Introduction

Cathy Wu

1.041/1.200 Transportation: Foundations and Methods

Readings

1. *Critical Issues in Transportation for 2024 and Beyond*. Washington, D.C.: National Academies Press, 2024. doi: 10.17226/27432.

A.k.a.

1.041/IDS.075/11.544 – Undergraduate

1.200/IDS.675 – Graduate

Outline

1. About the course
2. A nontechnical introduction to transportation
3. Why I study transportation

Quick poll

- Course/Program
- What do you think is the biggest problem or challenge in transportation?

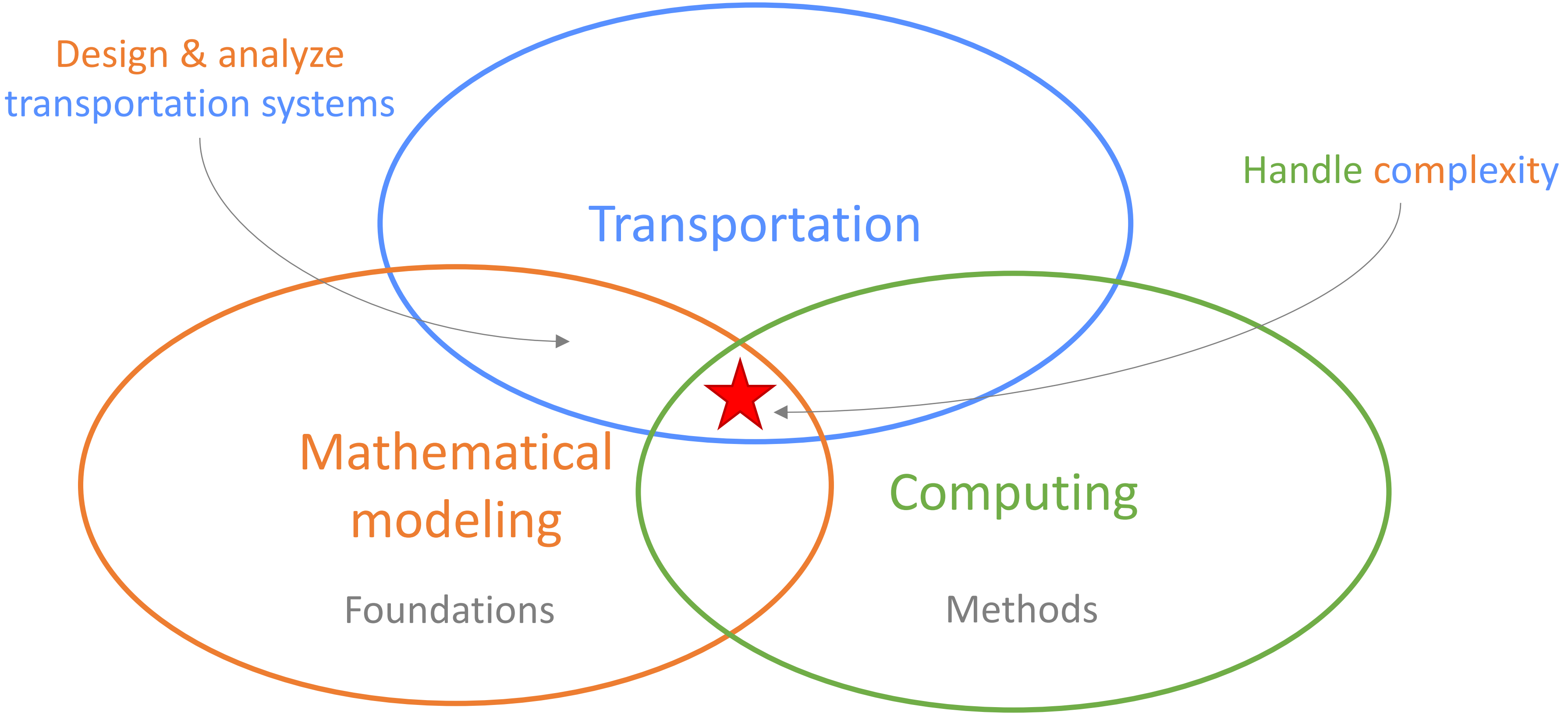
Get to know your fellow classmates:

- Join for Office Hours after class (same room as lecture)
  - If you're looking to find pset partners in the class, or just to meet other folks interested in transportation.
  - Regular office hours. Questions about the class, content, etc.

Outline

1. **About the course**
    a. **Course overview**
    b. Administrivia
2. A nontechnical introduction to transportation
3. Why I study transportation

This is not your typical intro transportation course

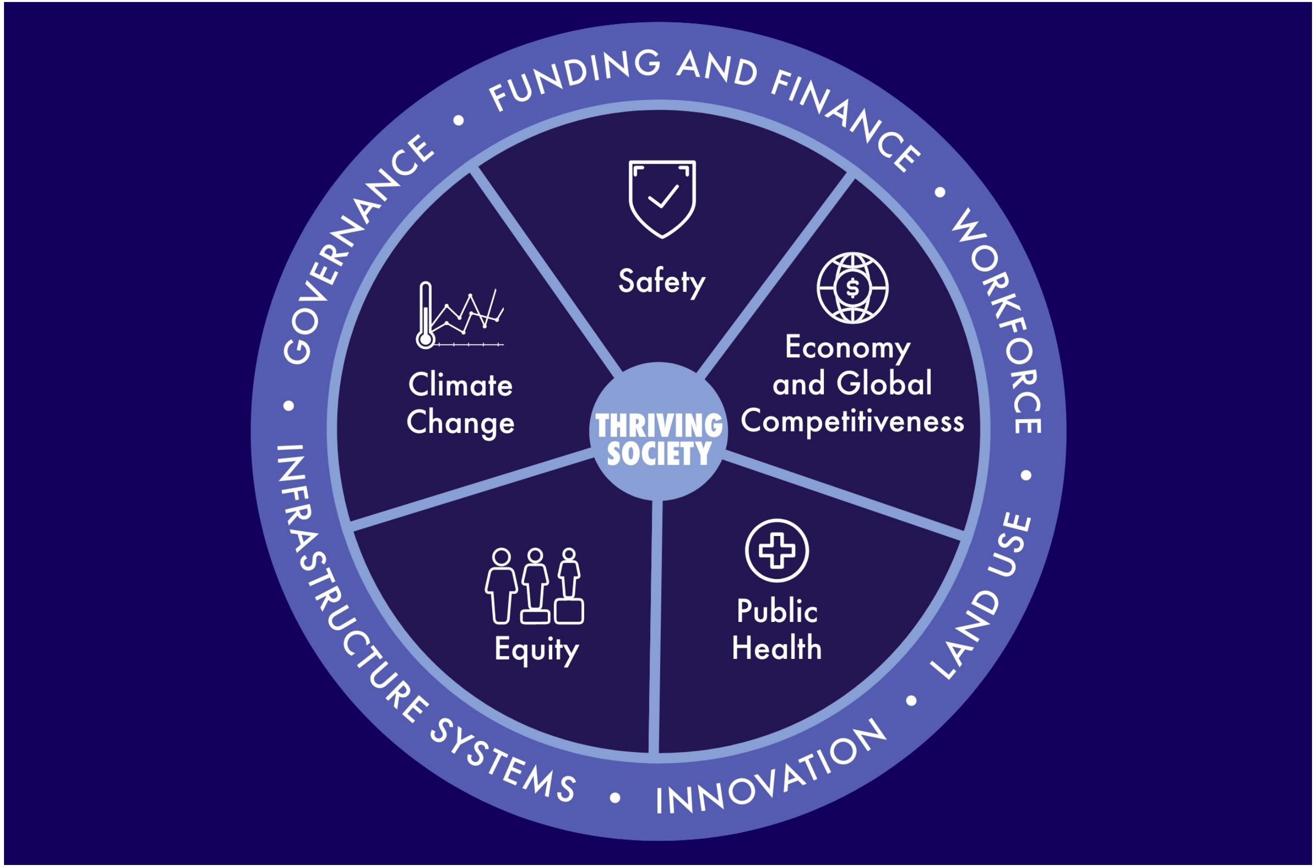


Your typical intro transportation course

Transportation Engineering 101

- Four-step model for transportation planning
- Traffic flow concepts
- Intersection design
- Traffic signal design
- Freeway level of service
- MUTCD
- Intelligent transportation systems
- Vehicle performance & physics
- Highway geometry design
- Roadway safety
- Pavements

Critical issues in transportation



Critical Issues in Transportation for 2024 and Beyond. Washington, D.C.: National Academies Press, 2024. doi: 10.17226/27432.

Critical issues in transportation

Executive Summary

A massive shift away from fossil fuels to clean energy has begun that will require a complete turnover of hundreds of millions of motor vehicles by 2050 to help meet national decarbonization goals. Commuting to work has changed dramatically because of the COVID-19 pandemic in ways that pose significant threats to public transportation. Ten thousand more people died from road crashes in 2022 than 10 years ago. Society at large is grappling with the nation's history of racial discrimination and increasing disparities in wealth and incomes. The dynamic changes being driven by these and other environmental, public health, and socioeconomic forces require reassessing the role of transportation in addressing societal challenges and the research that informs the choices that society will need to make in 2024 and the coming years.

Critical Issues in Transportation for 2024 and Beyond. Washington, D.C.: National Academies Press, 2024. doi: 10.17226/27432.

Take a dive deep into any of the critical issues

- Dozens of mobility-related courses at MIT: https://www.mmi.mit.edu/courses

11.449/11.149

Jinhua Zhao, Andrew Salzberg

DECARBONIZING URBAN MOBILITY

This summer's extreme weather and the just-released IPCC report have brought renewed attention to the urgent need to drive global carbon dioxide emissions to zero by 2050. Transportation is the single largest source of those emissions in the United States, and a major source globally. What combination of policy, technology, behavior change, and investment is best positioned to accelerate the decarbonization of urban mobility? A new course from MIT Mobility Initiative and DUSP Prof. Jinhua Zhao and transportation & climate change professional Andrew Salzberg will grapple with this question, drawing from the latest research and industry trends.

Sustainability, Decarbonizing

Climate change

1.253/11.543

Fred Salvucci

TRANSPORTATION POLICY, THE ENVIRONMENT, AND LIVABLE COMMUNITIES

Examines the economic and political conflict between transportation and the environment. Investigates the role of government regulation, green business and transportation policy as a facilitator of economic development and environmental sustainability. Analyzes a variety of international policy problems, including government-business relations, the role of interest groups, non-governmental organizations, and the public and media in the regulation of the automobile; sustainable development; global warming; politics of risk and siting of transport facilities; environmental justice; equity; as well as transportation and public health in the urban metropolis. Provides students with an opportunity to apply transportation and planning methods to develop policy alternatives in the context of environmental politics. Students taking graduate version complete additional assignments.

Transportation Policy, Environmental Justice, Equity

Equity, Public Health

16.485

Luca Carlone

VISUAL NAVIGATION FOR AUTONOMOUS VEHICLES

Covers the mathematical foundations and state-of-the-art implementations of algorithms for vision-based navigation of autonomous vehicles (e.g., mobile robots, self-driving cars, drones). Topics include geometric control, 3D vision, visual-inertial navigation, place recognition, and simultaneous localization and mapping. Provides students with a rigorous but pragmatic overview of differential geometry and optimization on manifolds and knowledge of the fundamentals of 2-view and multi-view geometric vision for real-time motion estimation, calibration, localization, and mapping. The theoretical foundations are complemented with hands-on labs based on state-of-the-art mini race car and drone platforms. Culminates in a critical review of recent advances in the field and a team project aimed at advancing the state-of-the-art.

Vision-Based Navigation, Autonomous Vehicle, Simulation

Safety

14.43/15.020

Jing Li

ECONOMICS OF ENERGY, INNOVATION, AND SUSTAINABILITY

Covers energy and environmental market organization and regulation. Explores economic challenges and solutions to transforming energy markets to be more efficient, accessible, affordable, and sustainable. Applies core economic concepts - consumer choice, firm profit maximization, and strategic behavior - to understand when energy and environmental markets work well and when they fail. They also conduct data-driven economic analysis on the trade-offs of real and proposed policy interventions. Topics include renewable generation sources for electricity, energy access in emerging markets, efficiency programs and fuel efficiency standards, transitioning transportation to alternative fuels, measuring damages and adaptation to climate change, and the effect of energy and environmental policy on innovation.

Energy and Environment, Alternative Fuels, Policy and Regulation

Economics

Course aim: Equip you with foundations & methods for future transportation systems

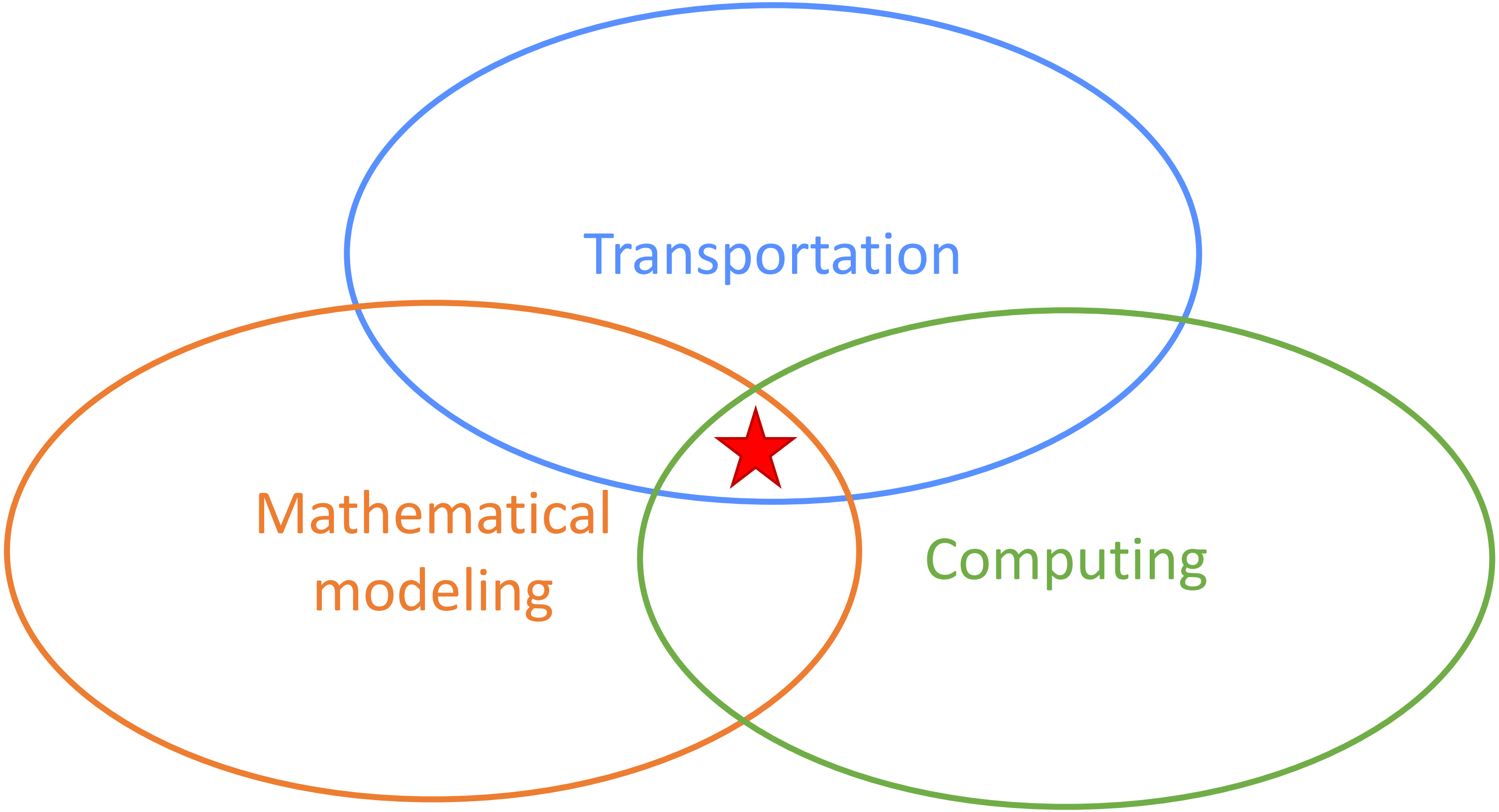
Mathematical modeling

Computing

Understanding the complex interactions among the articulated societal goals, transportation itself, and the foundational factors and policy levers is essential for transportation to be successful in contributing positively toward a thriving society. These interactions are discussed in more detail in the individual sections that follow, each of which corresponds to a box in Figure 1. Research and development (R&D) that accounts for the multi-faceted issues and interactions among the foundational factors and policy drivers, their transportation influences, and the achievement of societal goals will inform better policy choices to increase transportation's contributions to a thriving society.

Critical Issues in Transportation for 2024 and Beyond. Washington, D.C.: National Academies Press, 2024. doi: 10.17226/27432.

Transportation: Foundations & Methods



1.041J (UG) 1.200J (G)

Transportation: Foundation and Methods

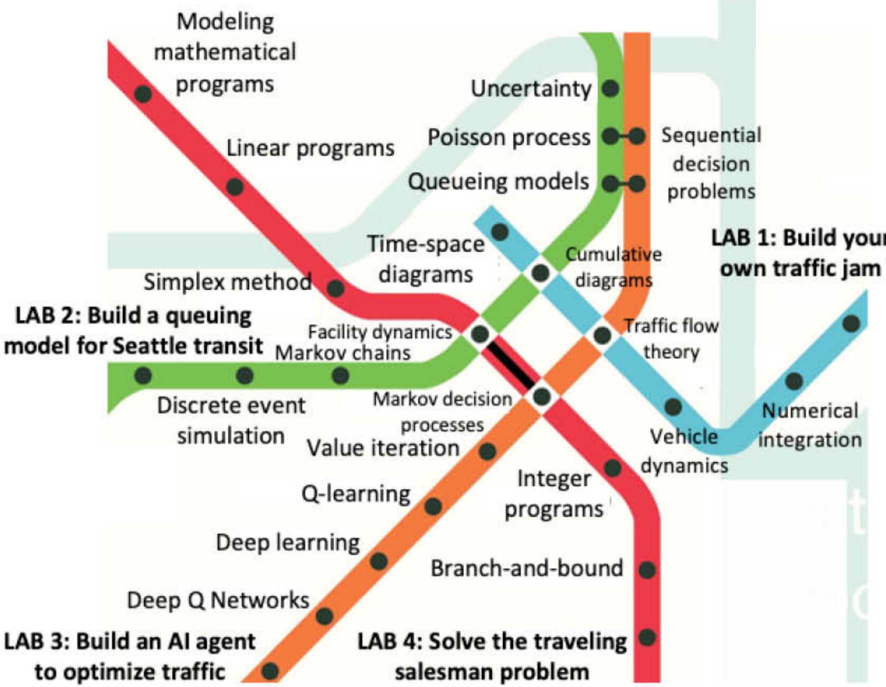
Weds & Fri
2:30–4:00 PM
1-135

Instructor:
Prof. Cathy Wu

What is the right mathematical tool for the right problem?

Learn systems engineering through transportation &

Gain practical skills with four fun computational labs



Civil and Environmental Engineering

Sustainability starts with Course 1

cee.mit.edu

Big picture overview of the course

Model transportation systems

- Unit 1 — Deterministic
- Unit 2 — Stochastic

Optimize transportation systems

- Unit 3 — Multi-stage
- Unit 4 — Single-stage

What we feel when we hear “traffic”

Traffic is not good or bad

Dictionary

Definitions from Oxford Languages · Learn more

traf·fic

/ˈtrafik/

noun

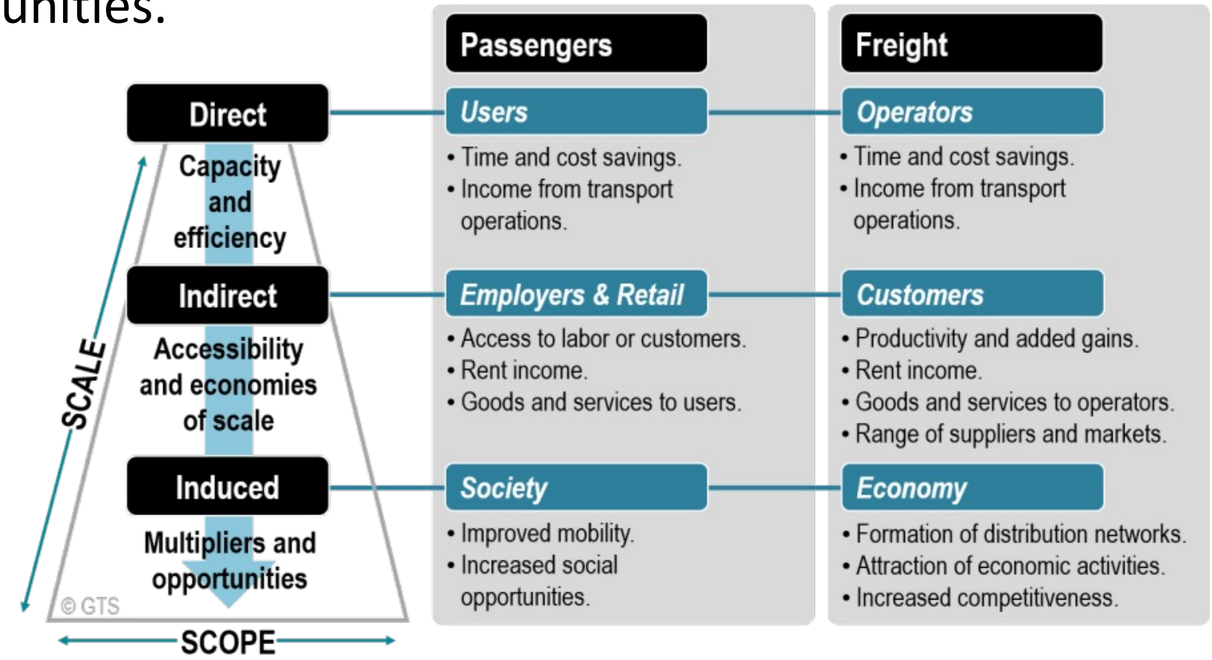
noun: **traffic**

1. vehicles moving on a road or public highway.
   "a stream of heavy traffic"

e.g., cars, pedestrians, trucks, trains, ships, planes, even robots and satellites

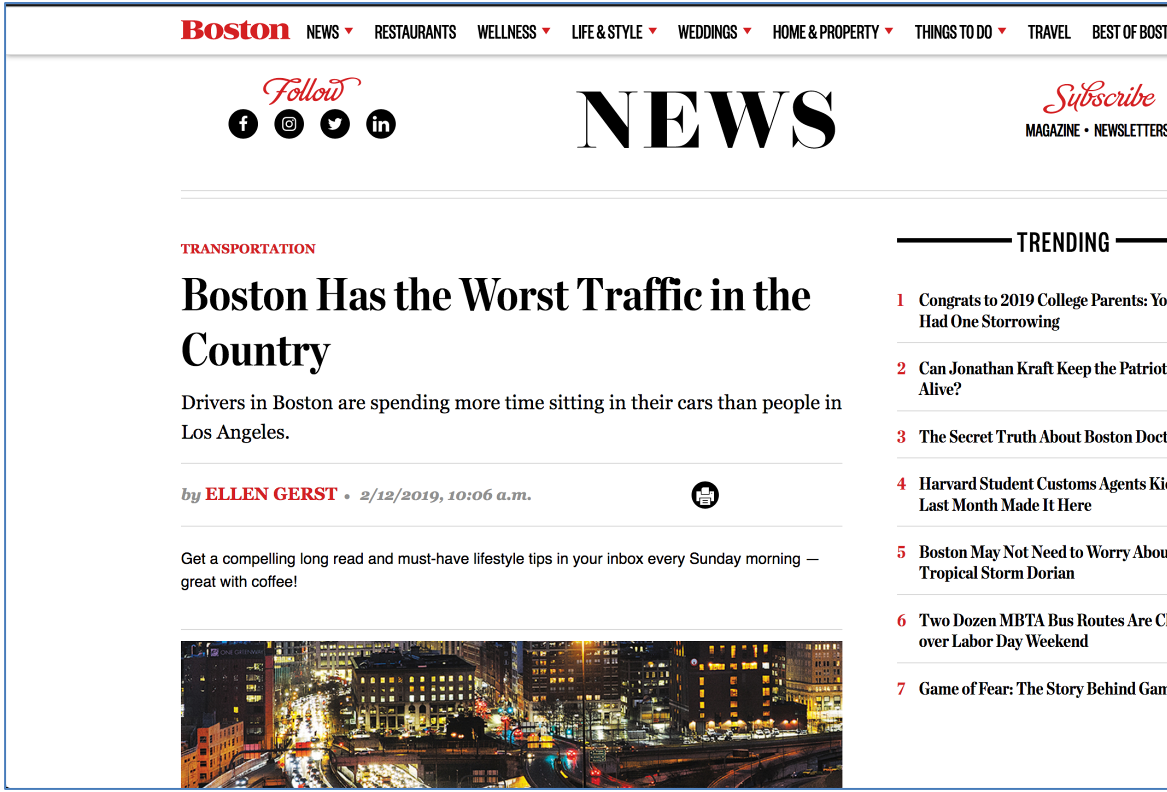
Traffic managed well

- Transportation can account for **half the GDP** of an advanced economy.
- Transportation as a positive **multiplier** of economic benefits & social opportunities.



Traffic managed poorly

#	U.S. city	Hours lost per year per driver
1	**Boston**	**164**
2	Washington, D.C.	155
3	Chicago	138
4	Seattle	138
5	New York City	133
6	Los Angeles	128


Boston NEWS RESTAURANTS WELLNESS LIFE & STYLE WEDDINGS HOME & PROPERTY THINGS TO DO TRAVEL BEST OF BOST

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TRANSPORTATION

Boston Has the Worst Traffic in the Country

Drivers in Boston are spending more time sitting in their cars than people in Los Angeles.

by ELLEN GERST • 2/12/2019, 10:06 a.m.

Get a compelling long read and must-have lifestyle tips in your inbox every Sunday morning — great with coffee!

TRENDING

1 Congrats to 2019 College Parents: Yo Had One Storrowing

2 Can Jonathan Kraft Keep the Patriot Alive?

3 The Secret Truth About Boston Doct

4 Harvard Student Customs Agents Ki Last Month Made It Here

5 Boston May Not Need to Worry Abou Tropical Storm Dorian

6 Two Dozen MBTA Bus Routes Are C over Labor Day Weekend

7 Game of Fear: The Story Behind Gam

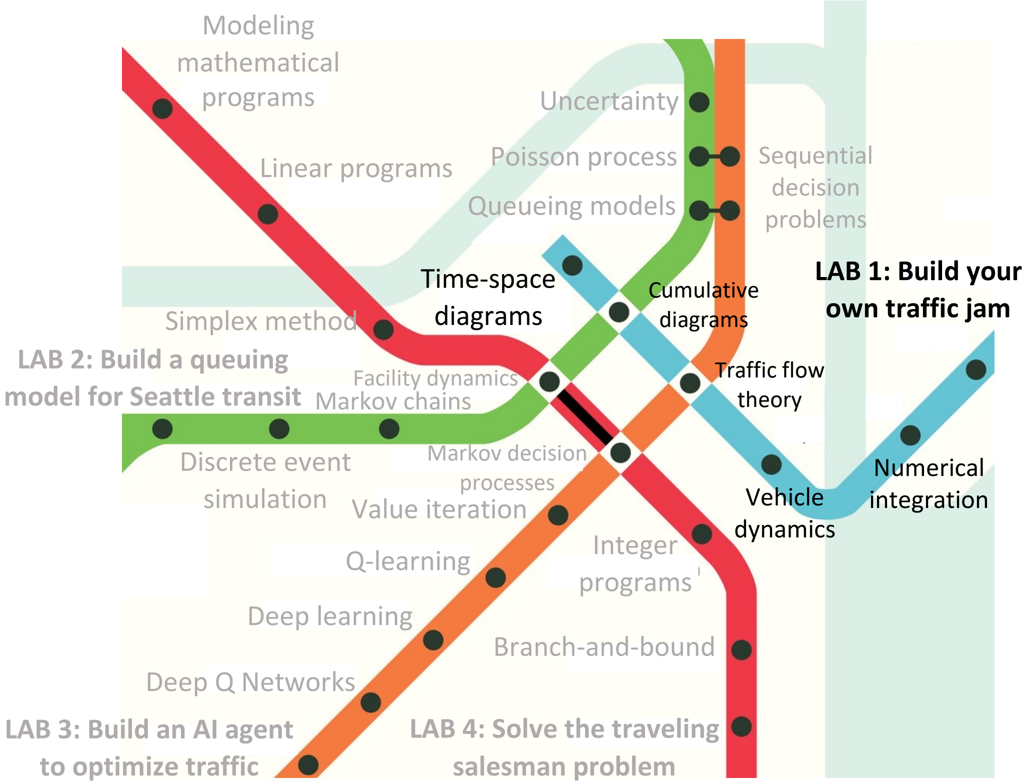
Sources:
Boston.com
Boston Magazine
[February, 2019]

Unit 1: Traffic flow fundamentals

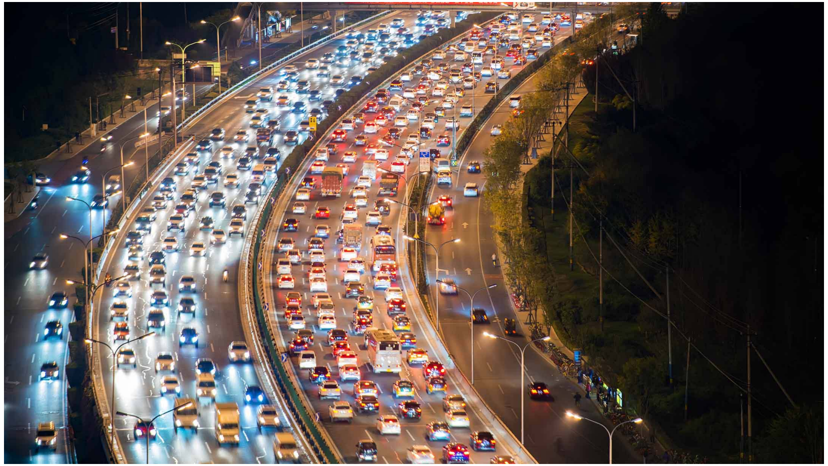
Unit 1

Modeling

Deterministic



Computational lab #1: Build your own traffic jam



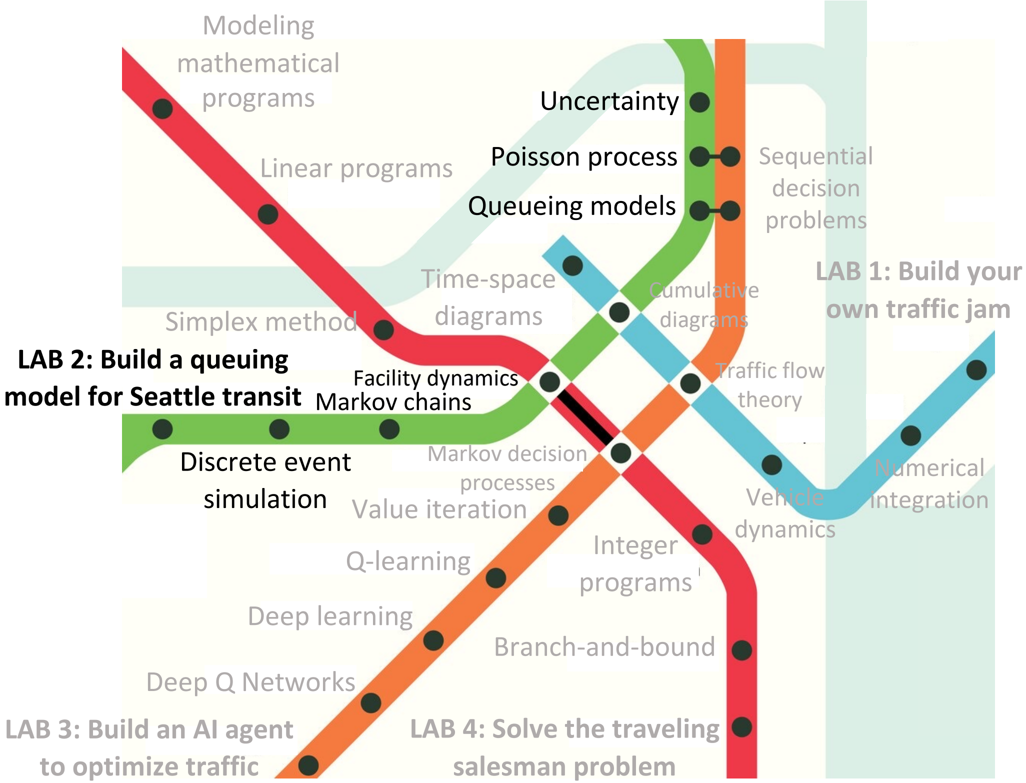
Unit 2: Queuing systems

Unit 2: Queuing systems

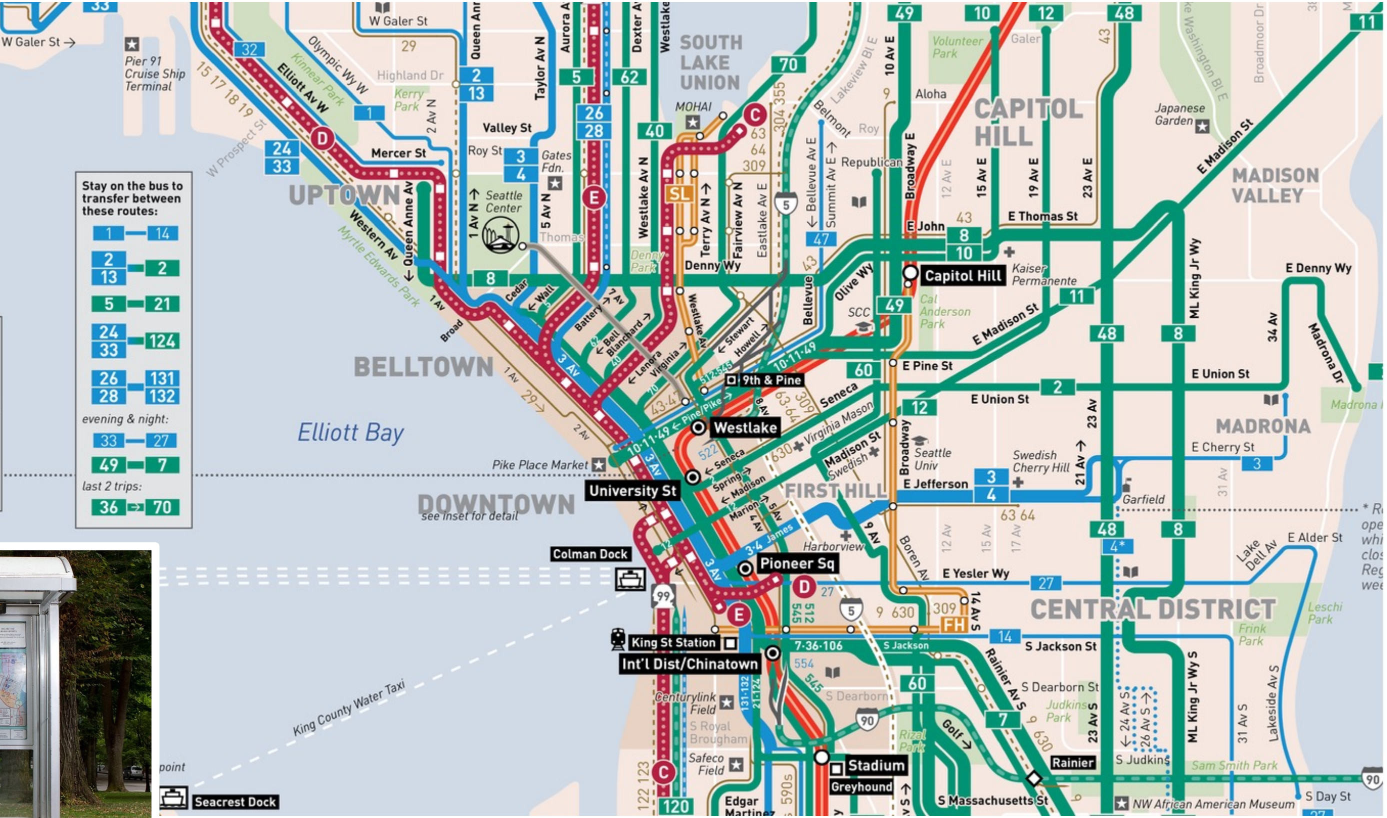
Unit 2

Modeling

Stochastic



CL#2: Build a queuing model for Seattle transit



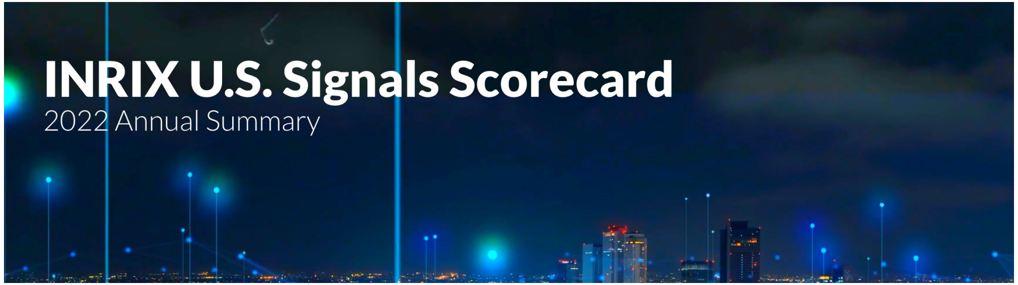
Unit 3: Machine learning for traffic control

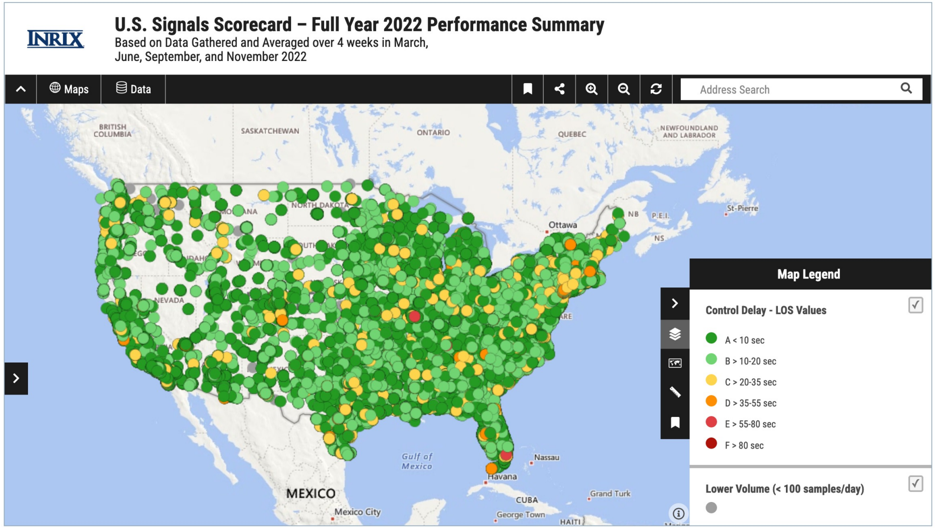
Unit 3

Optimizing

Multi-stage

Traffic control is still hard



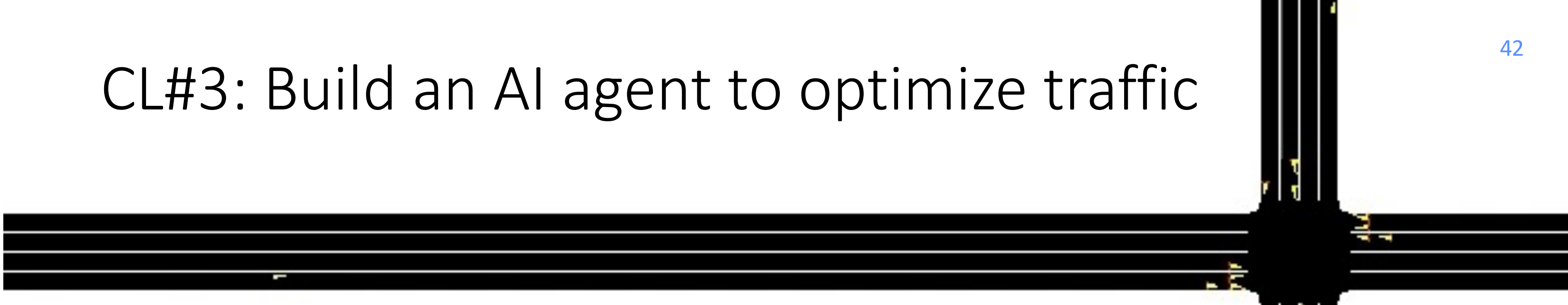


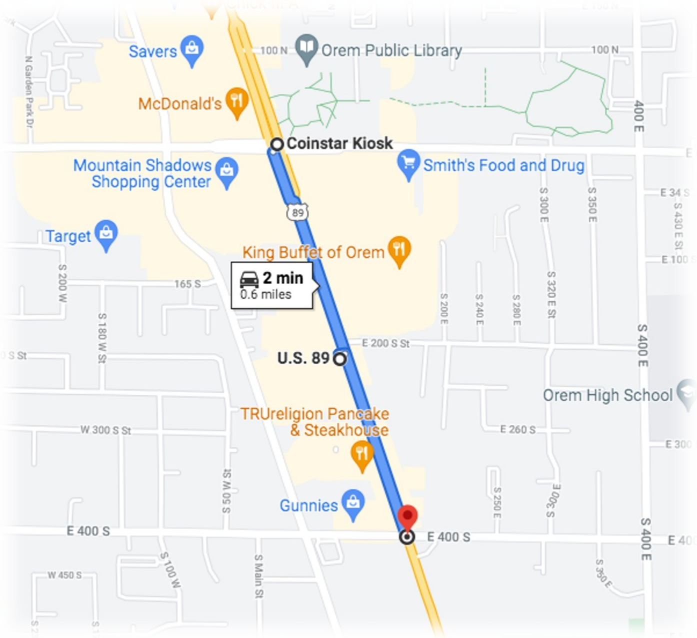
Inputs	Results
~5 Billion Total Number of Observed Crossings Used to Generate Results	**23,308** Intersection Avg Daily Traffic
~10 Million Number of Connected Vehicles Providing Location and Movement Data	**18.1** Seconds of Delay Per Vehicle
2022 Quarterly Data Collection: Mar 21-27, Jun 13-19, Sep 19-25, Nov 1-7	**63.5%** Arrival on Green
242,757 Signalized Intersections Analyzed	**117.4** Total Hours of Daily Delay
All 50 States (Plus District of Columbia)	**2.53 Days** Days to Generate 1 Metric Tonne of Carbon Emissions From Delay
400+ Regions; **1,150+** Counties	**0.97 Days** Days to Consume 1 Barrel of Oil From Delay

Results: **Average Traffic Signal**

INRIX U.S Signals Scorecard: 2022 Annual Summary. INRIX. https://inrix.com/signals-scorecard/.

CL#3: Build an AI agent to optimize traffic



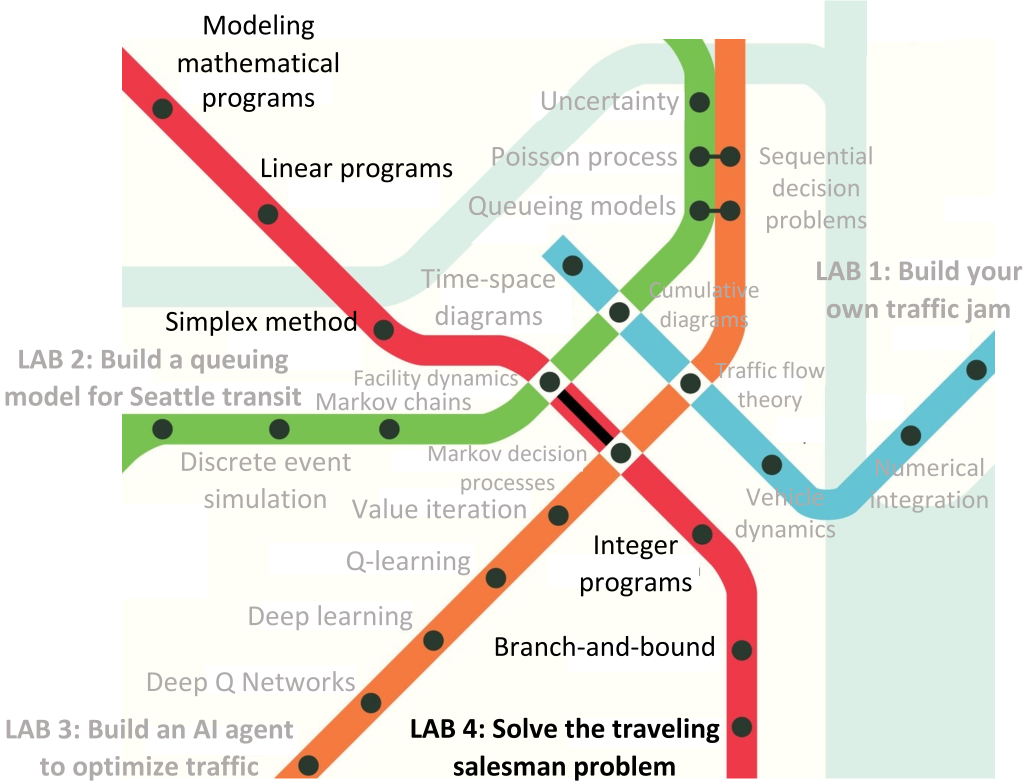


Unit 4: Optimizing transportation resources

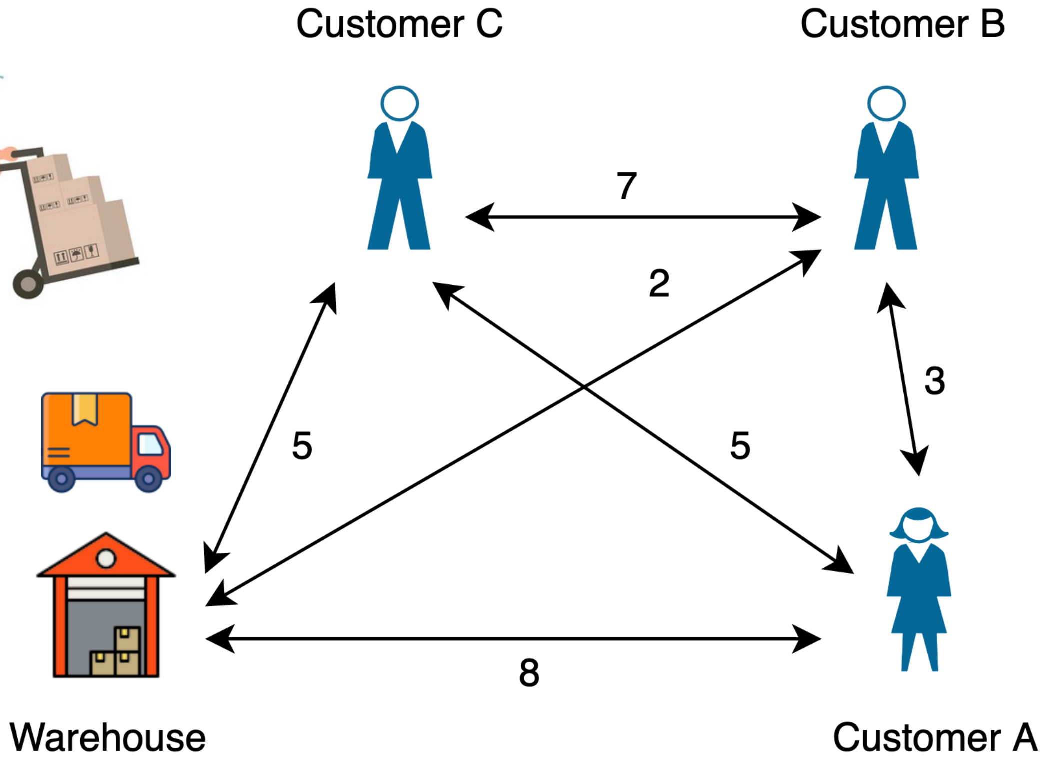
Unit 4

Optimizing

Single-stage



CL#4: Solve the traveling salesman problem



Course objectives

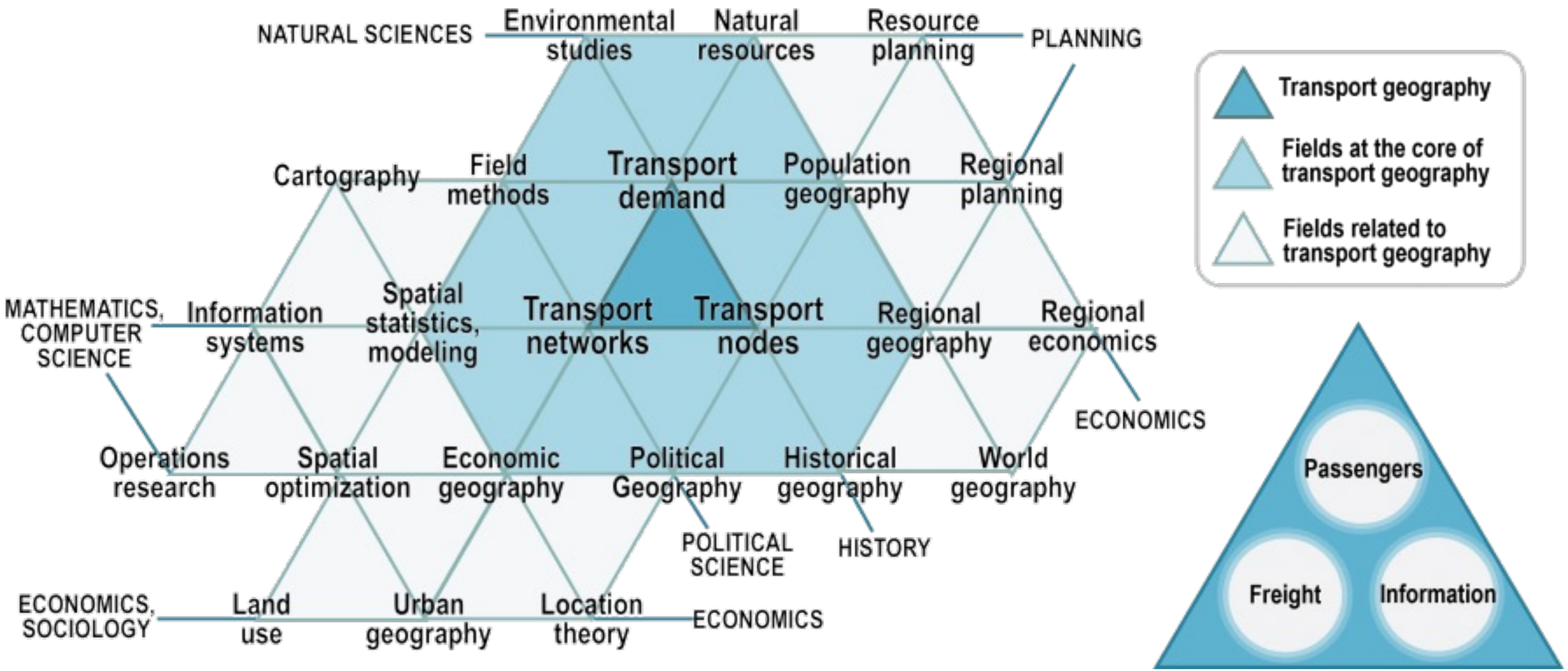
1. Introduction to techniques to **design, analyze, evaluate and control** the level of service of various **transportation systems**.
2. Introduction to **powerful modeling foundations**: queueing theory, reinforcement learning, mathematical programming
3. Special emphasis on **computational methods** and their application to transportation. Hands-on computational assignments. **Requires proficiency in Python.**

Discussion time

What is something that has nothing to do with transportation?

Transportation spans a lot of fields

- Transportation studies is intertwined with just about every department at MIT



Jean-Paul Rodrigue, The Geography of Transport Systems (2020) – Chapter 1

Ask questions

- Make the class your own by asking questions
  - In class, on Piazza, office hours, email us, etc.

- Transportation touches all of our lives, most parts of human endeavors, many many technical tools.

Outline

Team

- Prof. Cathy Wu <cathywu@mit.edu>
  - Office hours: WF4-4:30 (1-135)
- TAs:
  - Dingyi Zhuang <dingyi at mit dot edu>
- Staff email: 1-041-staff@mit.edu or 1-200-staff@mit.edu
- You can reach the staff generally via office hours or via email. **<u>Include "[1.041]" or "[1.200]" in your subject line.</u>**

Administrivia

- Lectures: WF 2:30 - 4:00 pm (1-135)
  - We will make lecture recordings available for review
  - We can’t guarantee the quality of the recordings (come to class! 😉)
- Recitations: TBD (**see Piazza for poll**)
- Check website & Piazza for the most up-to-date information.

- **Course webpage**: For class materials & info
  - https://web.mit.edu/1.041/www/
- **Piazza**: For class announcements, assessments, solutions
  - The Piazza is also a resource for you to collaborate with one another.
  - For obvious reasons, don't post answers in Piazza.
  - We (the staff) can’t answer each question on Piazza, so do come to office hours.
- **Gradescope**: For HW/quiz submissions
- **Canvas**: Code/project submissions, Zoom (in case of going remote)

Textbooks

- Unit 1: Daganzo, Carlos. **Fundamentals of transportation and traffic operations**. Emerald Group Publishing (2008).
  - Available online: http://ndl.ethernet.edu.et/bitstream/123456789/75532/1/66.pdf
- Unit 2: Larson, Richard C. and Amedeo R. Odoni. **Urban Operations Research**. Prentice-Hall (1981).
  - Available online: https://web.mit.edu/urban_or_book/www/book/
- Unit 3: Morales, Miguel. **Grokking deep reinforcement learning**. Manning Publications (2020).
  - Available online: https://www.manning.com/books/grokking-deep-reinforcement-learning
- Unit 4: Bradley, Stephen P., Arnoldo C. Hax, and Thomas L. Magnanti. **Applied mathematical programming**. Addison-Wesley (1977).
  - Available online: https://web.mit.edu/15.053/www/AppliedMathematicalProgramming.pdf
- Additional handouts will be distributed as needed.
- Lecture slides will be posted.

Evaluation

- Grades will be determined according to the following weights:
  - Undergraduate students:
    - 4 problem sets, including 4 computational labs (60%)
    - (Optional) Submit a video on any class topic for +5% extra credit
  - Graduate students:
    - 4 problem sets, including 3 computational labs (choose any of 4) (45%)
    - Class project (15%, with +5% extra credit for video submissions)
  - 2 in-class quizzes (30%)
  - Class participation (10%)
- Late policy (for PSets):
  - 3 late days, no questions asked. After that, late homework will be penalized 10% every 24 hours. Those submitting late must abide by honor code.
- PSet partners:
  - Check out https://psetpartners.mit.edu to find pset partners.
  - Sign up early; matching will be done at the end of the first week of classes.

Assignments

Assignments	Covers
Problem Set 1 **Problem Set 2** **Computational problem 1**	Unit 1
Problem Set 3 **Computational problem 2**	Unit 2
Problem Set 4 **Computational problem 3**	Units 3
Problem Set 5 **Computational problem 4**	Units 4
Project presentation + report **(Optional) Video**	Any unit

Class participation

- Class participation includes:
  - Live participation during lectures.
  - Answering questions for fellow students on Piazza.
  - Attending office hours and recitation.

Class project (grad students only)

- Groups of 1-2 are permitted.
- (Optional) Students may opt to do a video presentation
- Research project, which seeks to establish new knowledge in transportation research fields.
  - Project proposal
  - **Written report**
  - In-class presentation

Academic integrity & collaboration

- Bottom line:
  1. Use whatever sources you need to support your learning.
  2. **Cite your sources.**
  3. **No copying.** You must write up your own solutions.
  4. Don't allow others to copy your work.

- This applies to collaborators, a "friendly expert," another text, website, or a "bible."
- Also applies for use of Generative AI (GenAI) tools
  - Help with writing is fine, encouraged, and does not need to be cited.

- In general, use basic, common sense concepts of academic honesty.
- See the full academic integrity policy on course website.

http://web.mit.edu/academicintegrity/handbook/handbook.pdf

Break

If you have questions about registration, now is a good time.

Outline

1. About the course

2. **A nontechnical introduction to transportation**

   a. **Past: A brief history**

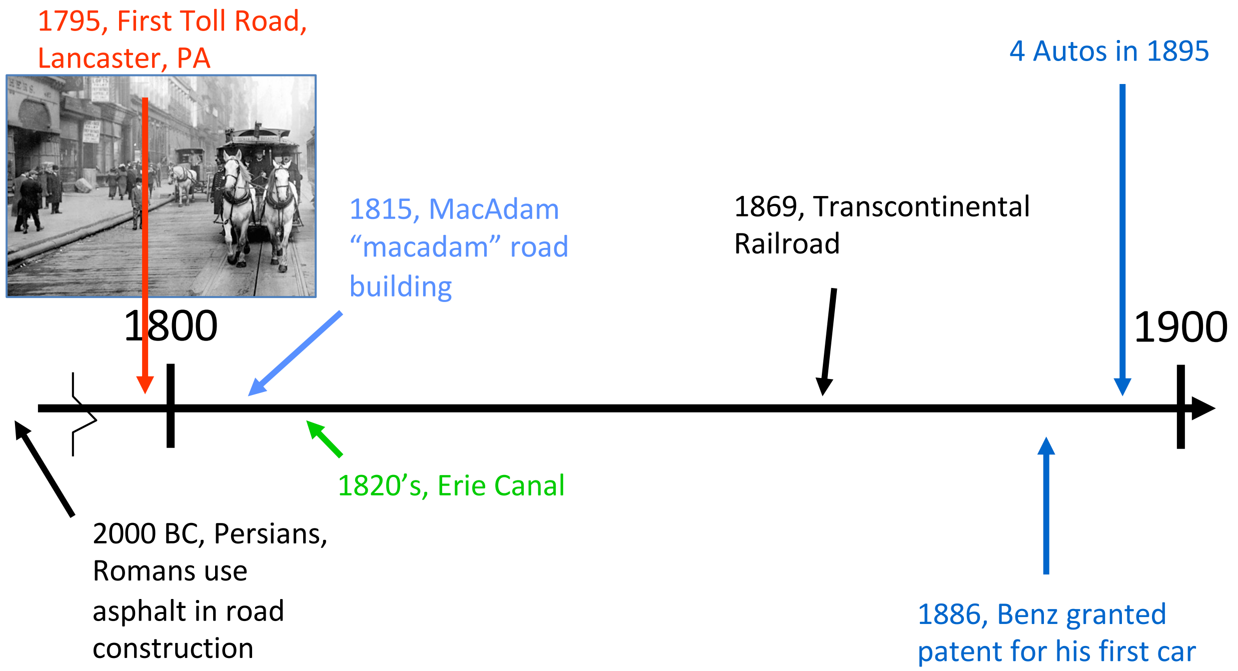
   b. Present: Three revolutions

   c. Future: Mega trends

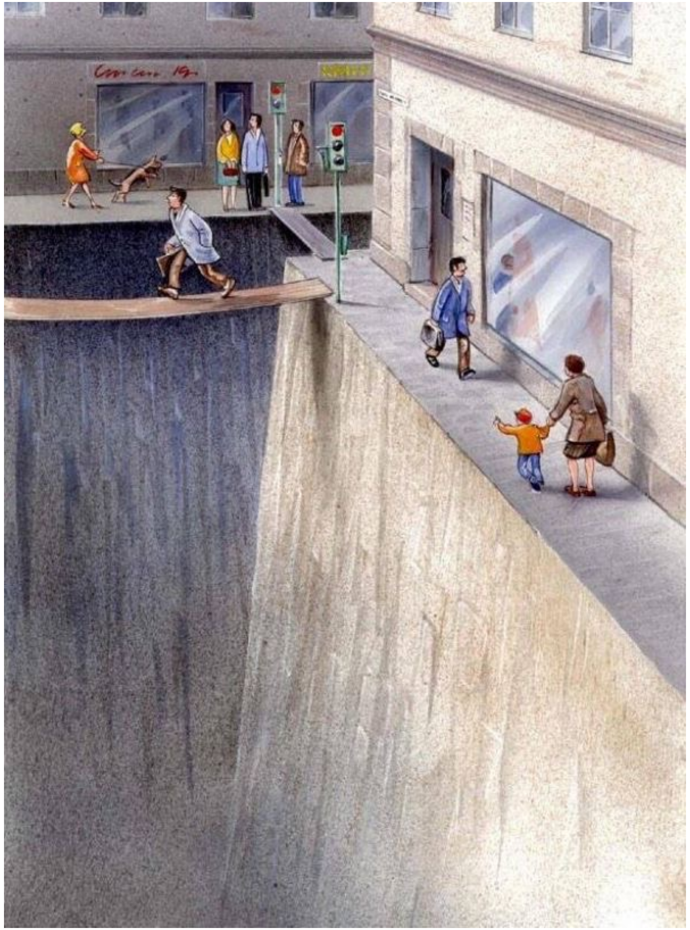
3. Why I study transportation

Automobility is a relatively recent phenomenon

- We have had asphalt roads for 4000+ years.
- We have had cars for 100 years.

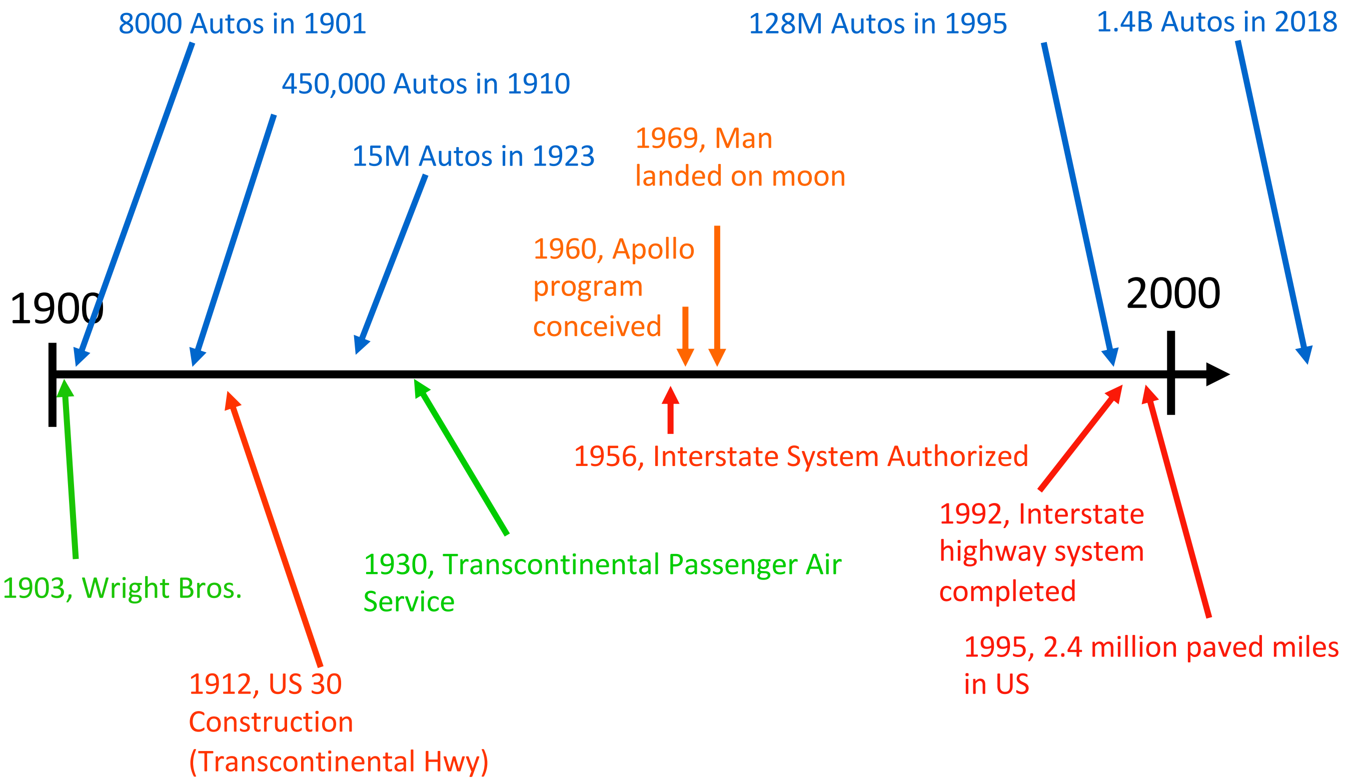


Today



Claes Tingvall (2014)

Timeline (1900—2000)



The Interstate Highway System

- Largest public works project in American history.
- Considered the greatest investment ever by the US.
  - Return on investment estimated at at least 6x.
- Cross country road trip: 62 days → 42 hours 😮
- Why such a big deal? Because the US is **huge**.
  - Connectivity is power.
  - Impact: The Interstate Highway System connected the vast spread of population centers of the US.


Wendover
INTERSTATE
1
The US' Greatest Ever Investment

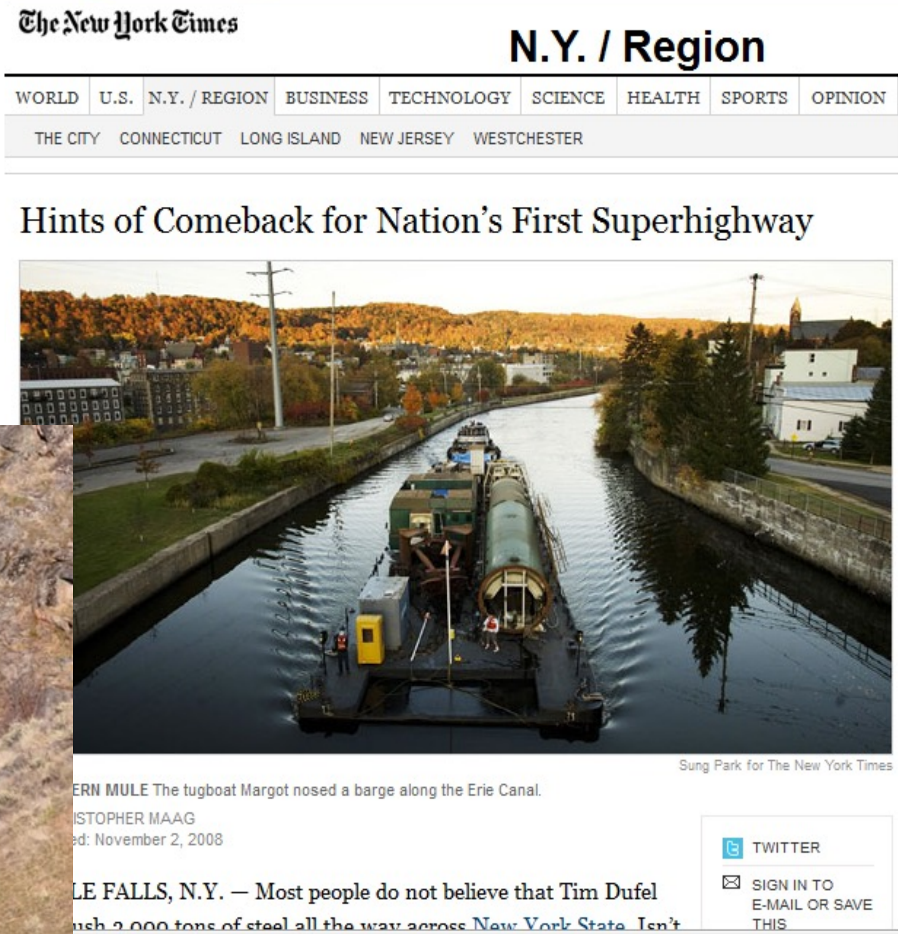
Landing a man on the moon
–vs–
Building the Interstate Highway System

What's harder? Why?

Erie canal (1825)

- Not just about roads.
- Planes, trains, ships, drones, bicycles, people, bison. Anything that moves through shared spaces.

(Wyoming, 2019)
Credit: Jacob W. Frank, National Park Service


The New York Times

N.Y. / Region

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

THE CITY | CONNECTICUT | LONG ISLAND | NEW JERSEY | WESTCHESTER

Hints of Comeback for Nation’s First Superhighway

Sung Park for The New York Times

ERN MULE The tugboat Margot nosed a barge along the Erie Canal.

ISTOPHER MAAG

ed: November 2, 2008

TWITTER

SIGN IN TO E-MAIL OR SAVE THIS

LE FALLS, N.Y. — Most people do not believe that Tim Dufel

ush 2,000 tons of steel all the way across New York State. Isn’t

Outline

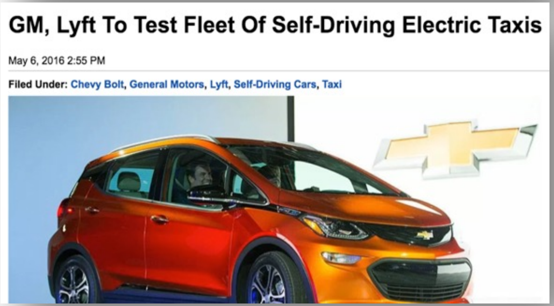
1. About the course
2. A nontechnical introduction to transportation
   a. Past: A brief history
   b. **Present: Three revolutions**
   c. Future: Mega trends
3. Why I study transportation

Vehicular CPS “revolutions” are currently underway

- *“The auto industry will change more in the next 5-10 years than it has in the last 50”*
  - M. Berra (GM), 2016

- Daniel Sperling (UC Davis): “Three revolutions”
  - electrification
  - automation (& connectivity)
  - sharing

- Shared = Uber, Lyft, Blue Bikes
- Shared + electric = Bird, Lime
- Electric + automated = Tesla
- Electric + automated + shared = Waymo, GM Cruise


GM, Lyft To Test Fleet Of Self-Driving Electric Taxis

May 6, 2016 2:55 PM

Filed Under: Chevy Bolt, General Motors, Lyft, Self-Driving Cars, Taxi

Timeline (2000—Present & Future)

Physical infrastructure → Digital infrastructure

Some key events:

- 2000: Zipcar pioneers sharing of a vehicle.
- 2004/2007: DARPA grand challenges launch autonomous vehicle industry
- 2007: iPhone 1 unveiled → Smartphone adoption reaches 73% (2021)
- 2010: Google autonomous street view

Bonus event:

- 2010: SpaceX became the first privately funded company to successfully launch, orbit and recover a spacecraft

Transportation *cyber physical systems* (CPS)

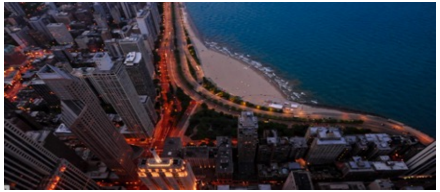
Phone based

(lifespan 18 months)

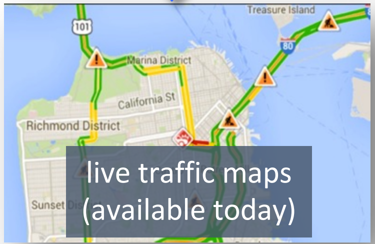
Vehicle based

(lifespan 10 years)

Infrastructure based



(lifespan 50-100+ years)

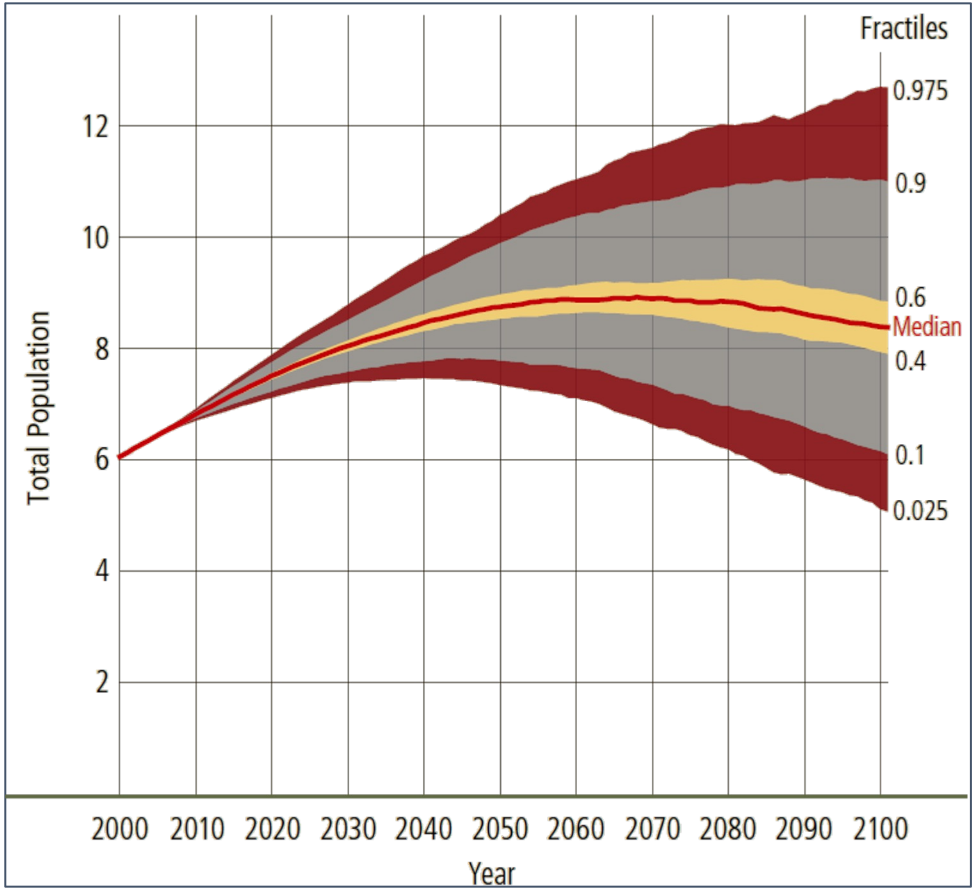


Outline

Transportation demands

- Growth of population
  - US: 300 million in 2006, 420 million in 2050
  - Larger growth in China and India

World population

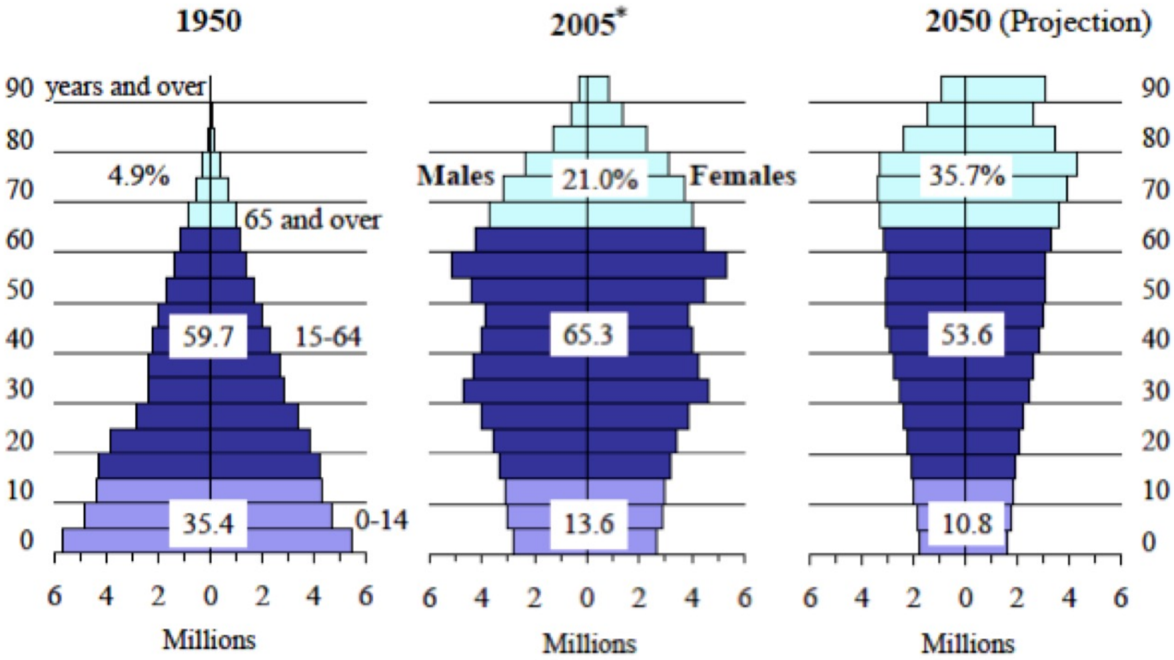


Rodney Brooks. Megatrend: The Demographic Inversion (2017)

Transportation demands

- Population inversion:
  - “Senior tsunami” from baby boomers
  - Decline in birth rate

Japanese age groups



Rodney Brooks. Megatrend: The Demographic Inversion (2017)

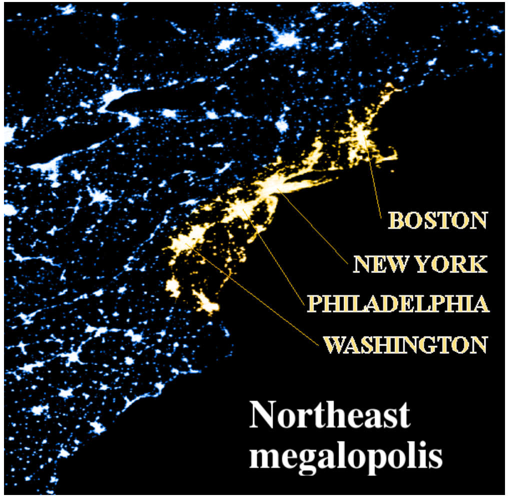
Urbanization

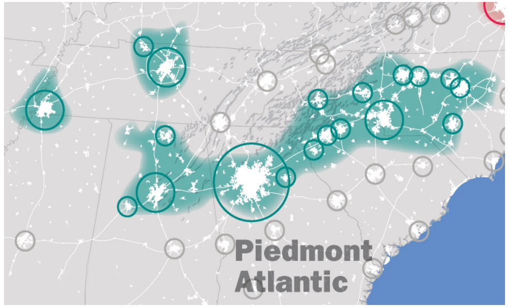
- Since 2006 more than half the world population lives in urban areas
- By 2050, expected to grow to 80%

- Top 100 US metropolitan areas
  - Only 12% of the landmass, but
  - 65% of the population
  - 74% of the most educated citizens
  - 77% of knowledge economy jobs
  - 74% of GDP

Increasing criticality of key ports and corridors

- Growth of mega regions
  - Northeast, Northern California, etc.
- 1.9 million tractor-trailer trucks in 2005, up 13% since 2001
- Highway vehicle miles traveled (VMT) are projected to grow 60%
- Container ships volume expected to increase 186% in 20 years
- Doubling of freight traffic by train





Growing complexity of urban landscape

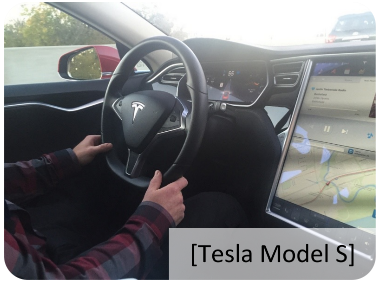
- More than half the jobs are more than 10 miles outside of downtown
- Growth of the "exit ramp economy" – low density developments along suburban freeways
- In 2005, more of America's poor live in metro suburbs than in the city core

Outline

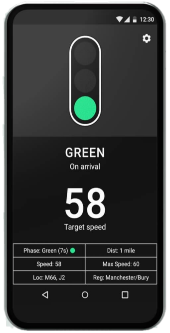
1. About the course
2. A nontechnical introduction to transportation
3. **Why I study transportation**

The gap between technology and societal impact

Waymo

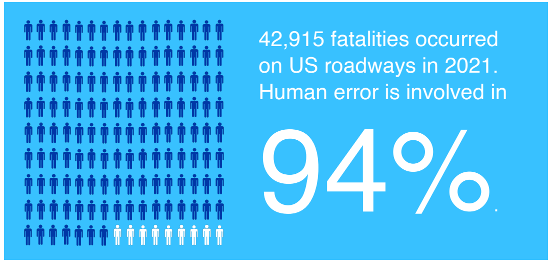


[Tesla Model S]



GLOSA Demo app [1]

Connected and automated vehicle (CAV) technologies

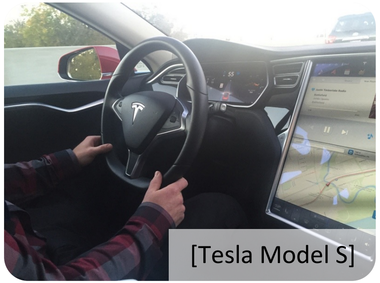


43K annual US fatalities, among leading causes of death of young people

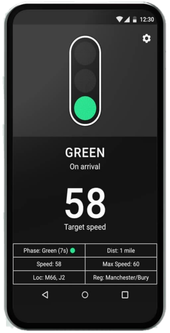
Road safety

The gap between technology and societal impact

Waymo



[Tesla Model S]



GLOSA Demo app [1]

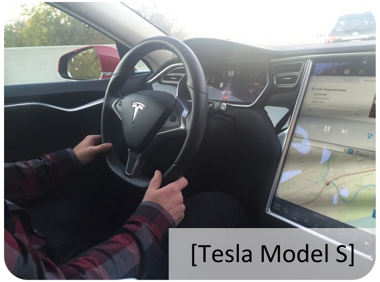
Connected and automated vehicle (CAV) technologies

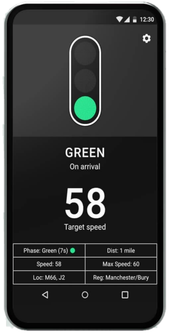
1 hour each day / American driver

Congestion

The gap between technology and societal impact


Waymo





GLOSA Demo app [1]

Connected and automated vehicle (CAV) technologies

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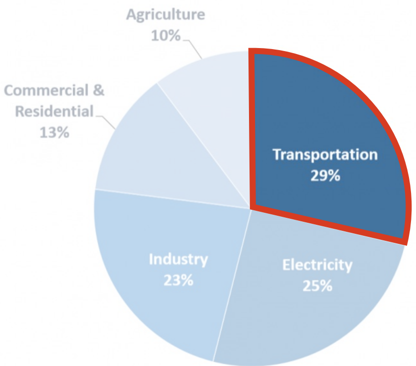
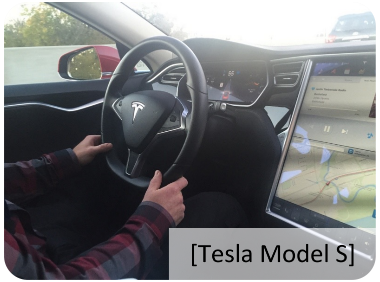


Transportation is the largest contributing sector of greenhouse gas emissions in the US at 29%, mostly on roadways

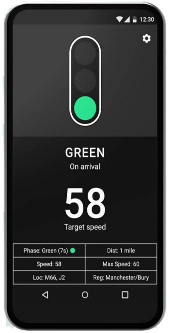
Environmental impact

The gap between technology and societal impact

Waymo



[Tesla Model S]



GLOSA Demo app [1]

Connected and automated vehicle (CAV) technologies

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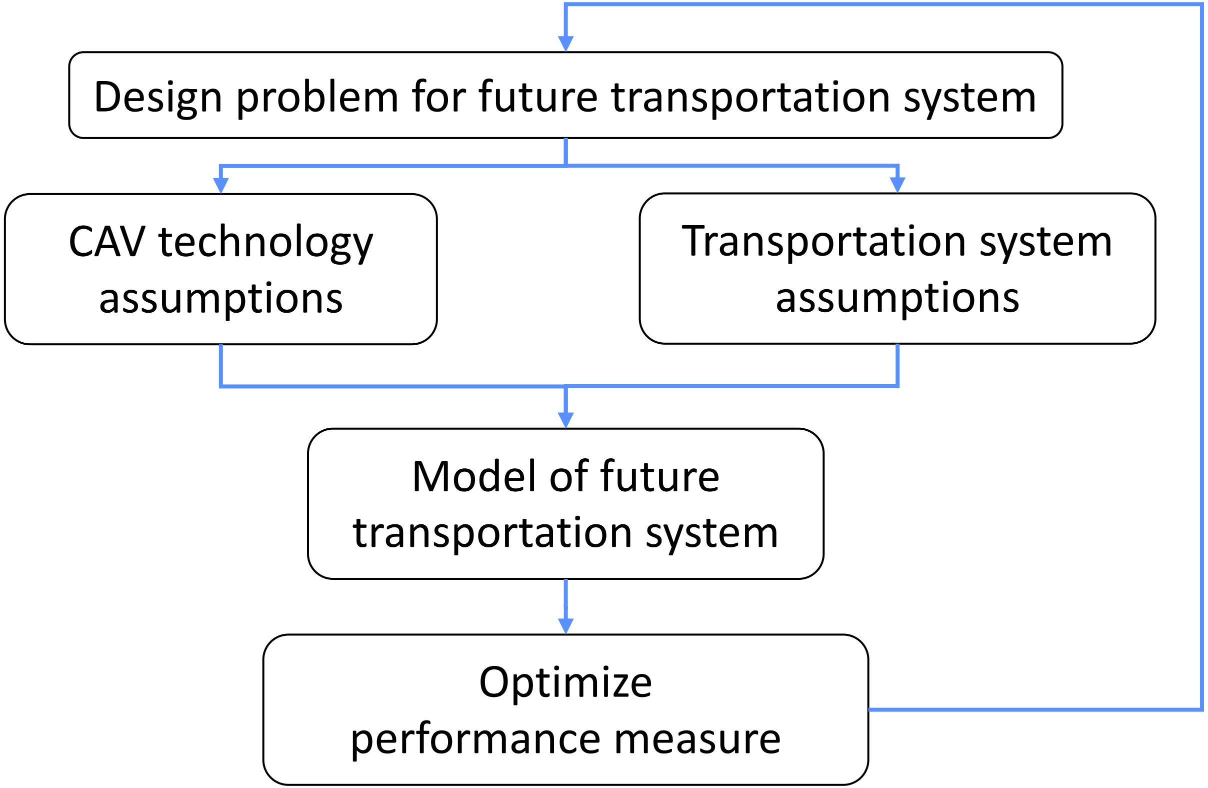
Equity

Access

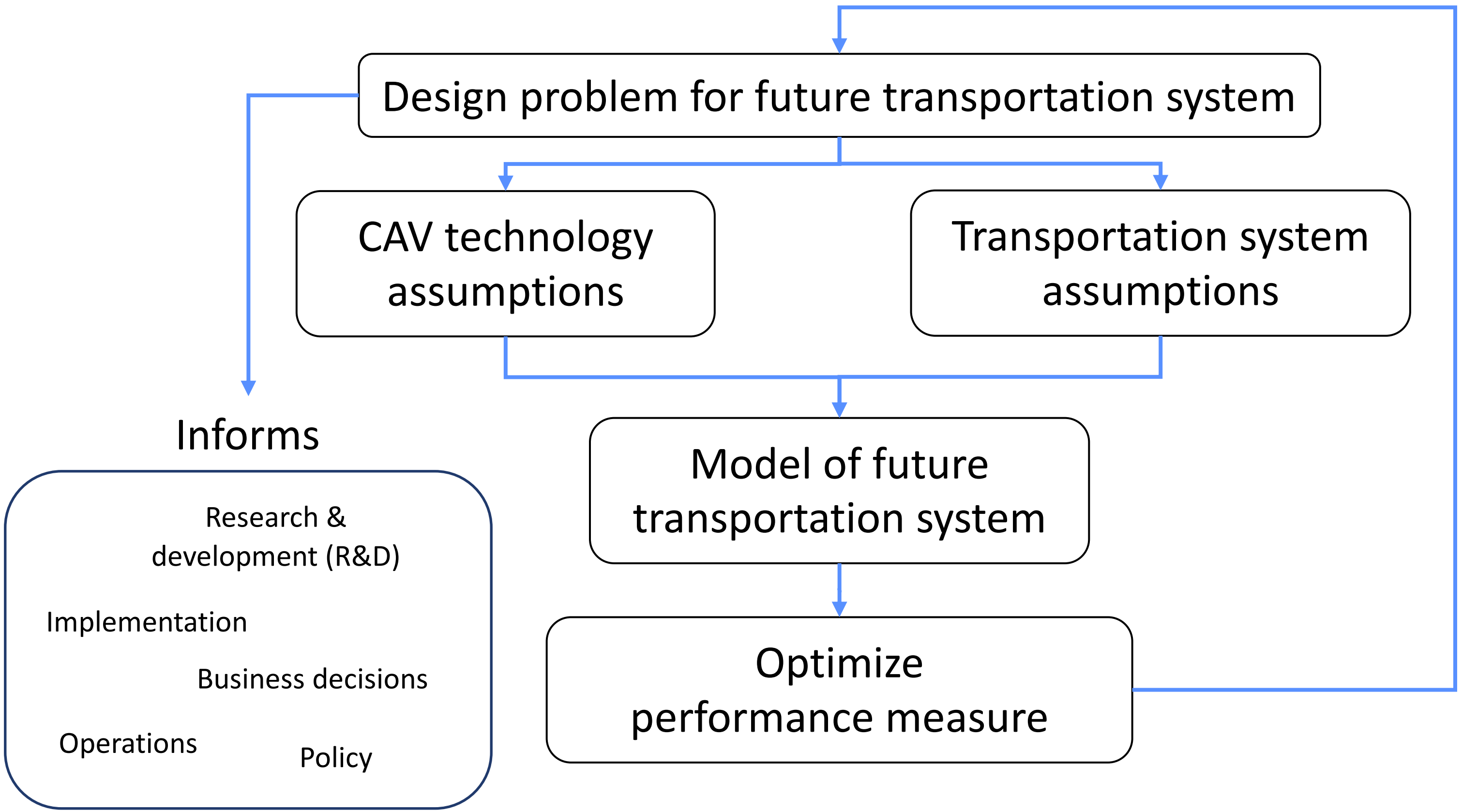
Public health

...

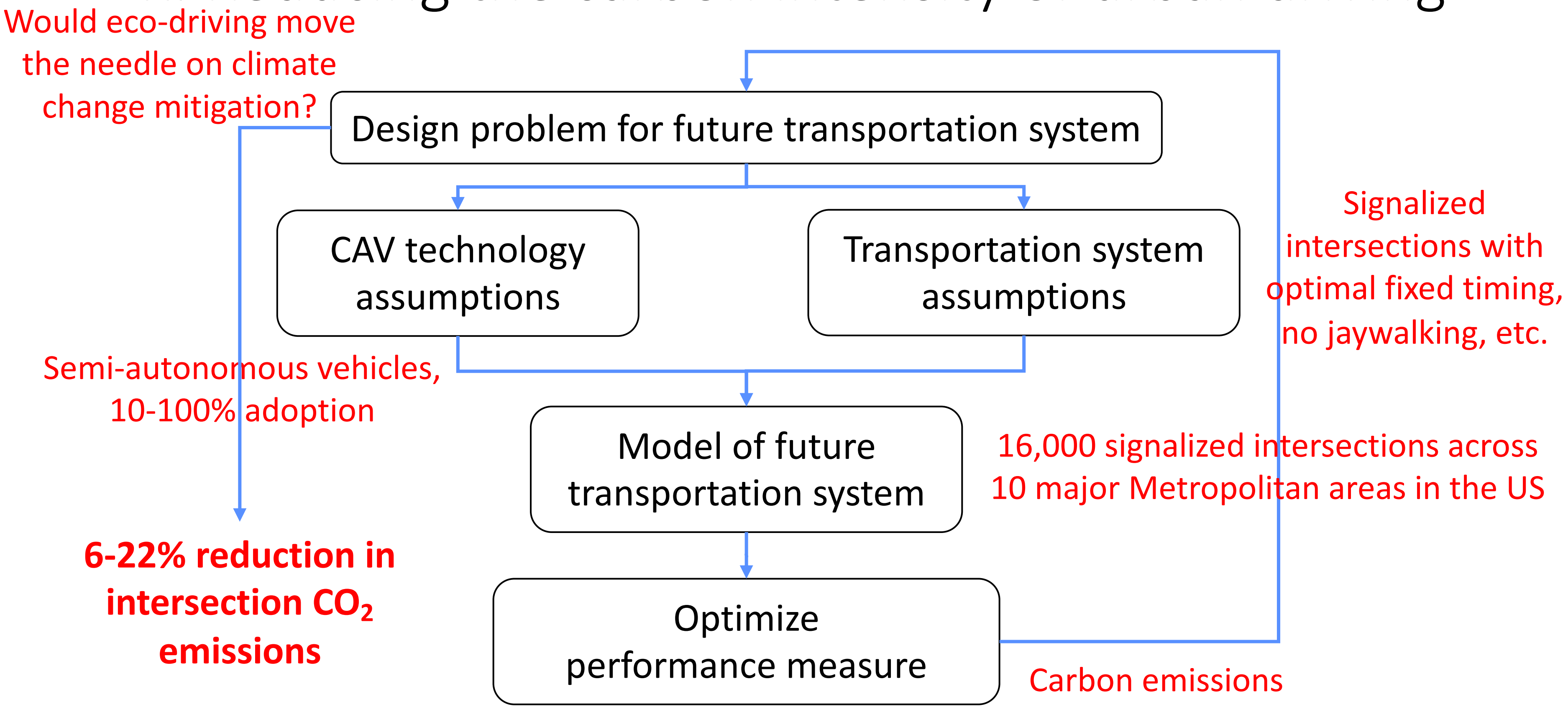
Basic research flow diagram



Basic research flow diagram



Ex: Reducing the carbon intensity of urban driving



Jayawardana, et al. "Mitigating Metropolitan Carbon Emissions with Semi-autonomous Vehicles using Deep Reinforcement Learning," in review.

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- Register to attend:
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- Diverse topics spanning mobility, broadly defined
- Great complement to this course

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References

1. Some slides adapted from:
   - Prof. Carolina Osorio (MIT 1.041)
   - Prof. Dan Work (Vanderbilt CE 3501)