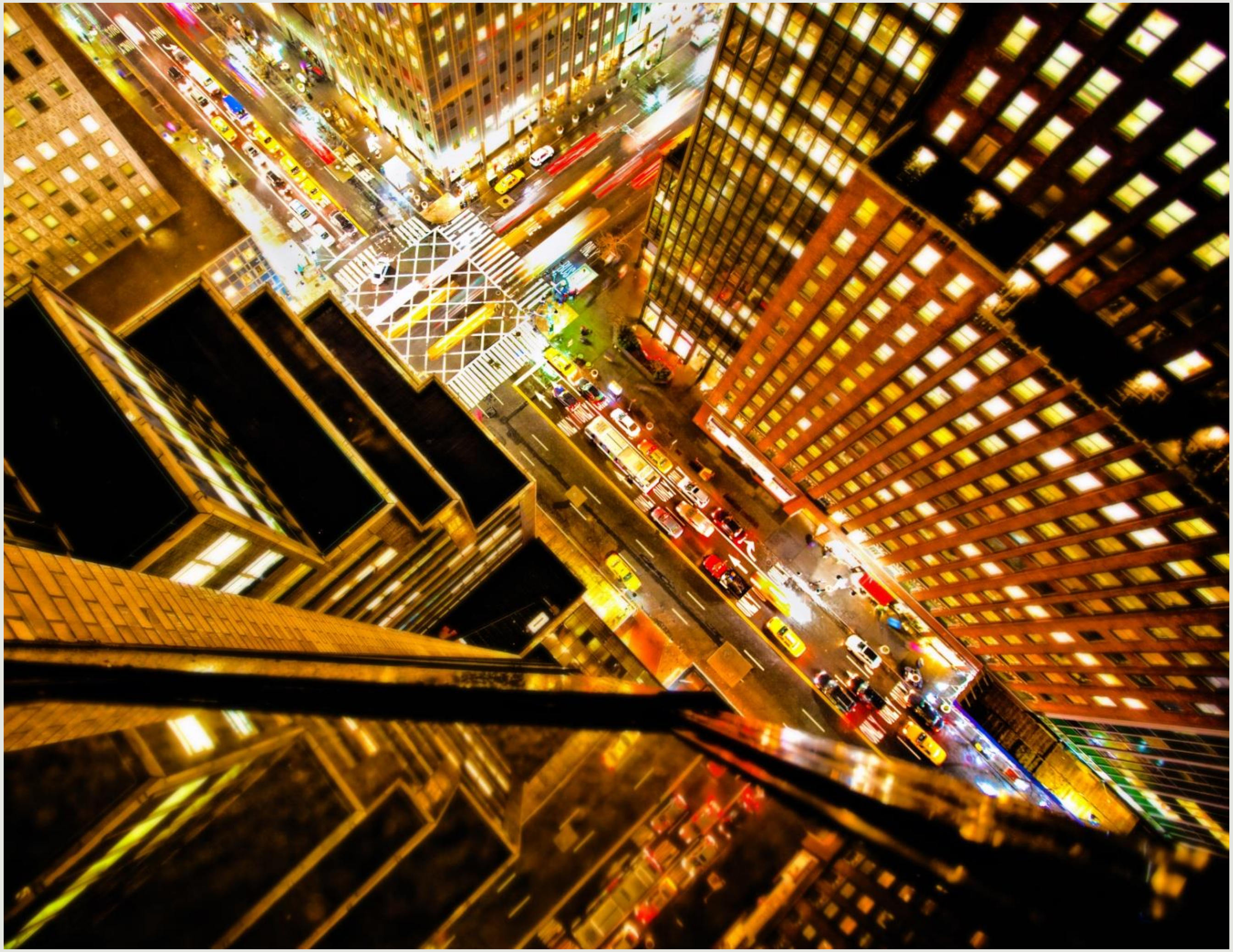
Simulation-based Transportation Optimization

Carolina Osorio



2016 EU-US Frontiers of Engineering Symposium

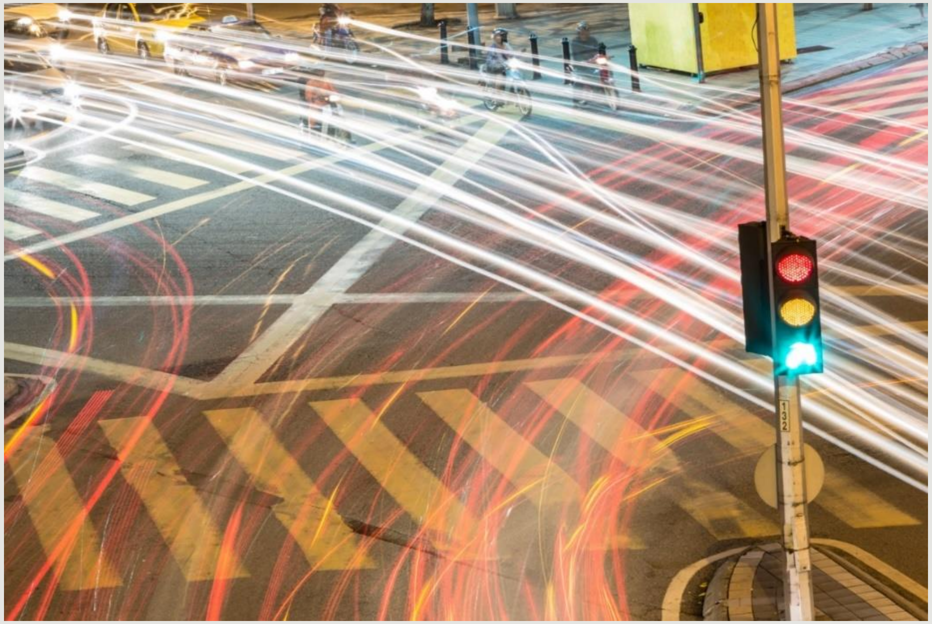
Department of Civil & Environmental Engineering
Massachusetts Institute of Technology

Outline

- Next generation mobility systems
- Engineering challenges of the future
- Recent advancements

Next Generation Mobility Systems

- IOT: travelers, vehicles, infrastructure are increasingly equipped with sensors
- Rise in connectivity (V2V, V2I): increasingly intricate systems
- Empowering data
  - Travelers have a better understanding of their travel alternatives
  - They are becoming real-time optimizers of their trips



Shapes the systems of the future:

1. User-centric
2. Sustainable
3. Quickly evolving

Carolina Osorio
Department of Civil & Environmental Engineering Massachusetts Institute of Technology

Next Generation Mobility Systems

1. User-centric : the unique on-demand needs and preferences of each traveler will be at their core

2. Sustainable

- Major contributor to fuel consumption and greenhouse gas emissions
- Pressing necessity to mitigate the impacts of congestion: energy, environment, economy, society

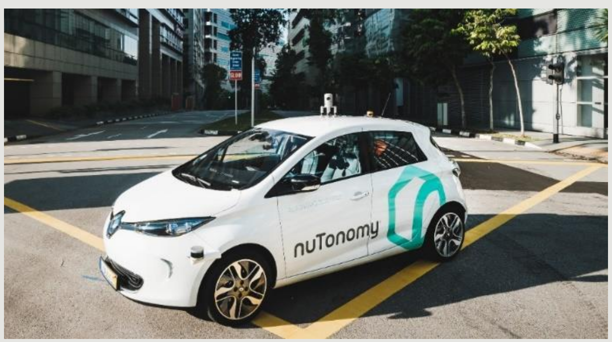
Carolina Osorio

Department of Civil & Environmental Engineering Massachusetts Institute of Technology

Next Generation Mobility Systems

3. Quickly evolving

- Big data era has welcomed new stakeholders into the sector
- Their disruptive innovations have allowed the system to evolve at an unprecedented fast pace



Next Generation Mobility Systems

1. User-centric
2. Sustainable
3. Quickly evolving

Use high-resolution data to:

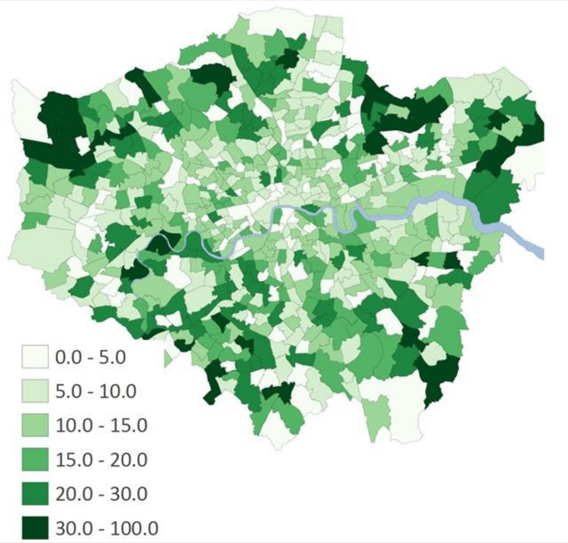
1. Formulate models
2. Calibrate models
3. Use models to inform the design of mobility systems

Carolina Osorio

Department of Civil & Environmental Engineering Massachusetts Institute of Technology

1. Formulate Models

- Improve our understanding of:
  - traveler behavior: how individuals make, and revise, travel decisions
  - the interaction of travelers, vehicles and the infrastructure
- Adapt transportation system
- Influence behavior

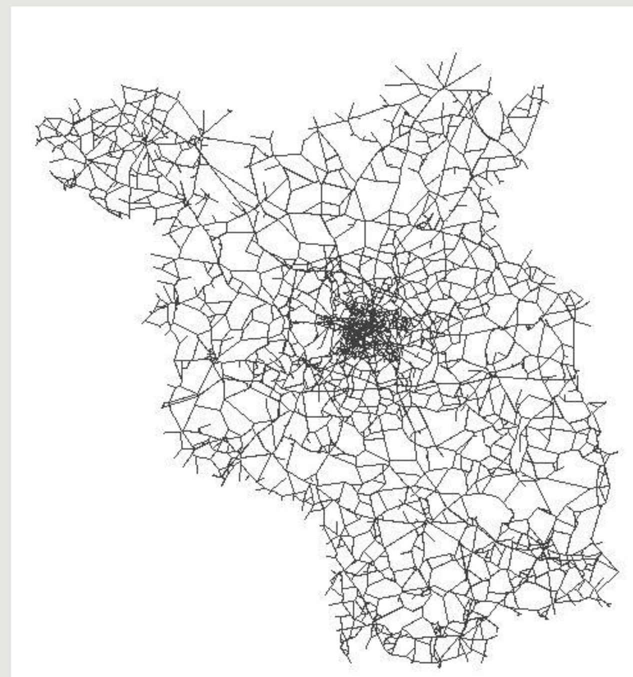


- Goulet Langlois, Koutsopoulos and Zhao (2016)
- TfL smart card data used to infer users travel patterns
- Identified clusters of travel and activity patterns
- Studied how short-term travel choices relate to long-term elements of lifestyle as captured from socio-demographic characteristics

Carolina Osorio

2. Calibrate Models

- Replicate observed travel patterns
- Berlin Metropolitan Area
- Over 24,000 links; 11,000 nodes and 172,000 trips
- Poster !



Zhang, Osorio, Flötteröd (2015, 2016)

Carolina Osorio

Next Generation Mobility Systems

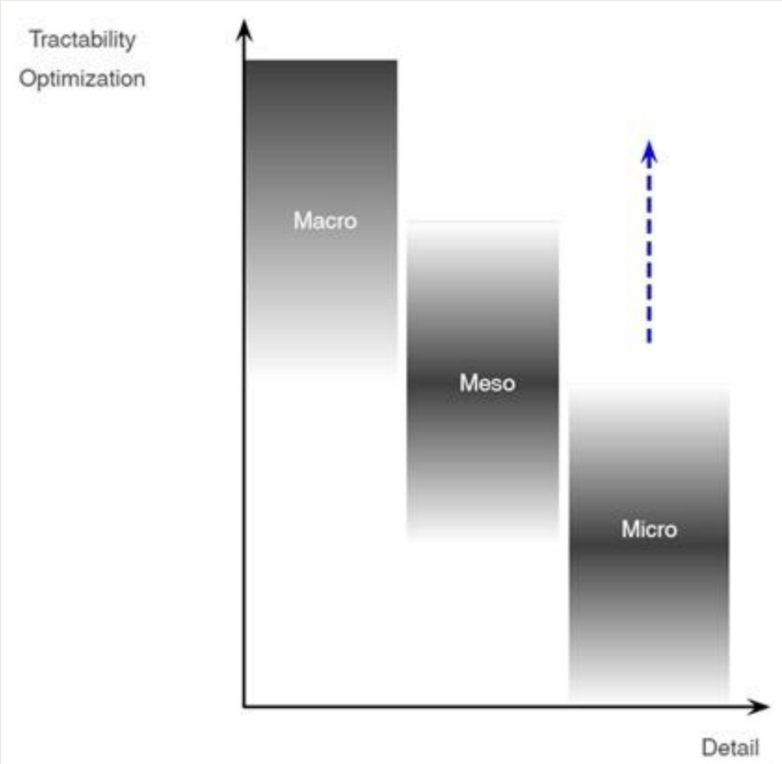
1. User-centric
2. Sustainable
3. Quickly evolving

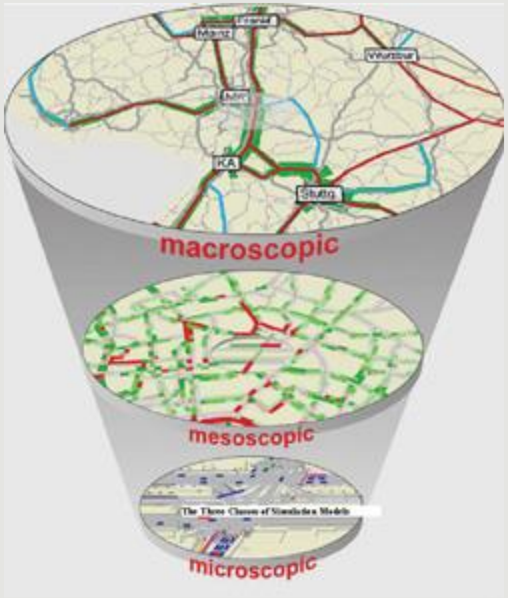
Use high-resolution data to:

1. Formulate models
2. Calibrate models
3. Use models to improve the design of mobility systems

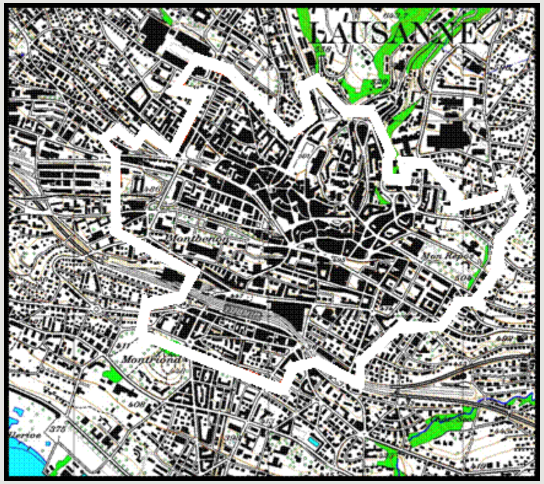
Carolina Osorio
Department of Civil & Environmental Engineering Massachusetts Institute of Technology

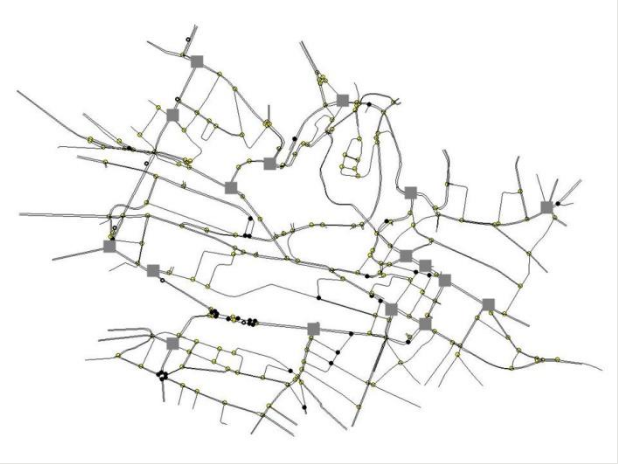
Transportation Modeling Paradigms

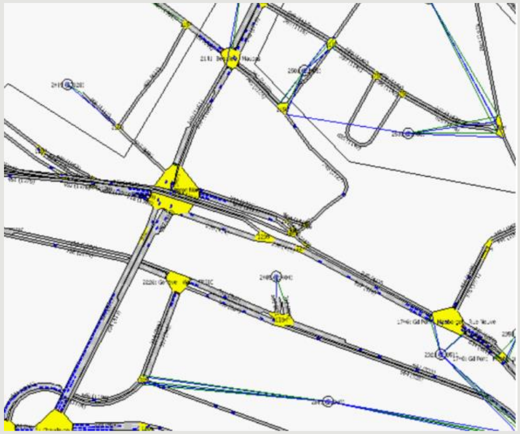


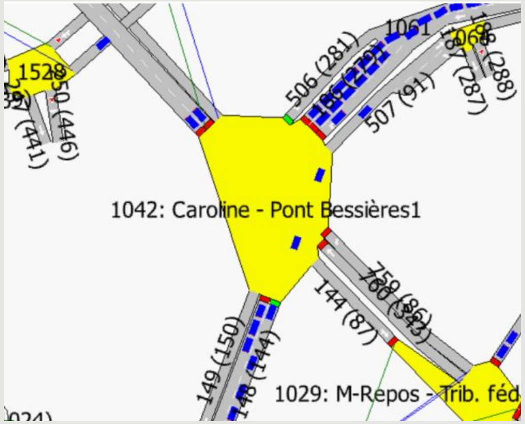


High-resolution Models









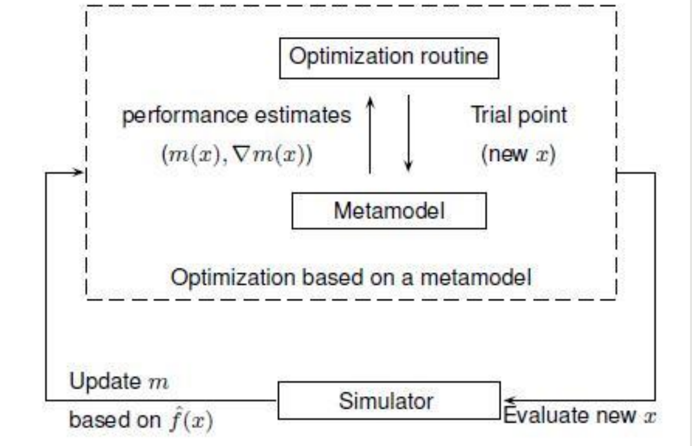
Carolina Osorio

Department of Civil & Environmental Engineering
Massachusetts Institute of Technology

Simulation-based Optimization

- Computationally inefficient, stochastic, no closed-form available for optimization
- Efficiency is critical for transportation practice
- Current algorithms:
  - Black-box approach, asymptotic properties, not efficient

How can inefficient simulators be used efficiently for optimization?



$$\min_{x \in \Omega} E[F(x)] \quad \leftrightarrow \quad \min_{x \in \Omega} m_k(x)$$

- Embed analytical structural information in the algorithm
- Derive structure from analytical models
- Use of efficient analytical models: differentiable, scalable
- Transcend the use of a single modeling paradigm

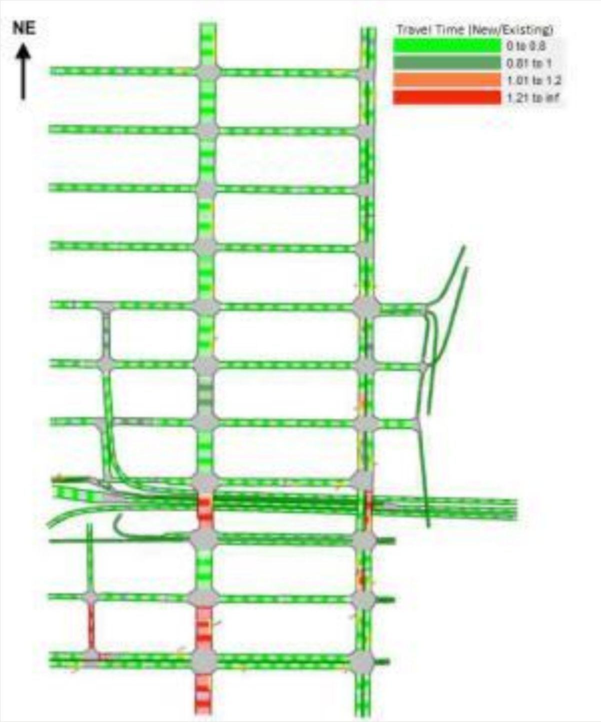
Carolina Osorio

Department of Civil & Environmental Engineering, Massachusetts Institute of Technology

Accounting For Intricate Behavior

- New York City
- Critical area: Queensboro Bridge
- Traffic signal control
- Intricate traffic dynamics: highly congested, multi-modal, pedestrian traffic, grid topology, short links, intricate travel behavior

New York City



Osorio et al. (2014) *Proc. ISTS*

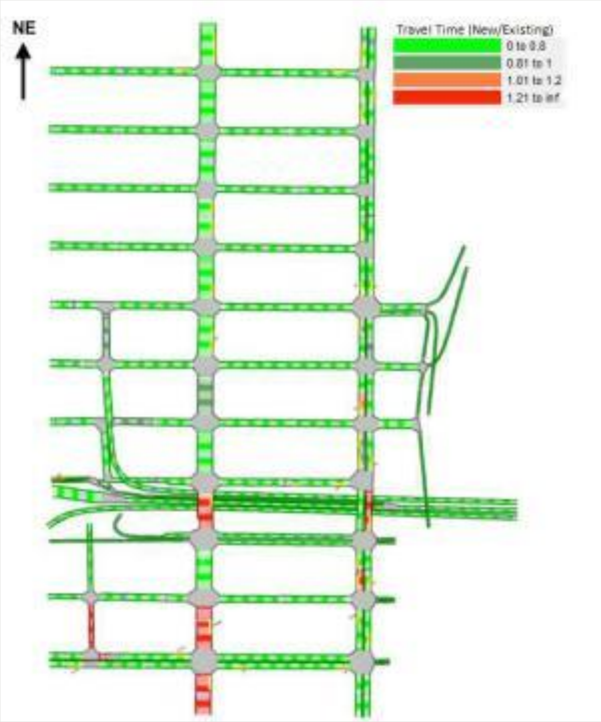
- Morning-peak period
- 134 Roads, 41 intersections
- An average of over 11,000 trips

Improvements of:

- average trip travel time by 10%
- average queue-length by 28%
- spillback probabilities by 23%
- average throughput by 2%

- Traffic-responsive signal control

New York City



Osorio et al. (2014) *Proc. ISTS*

- We can account for intricate behavior for optimization
- There is great room for improvement to mitigate congestion with minimal investment

Pushing the frontiers of large-scale control

- 924 links, 2600 lanes, 28000 trips
- Control 96 intersections
- Simulation budget of 50 runs
- NYCDOT signal plan: average link density

How did we do this?

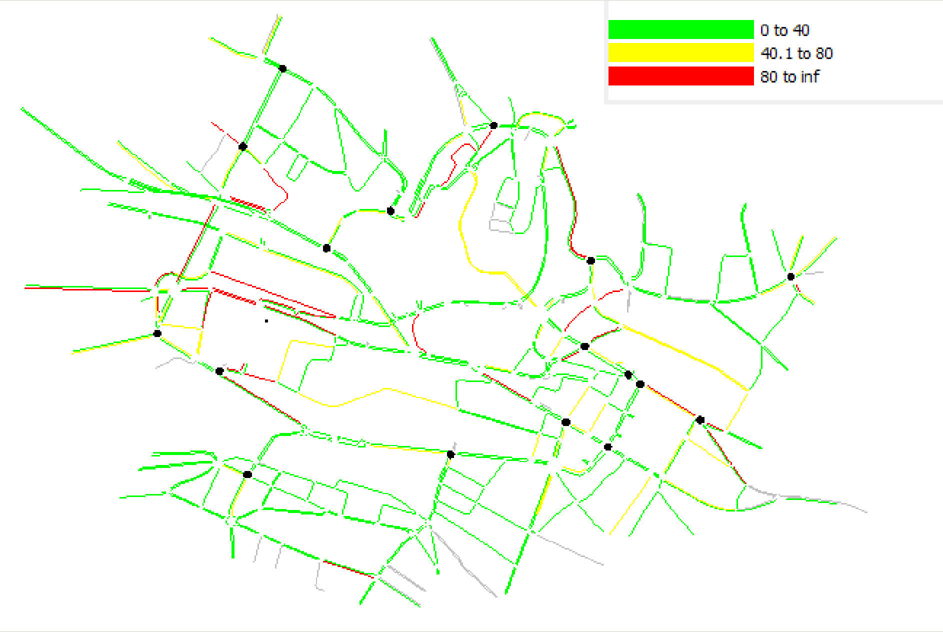
Learning about problem structure

Carolina Osorio

Department of Civil & Environmental Engineering
Massachusetts Institute of Technology

Large-scale Optimization

- 603 links, 231 intersections, 12400 trips
- City-wide signal control: 17 intersections
- What can be done with only 150 simulation runs?



Osorio and Chong (2016) *Transp. Science*

Carolina Osorio
Department of Civil & Environmental Engineering Massachusetts Institute of Technology

What do travelers care about?

- With big data we can rethink how we evaluate network performance
- Reliable and robust networks
- Travel time reliability is important in route and mode choice
- Enhancing network reliability is a critical goal of major transportation agencies
- Osorio, Chen and Santos (2012) *Proc. INSTR*

- Sustainable networks
- Use of instantaneous vehicle performance

  Osorio and Nanduri (2015) *Transp. Science, Transp. Res. Part B*

Carolina Osorio

Department of Civil & Environmental Engineering Massachusetts Institute of Technology

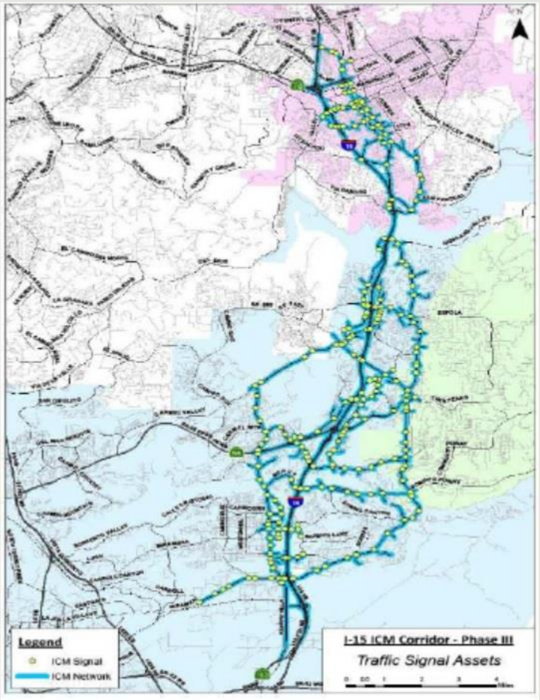
Integrated on-demand mobility services

- On-demand vehicle-sharing
- Integrated systems
  - How can we complement the existing road and transit network?
  - City of Boston
  - Improving both utilization, revenue and accessibility

Ongoing Work

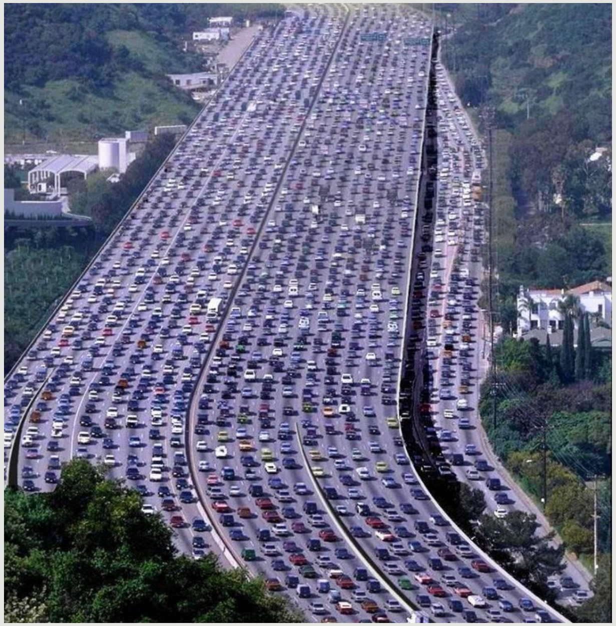
- Real-time high-resolution control
- Demand management: real-time congestion pricing
- Algorithms for autonomous and mixed vehicle fleets

Bailey, Osorio Antunes and Vasconcelos (2015) *Proc. Mobil.TUM*



Main Goal

Enable the use of high-resolution models, formulated at the scale of individual travelers, to optimize urban networks at the scale of full cities or regions



Carolina Osorio

Special Thanks To

Nate Bailey	Evan Fields	Chao Zhang
Xiao Chen	Jing Lu	Kevin Zhang
Linsen Chong	Kanchana Nanduri	Tianli Zhou

- António Antunes (Uni. Coimbra), Gunnar Flötteröd (KTH)
- http://cee.mit.edu/osorio

- Work partially funded by:
  - National Science Foundation Awards 1351512, 1334304 and 1562912
  - MIT Portugal Program
  - Ford-MIT Alliance