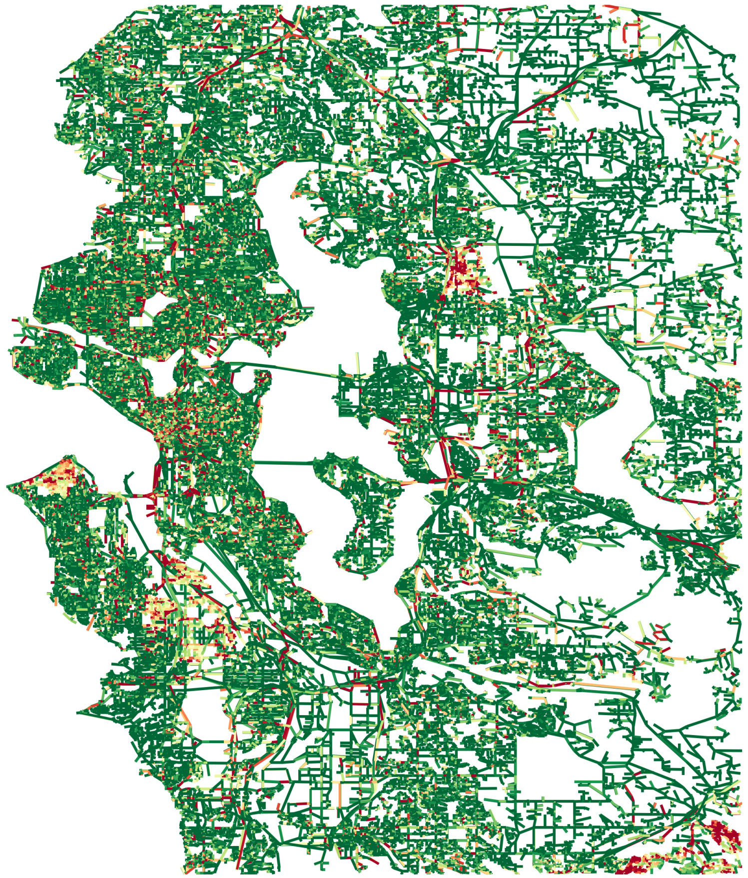
Visualization of congestion on Seattle metro-area

- 6PM
- Weekday
- OpenStreet Map

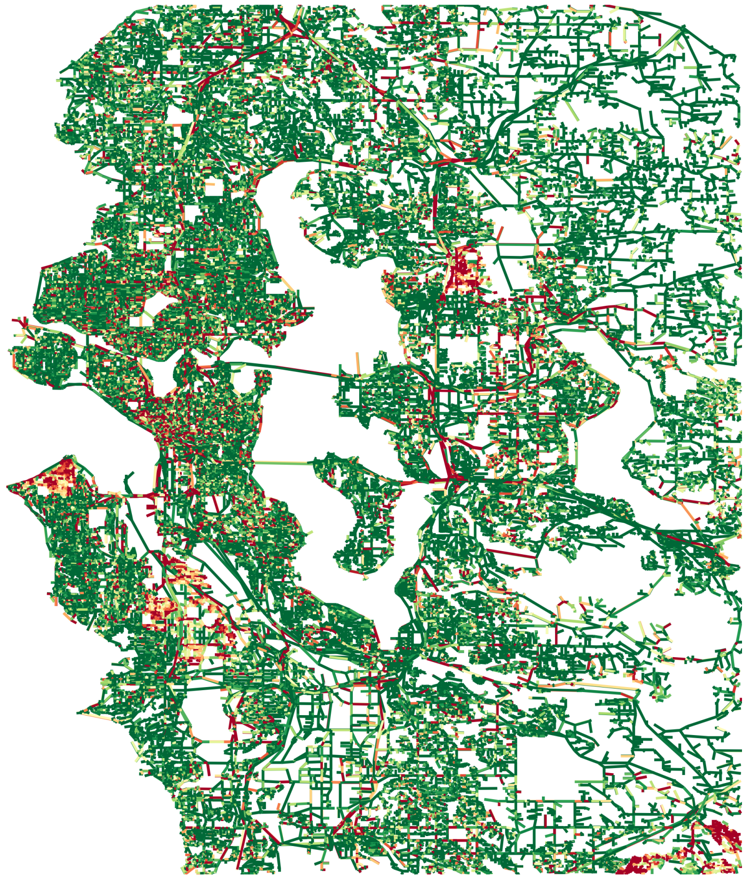


Time evolution of the Seattle network 4pm-6pm

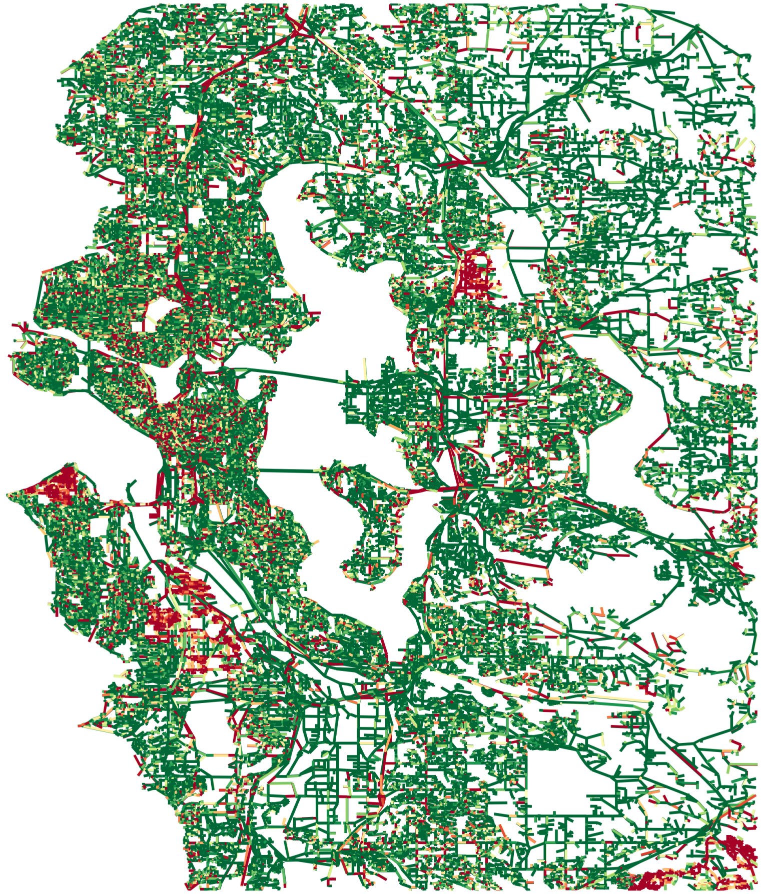
Increase in traffic congestion → larger travel times in congested arterials



4pm



5pm

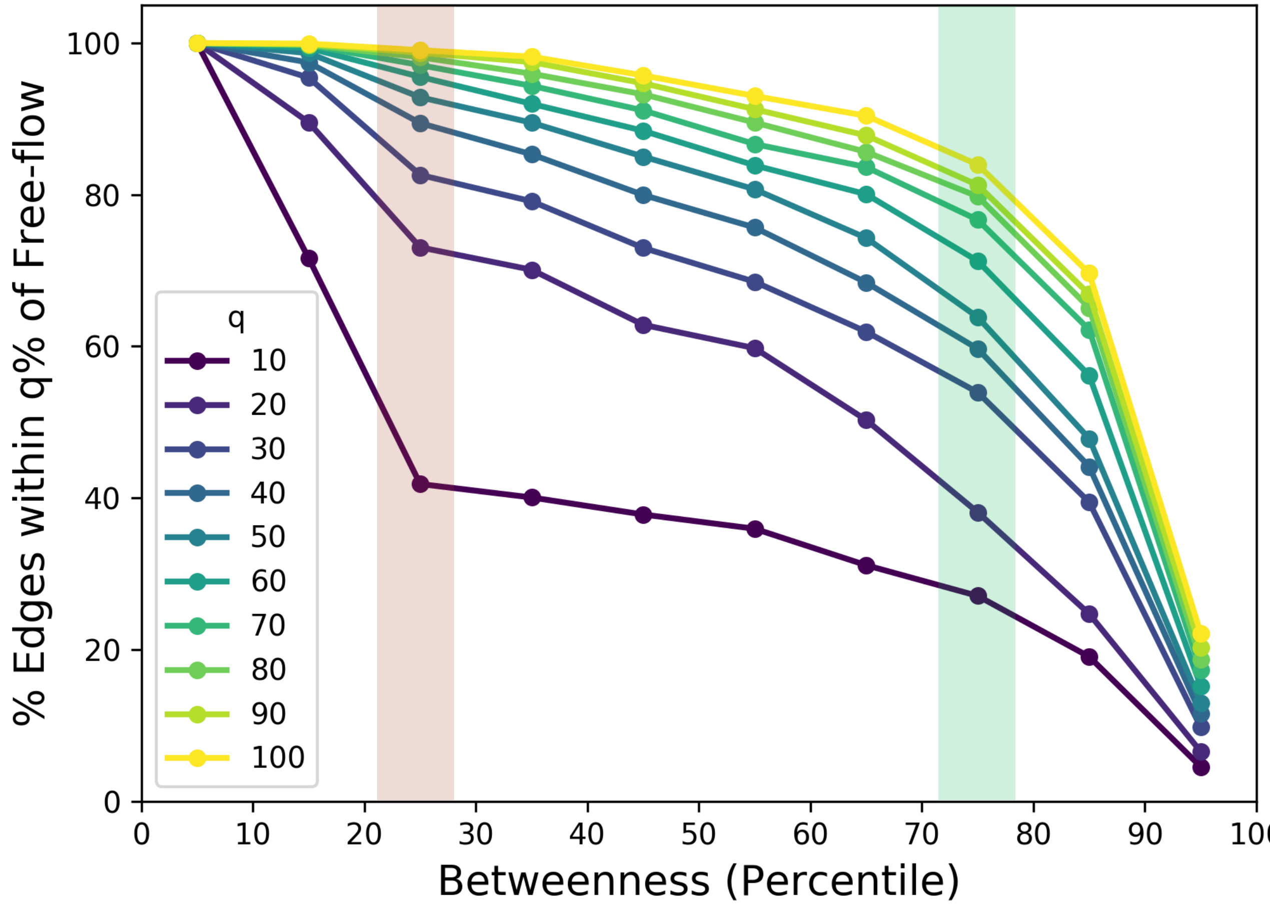


6pm

Graph Pseudo-Sparsification

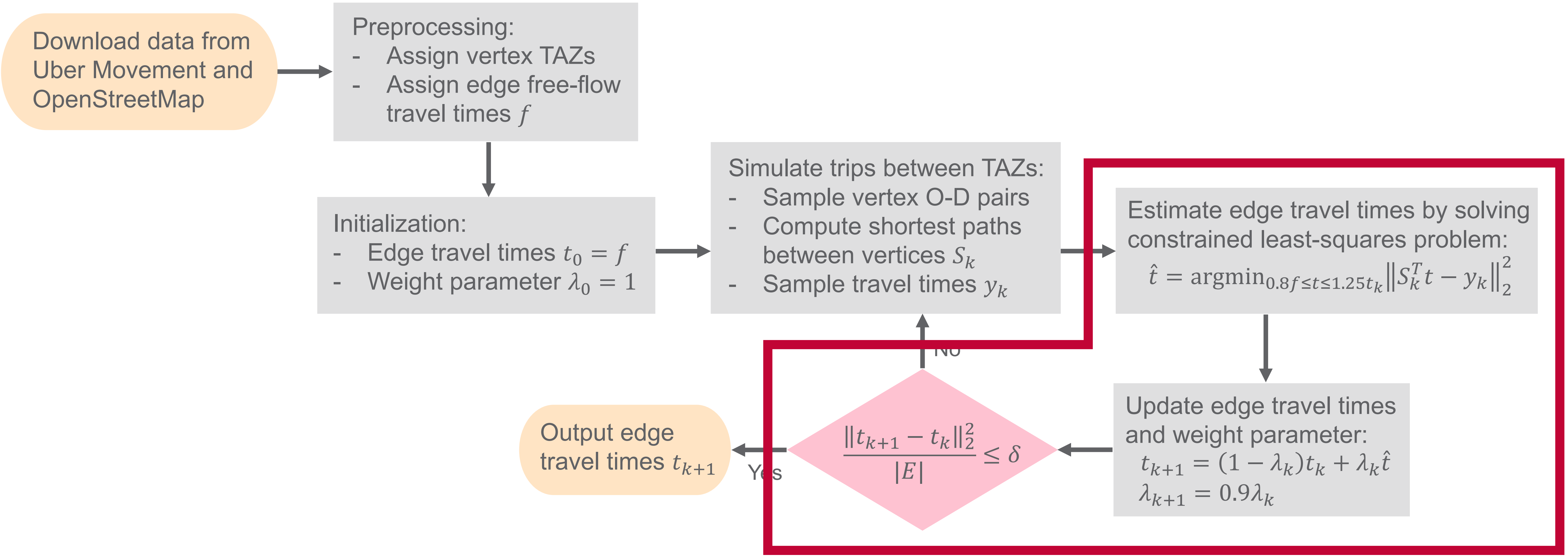
Edges with lower betweenness are more likely to have estimated travel times closer to their free-flow travel times.

Impact of using the 25% betweenness percentile as sparsification threshold



$$q = \frac{|t - f|}{f}$$

Graph Pseudo-Sparsification: Method



Summary and Future Work

- Leveraged coarse-grained Uber Movement data in the form of TAZ O-D pair summary statistics to provide estimates of fine-grained, street-level travel times.
- Solved Large metropolitan areas like Los Angeles and Seattle.
- Implement HPC based software for (near)real time estimation.
- Include Multi-Modal information: bi-cycles, bus, peds, etc.
- Open source the software with Laptop/Cloud/Supercomputer support.

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Thank you