Spring 2025

01 Introduction

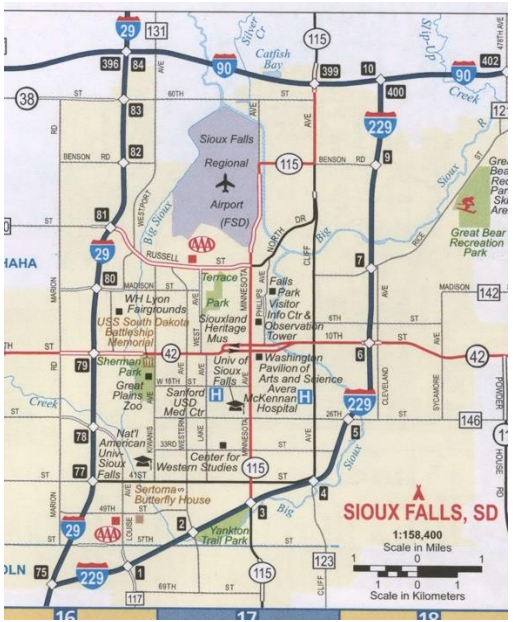
CIVIL-477 Transportation network modeling & analysis

École
polytechnique
fédérale
de Lausanne

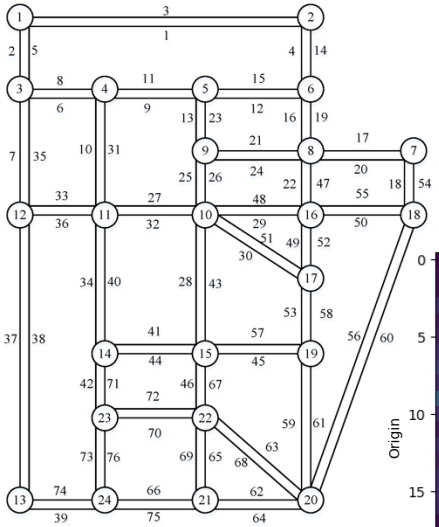
About this course

- Overview
  - An introduction to the classics and new advances in transportation network ***modeling*** and optimization.

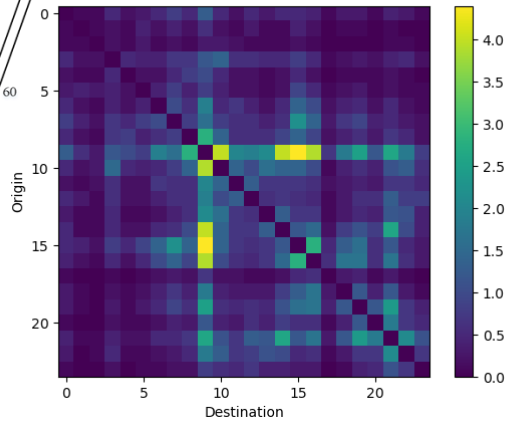
Real-world Scenario



Network



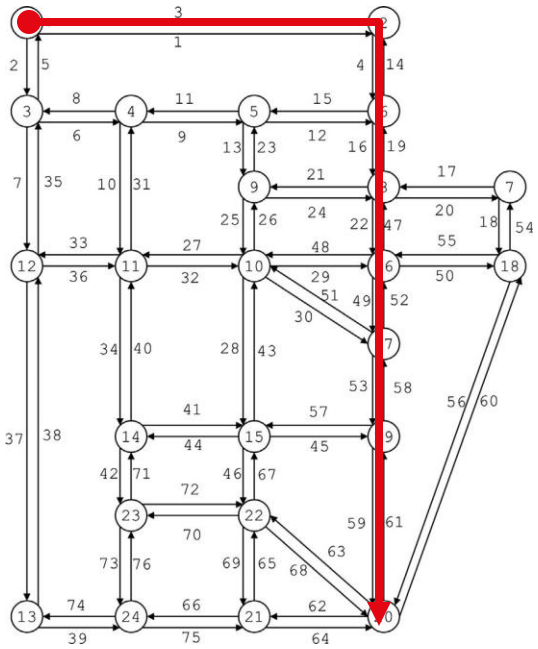
Demand



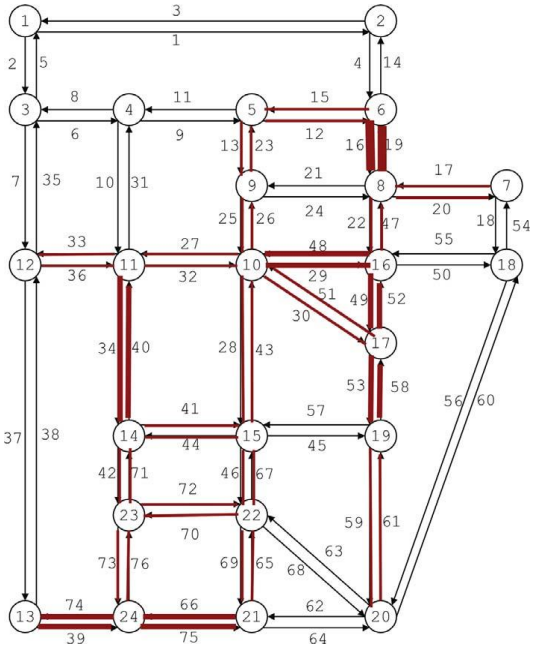
About this course

- Overview
  - An introduction to the classics and new advances in transportation network modeling and ***optimization***.

Shortest Path



Traffic Equilibrium



About this course

- Modules and topics
  - Basics
    - Network and route choice
    - Game theory and traffic equilibrium
    - Optimization primer
  - Classic traffic assignment
    - Static traffic assignment
    - Stochastic traffic assignment
  - Traffic demand management
    - Network and incentive design
  - Emerging topics
    - Shared mobility
    - Autonomous vehicles

About this course

- Schedule

Week	Date	Topic	
1	19.02	Introduction	Module 1: Basics
2	26.02	Network and route choice	
3	05.03	Game theory and traffic equilibrium	
4	12.03	Optimization primer	
5	19.03	Static traffic assignment: Base model I	Module 2: Classics
6	27.03	Static traffic assignment: Base model II	
7	02.04	Static traffic assignment: Extensions	
8	09.04	Stochastic traffic assignment	
9	16.04	Mid-term	
10	23.04	*Easter break*	
11	30.04	Traffic demand management	Module 3: Design
12	07.05	Emerging topic I: Shared mobility	Module 4: Emerging topics
13	14.05	Emerging topic II: Autonomous vehicles	
14	21.05	*(TBD)*	
15	28.05	Project: final presentation	

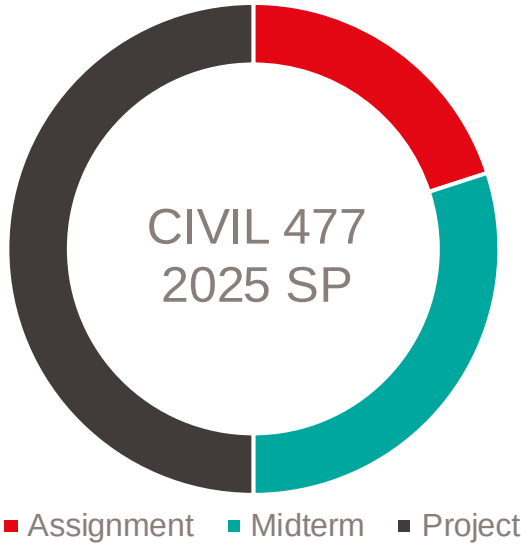
About this course

- Lecturers
  - Kenan Zhang
    - Director of HOMES
    - Assistant professor since Sep. 2023
    - PhD from Northwestern University
    - Contact: kenan.zhang@epfl.ch

  - Xuhang Liu
    - PhD at HOMES
    - Contact: xuhang.liu@epfl.ch

About this course

- Grading
  - Assignment (20%)
    - individual work, published after Module 1
    - one Q&A session before deadline, no late submission accepted
    - discussion with other students and ChatGPT is allowed but must be declared
  - Midterm (30%)
    - open-book and in-class
    - cover Modules 1 & 2
    - based on assignment
  - Project (50%)
    - individual or group of two
    - final presentation (20%), project report (30%)
    - topic selected from a candidate list or self-proposed



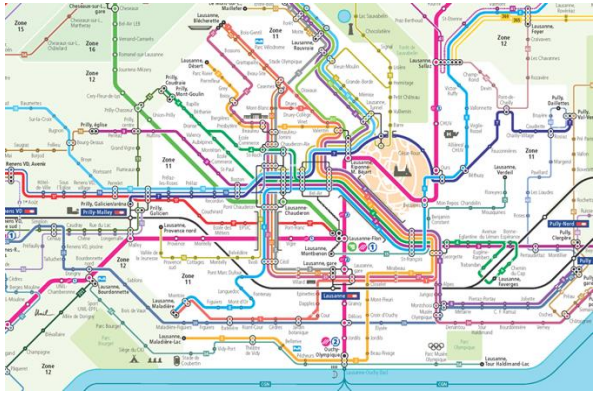
Questions?

What is a transportation network?

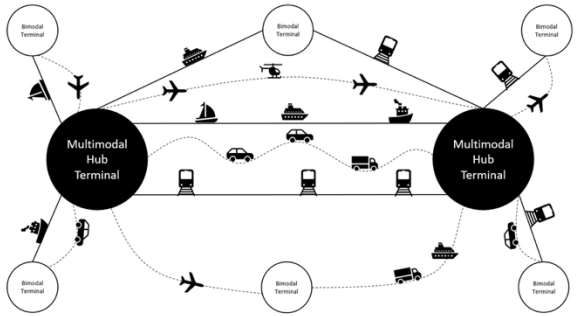
- Examples

Road Network

Rail Network



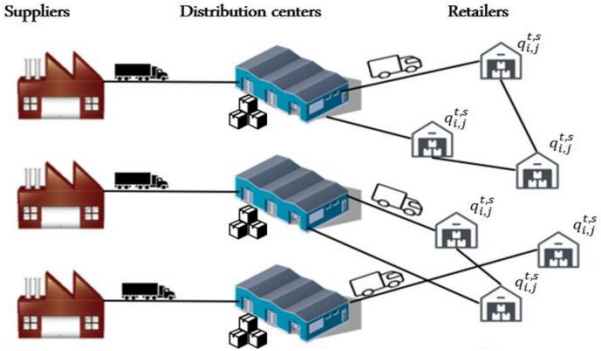
Transit Network



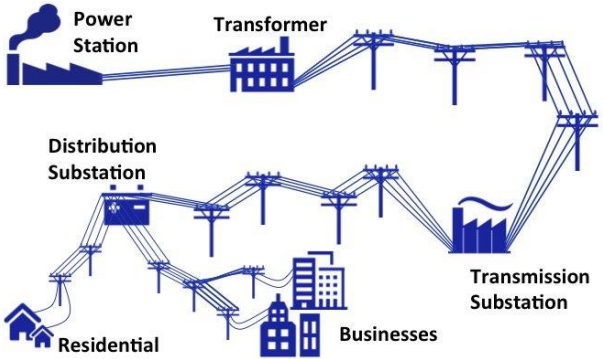
Multi-modal Network

What is a transportation network?

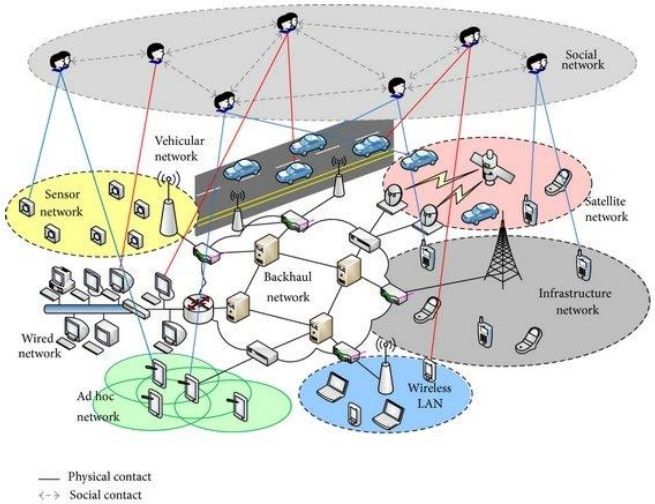
- Examples



Logistics Network



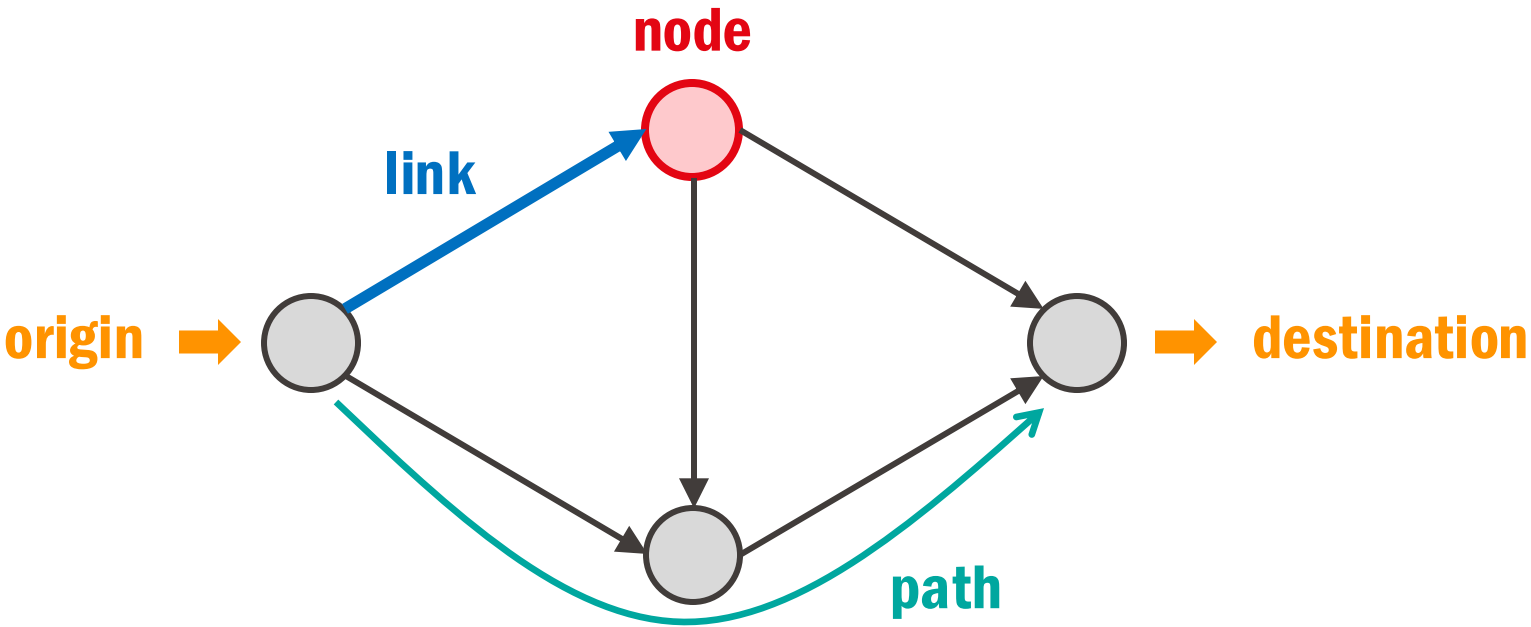
Power Network



Communication Network

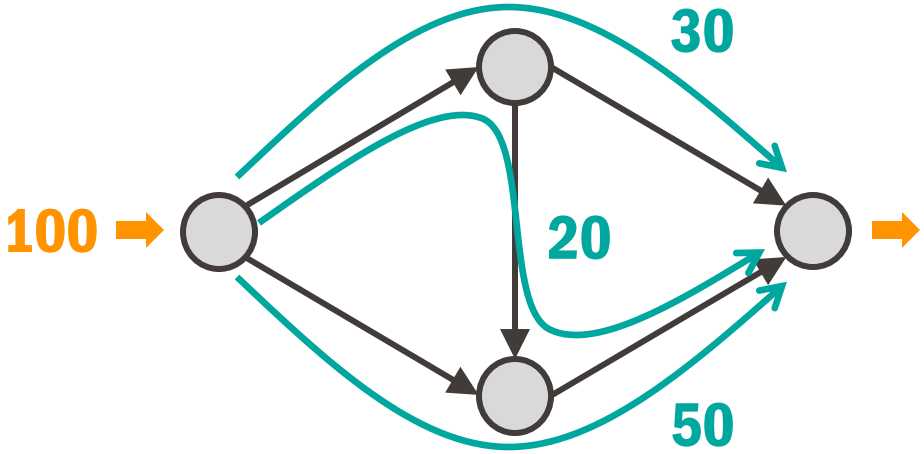
What is a transportation network?

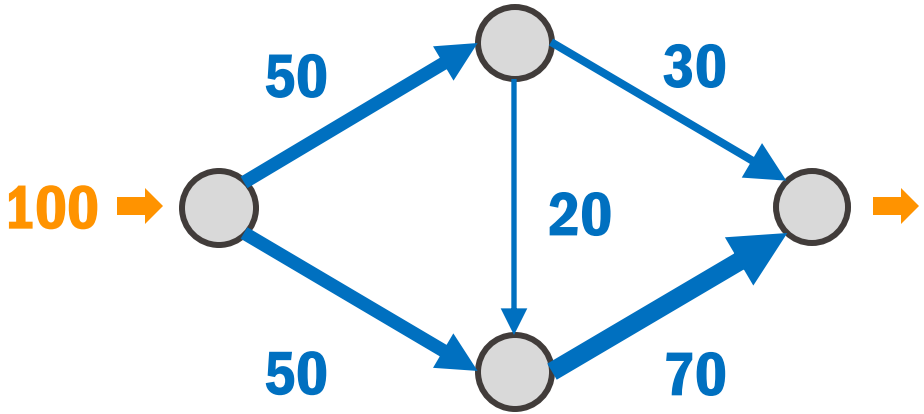
- Key elements



What is a transportation network?

- Key elements

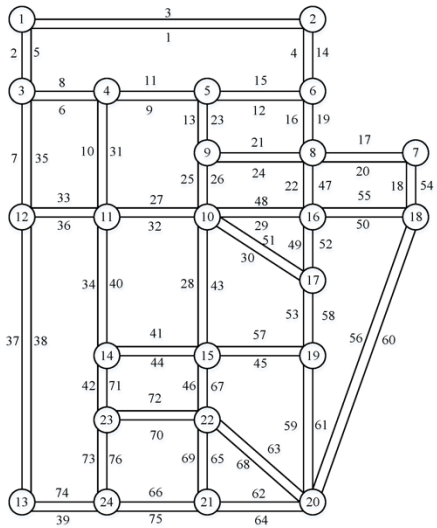




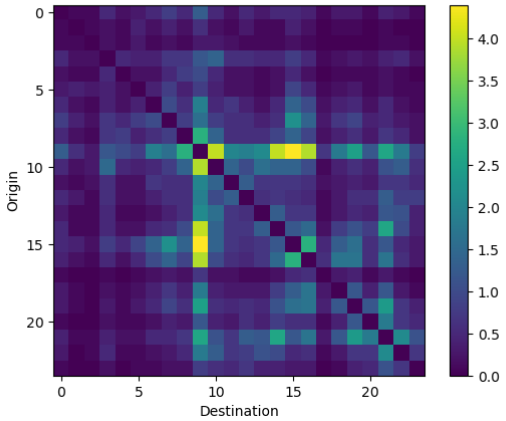
What is traffic assignment?

- Assign traffic flows on a given transportation network according to certain ***rules*** and satisfying certain ***constraints***

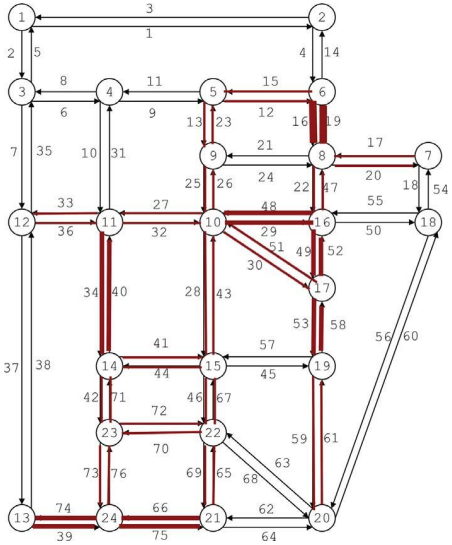
Network



Demand

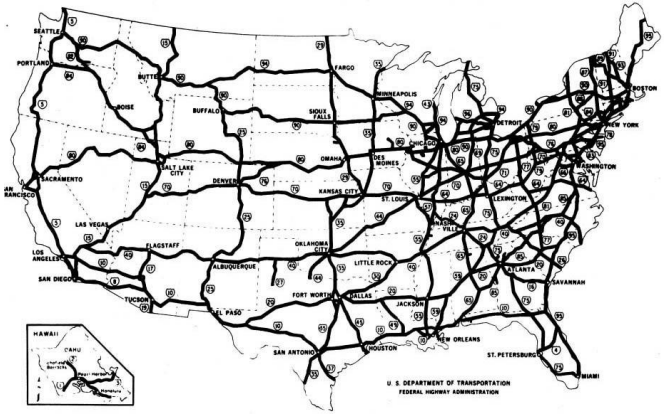


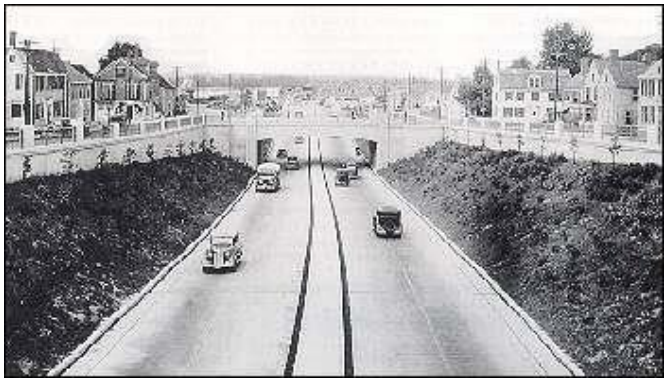
Traffic Flows



What is traffic assignment?

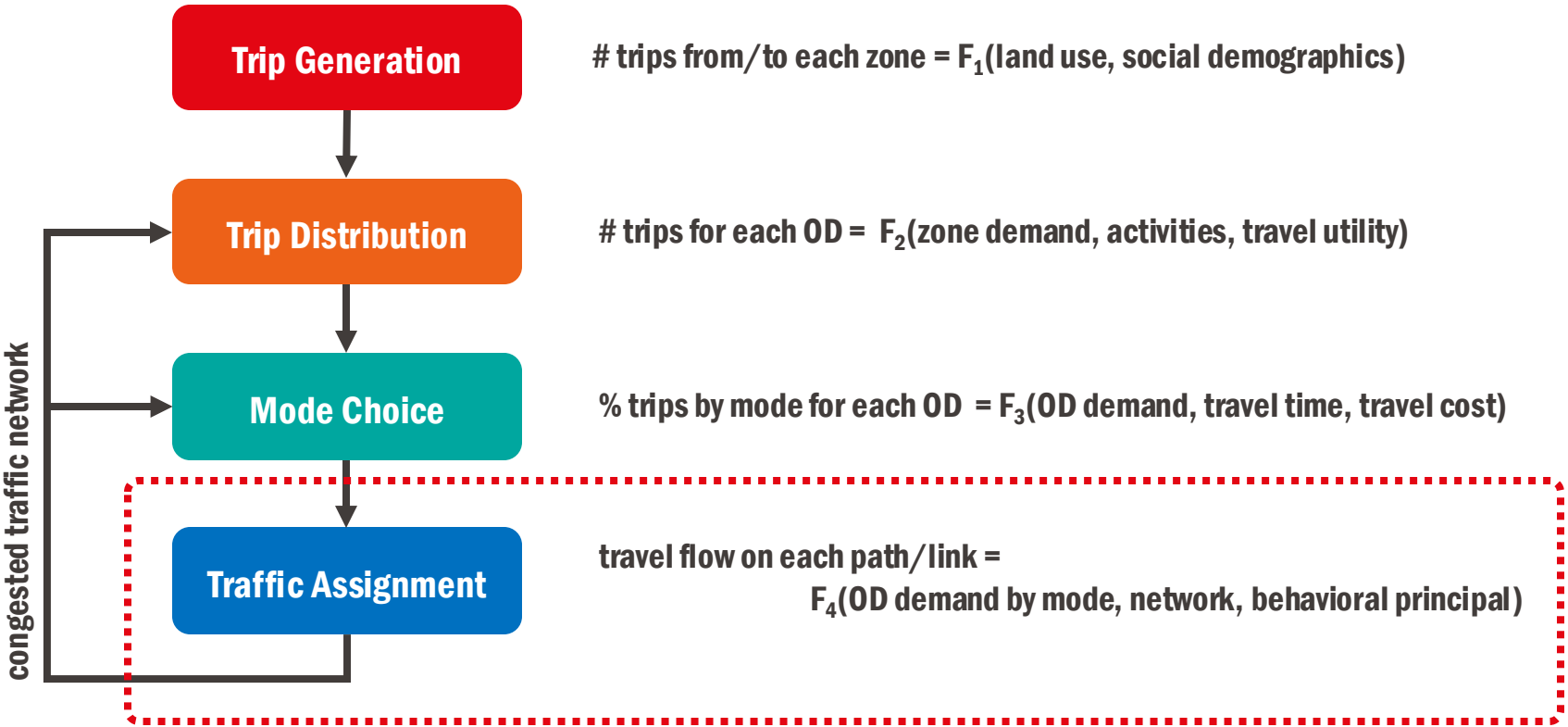
- A brief history
  - First developed in the 1950s
    - New highway systems in the U.S.
      - e.g., Federal Aid Highway Act of 1956
    - Task of urban travel forecasting
      - e.g., traffic flow prediction
  - Early studies
    - Detroit (DMATS) 1953-1956
      - early use of gravity model
    - Chicago (CATS) 1956-1962
      - shortest-path routing and link assignment
    - Philadelphia (PJTS) 1959-1967
      - land-use interactions





What is traffic assignment?

- Four-step model for traffic forecasting



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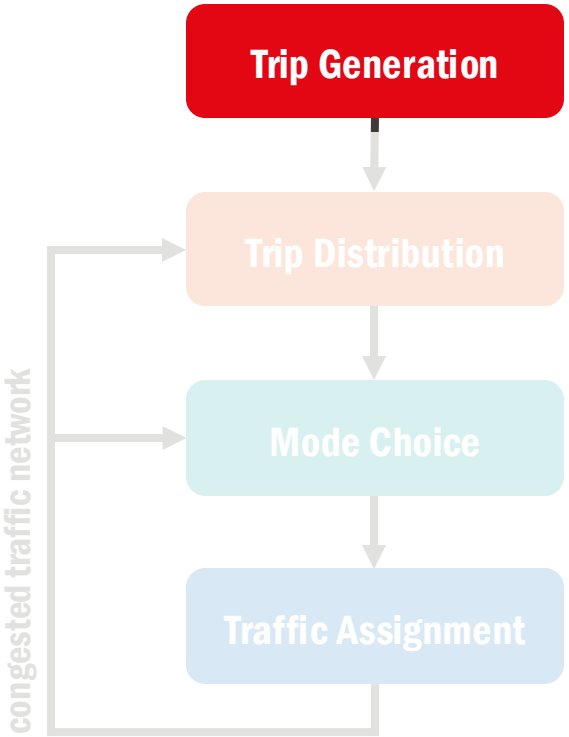

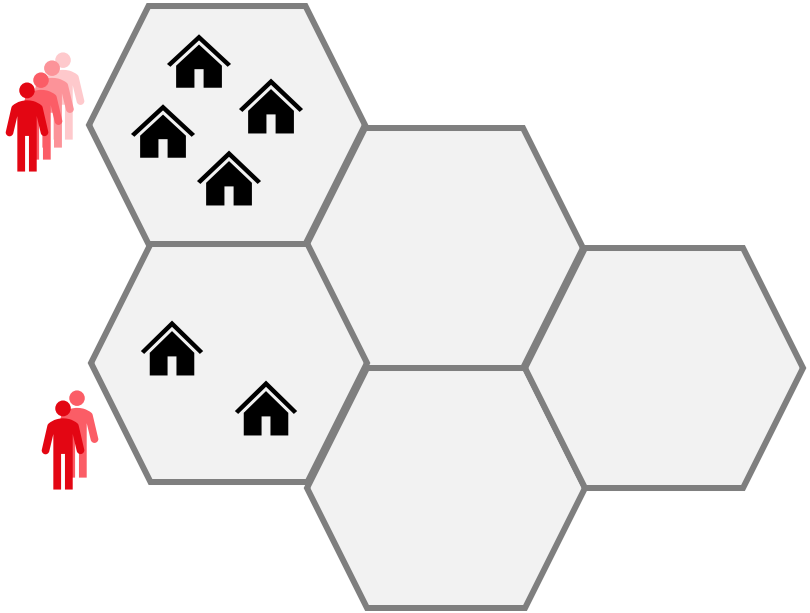

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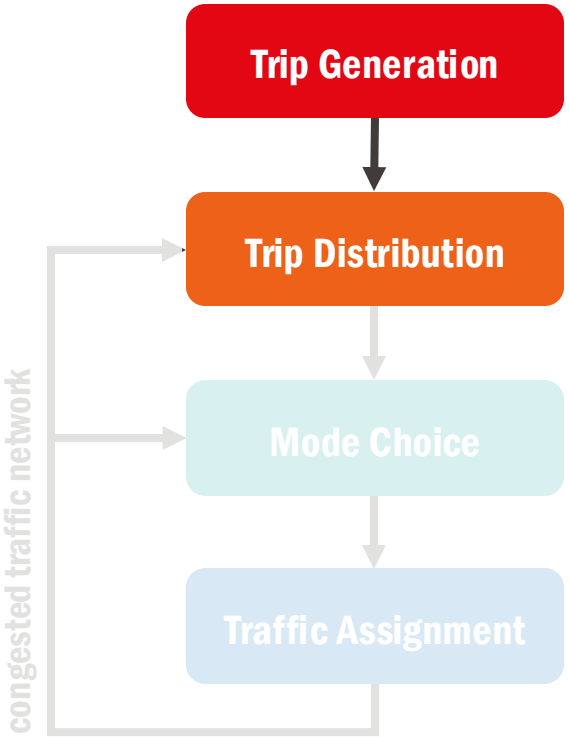

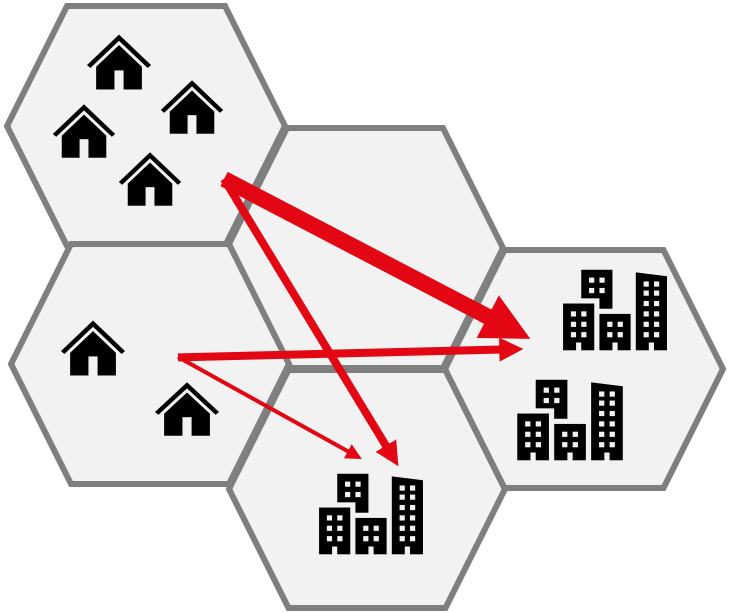

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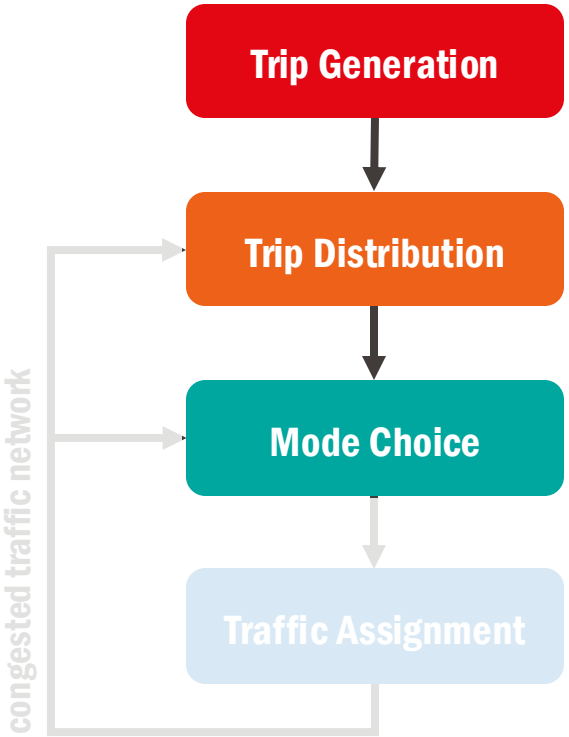

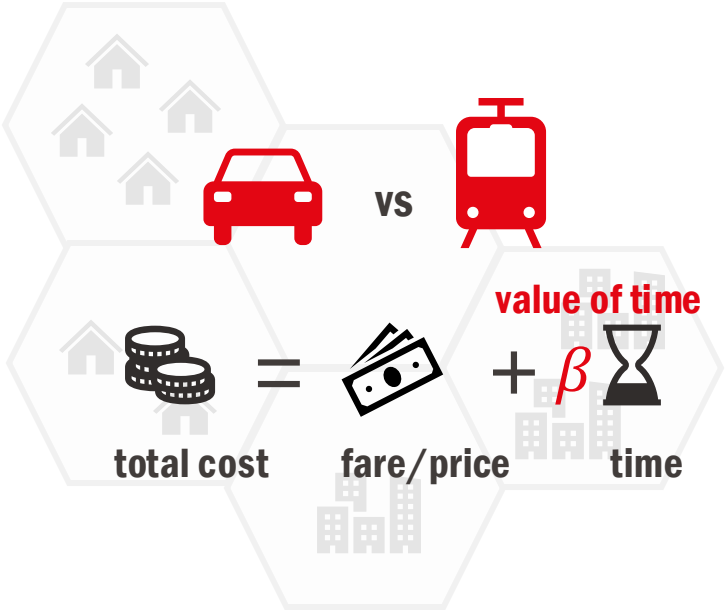

What is traffic assignment?

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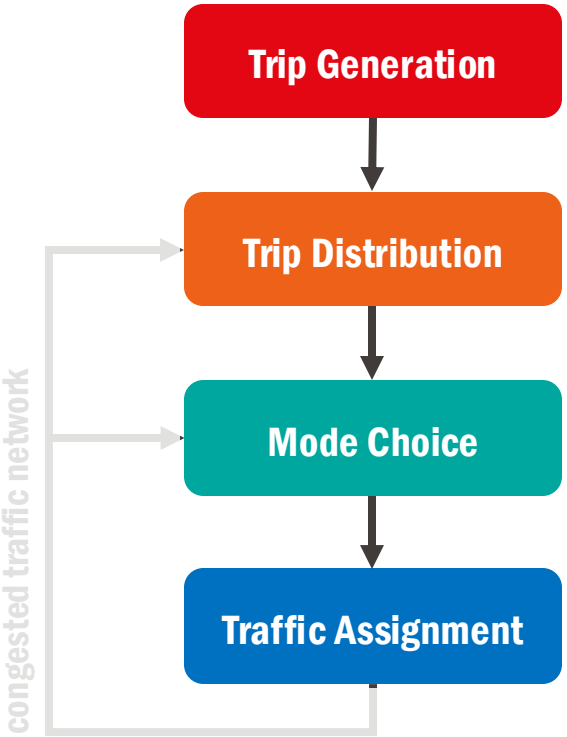

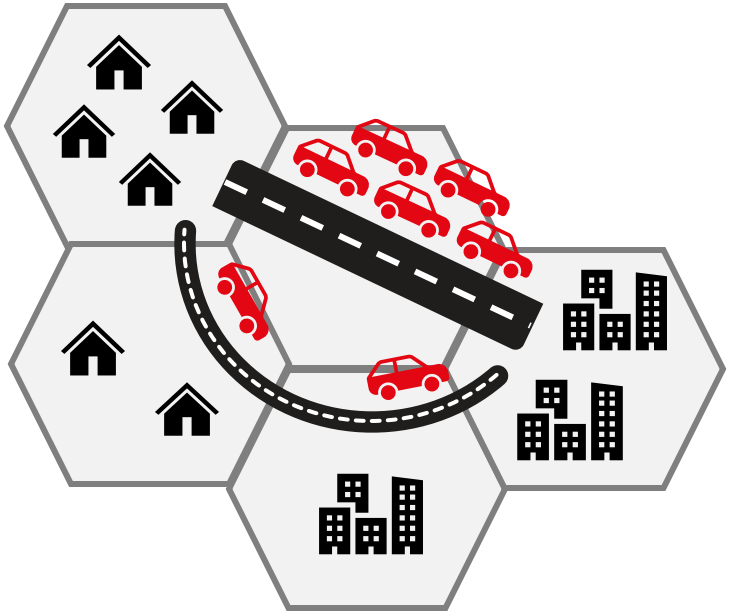

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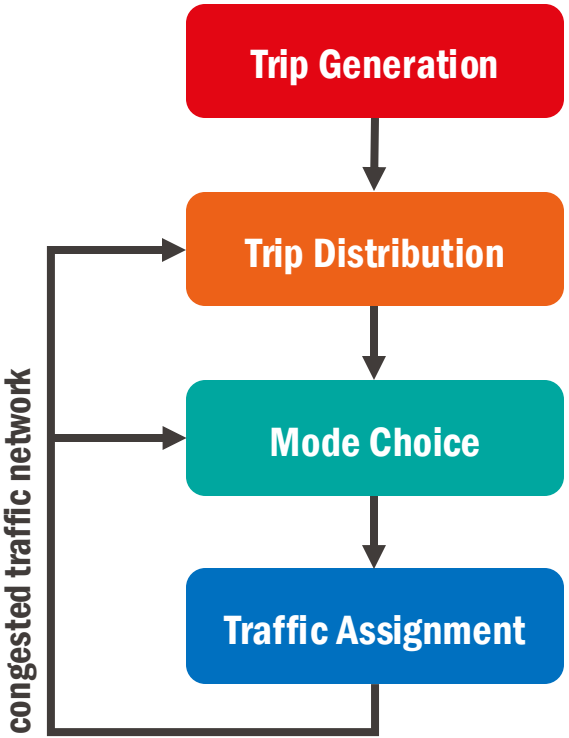
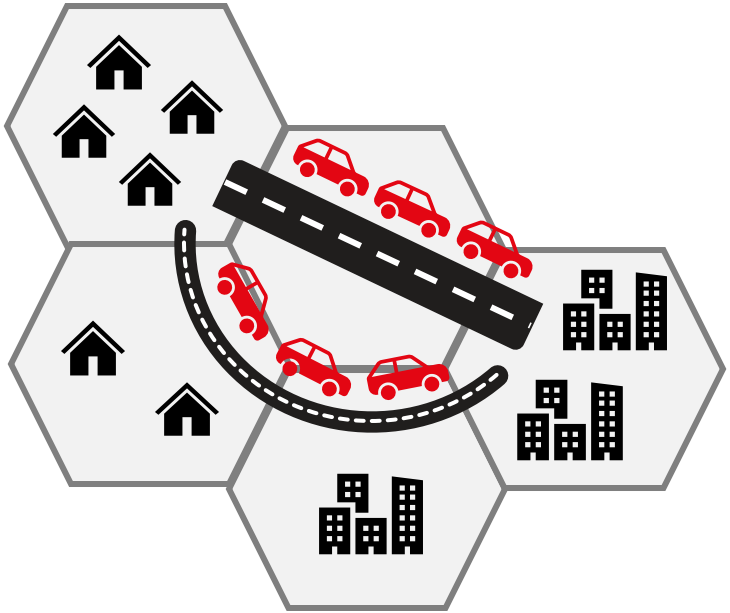




Questions?

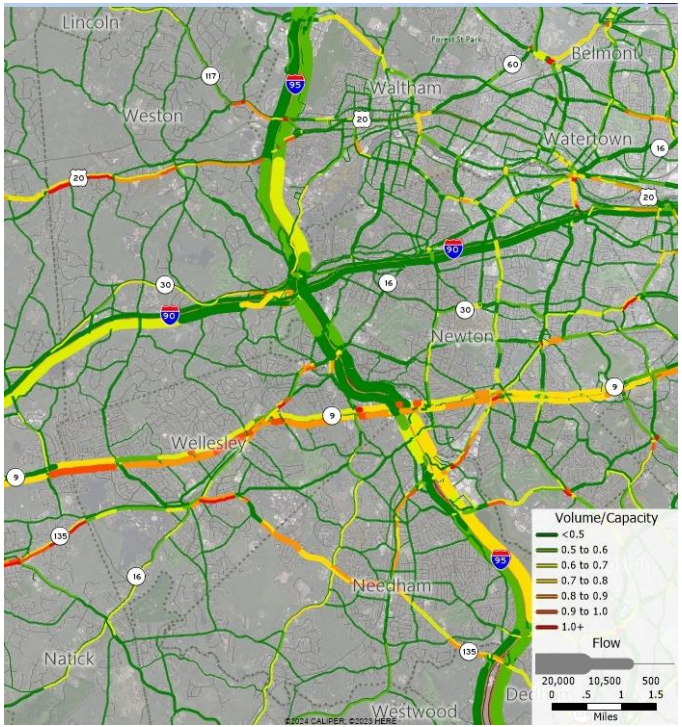
Why taking this course?

- Science behind most transportation planning software

TransCAD®
Transportation Planning Software

Transit assignment

Regional traffic assignment



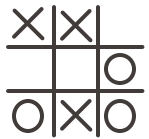
Why taking this course?

- Classic domain of transportation research

TRB
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

AEP40: Transportation Network Modeling Committee
AEP30: Traveler Behavior and Values
ACP50: Traffic Flow Theory and Characteristics

- Related research topics



game theory

optimization

operations research

machine learning
reinforcement learning

control

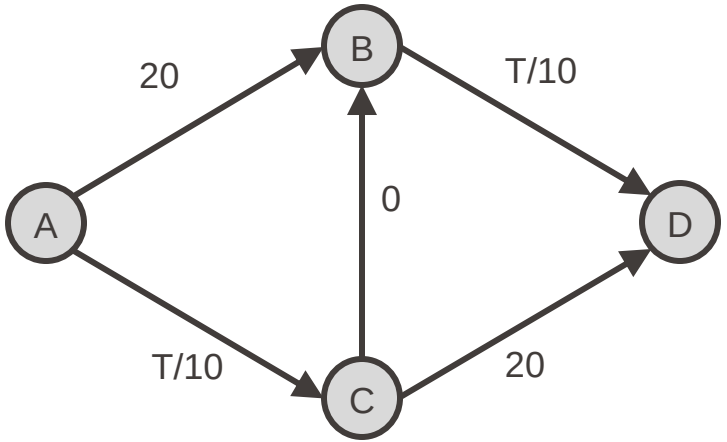
Why taking this course?

- Better understand real-world problems
  - Explain contradictory phenomena
    - e.g., Braess paradox
  - Answer what-if problem
  - Estimate long-term impact

Braess paradox

- Named after German mathematician Dietrich Braess
  - Adding a new road may even increase traffic congestion

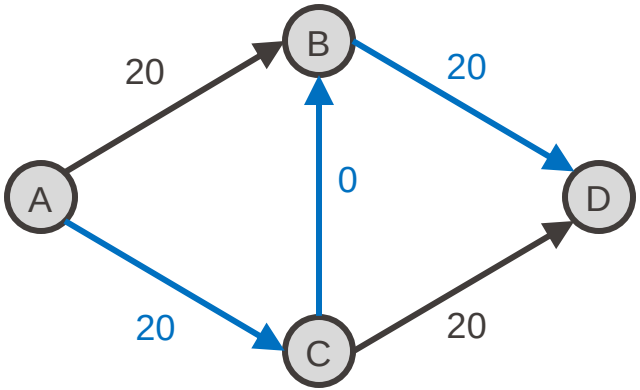
https://www.youtube.com/watch?v=8mlH9bnvWVE



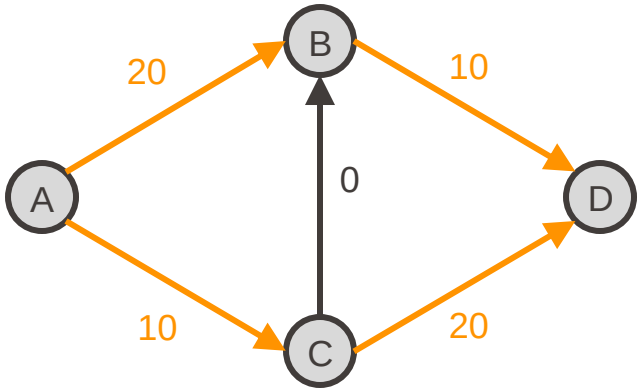
Braess paradox

- Named after German mathematician Dietrich Braess
  - Adding a new road may even increase traffic congestion
  - Rooted in the difference between user equilibrium (UE) and system optimum (SO)
    - measured by price of anarchy (PoA)

$TT_{\mathrm{UE}} = 40 * 200$



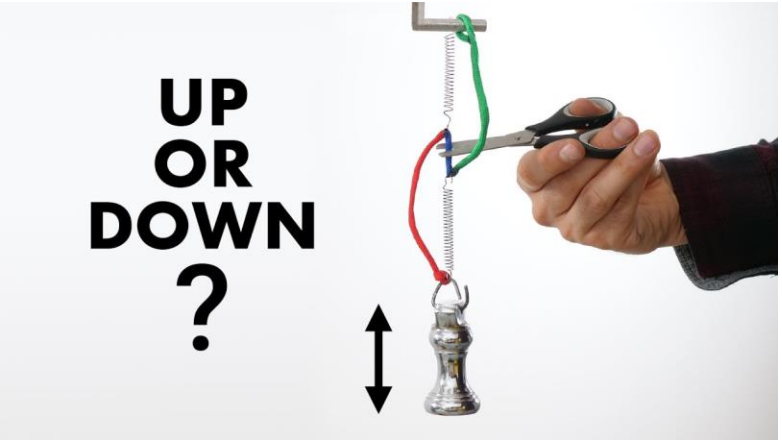
$TT_{\mathrm{SO}} = 30 * 200$



$$PoA = \frac{TT_{\mathrm{UE}}}{TT_{\mathrm{SO}}} = \frac{4}{3}$$

Braess paradox

- Named after German mathematician Dietrich Braess
  - Adding a new road may even increase traffic congestion
  - Rooted in the difference between user equilibrium (UE) and system optimum (SO)
  - Real-world validations and applications, and beyond transportation



https://www.youtube.com/watch?v=Cg73j3QYRJc

nature communications

Article

https://doi.org/10.1038/s41467-022-32917-6

Understanding Braess' Paradox in power grids

Received: 21 September 2021

Accepted: 23 August 2022

Published online: 14 September 2022

Check for updates

Benjamin Schäfer[1,2,3,4,11], Thiemo Pesch[5,11], Debsankha Manik[4,6,11], Julian Gollenstede[7], Guosong Lin[7], Hans-Peter Beck[7], Dirk Witthaut[8,9,11] & Marc Timme[4,6,10,11]

The ongoing energy transition requires power grid extensions to connect renewable generators to consumers and to transfer power among distant areas. The process of grid extension requires a large investment of resources and is supposed to make grid operation more robust. Yet, counter-intuitively, increasing the capacity of existing lines or adding new lines may also reduce the overall system performance and even promote blackouts due to Braess' paradox. Braess' paradox was theoretically modeled but not yet proven in realistically scaled power grids. Here, we present an experimental setup demonstrating Braess' paradox in an AC power grid and show how it constrains ongoing large-scale grid extension projects. We present a topological theory that reveals the key mechanism and predicts Braessian grid extensions from the network structure. These results offer a theoretical method to understand and practical guidelines in support of preventing unsuitable infrastructures and the systemic planning of grid extensions.

Why taking this course?

- Better understand real-world problems
  - Explain contradictory phenomena
    - e.g., Braess paradox
  - Answer what-if problem
    - e.g., A1 highway expansion
  - Estimate long-term impact

A1 highway expansion

- How to reduce the 14,000 hours congestion on A1?
  - Option 1: Expand highway capacity by adding one more lane
  - Option 2: Invest public transport

OPINION

L'invité

L'élargissement des autoroutes ne résoudra pas les problèmes de congestion

Vincent Kaufmann et seize autres personnes du monde académique signent cette tribune liée à la votation sur les autoroutes.

L'invité **Vincent Kaufmann** - Professeur à l'EPFL
Publié: 04.11.2024, 06h41

1

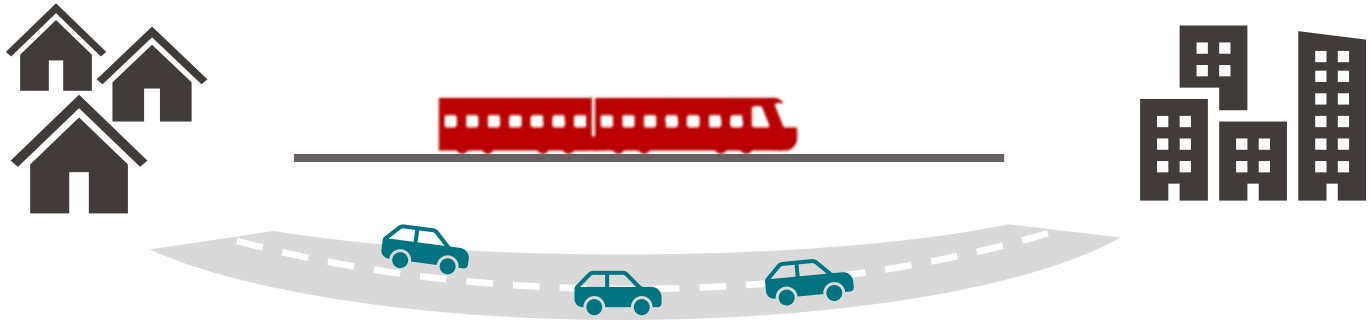
https://www.24heures.ch/lelargissement-des-autoroutes-ne-resoudra-pas-les-problemes-de-congestion-338022222248

A1 highway expansion

- A simple model to analyze highway extension
  - Mode choice in daily commute

value of time

total cost = fare/price + β time



A1 highway expansion

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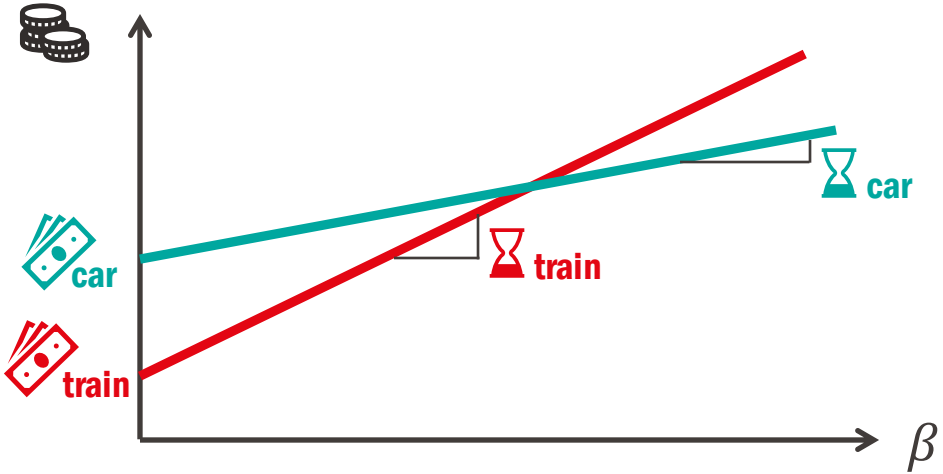

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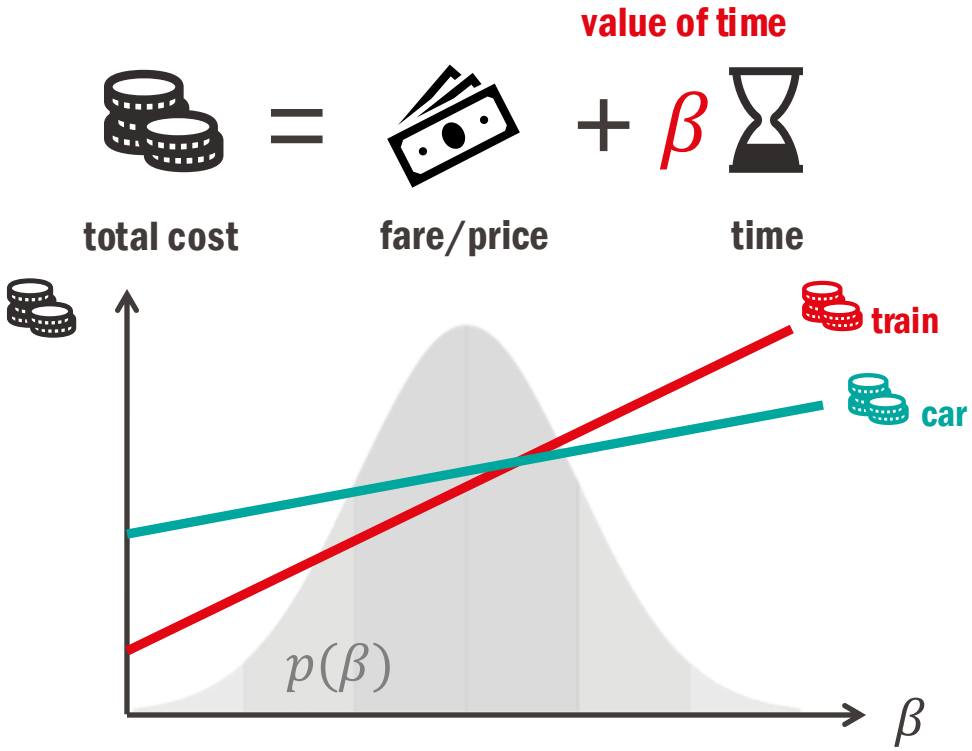

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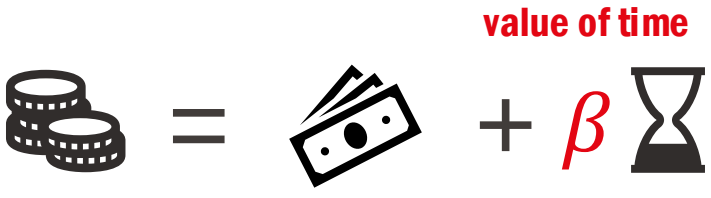
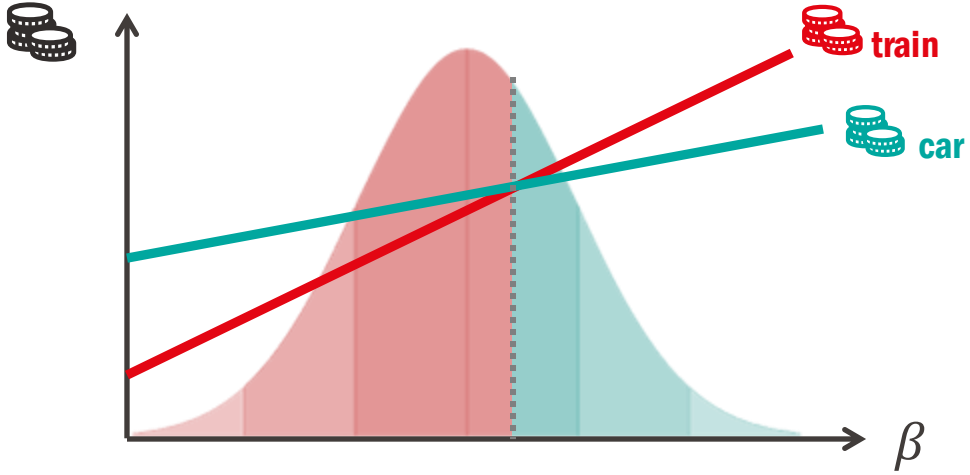
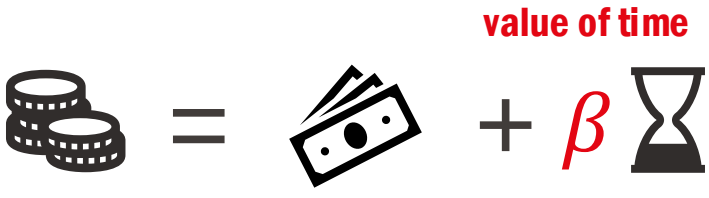


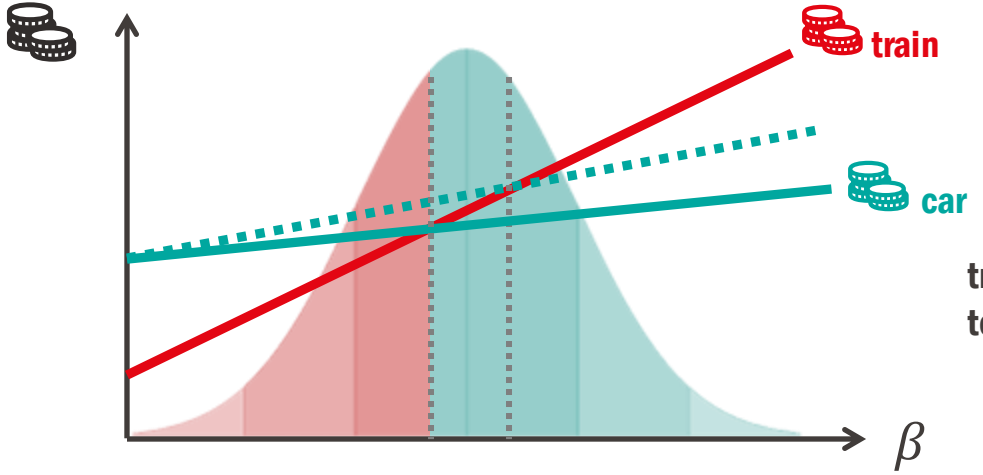


current demand split between two modes

A1 highway expansion

- A simple model to analyze highway expansion
  - Mode choice in daily commute

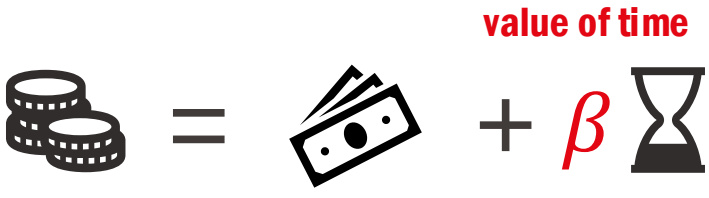


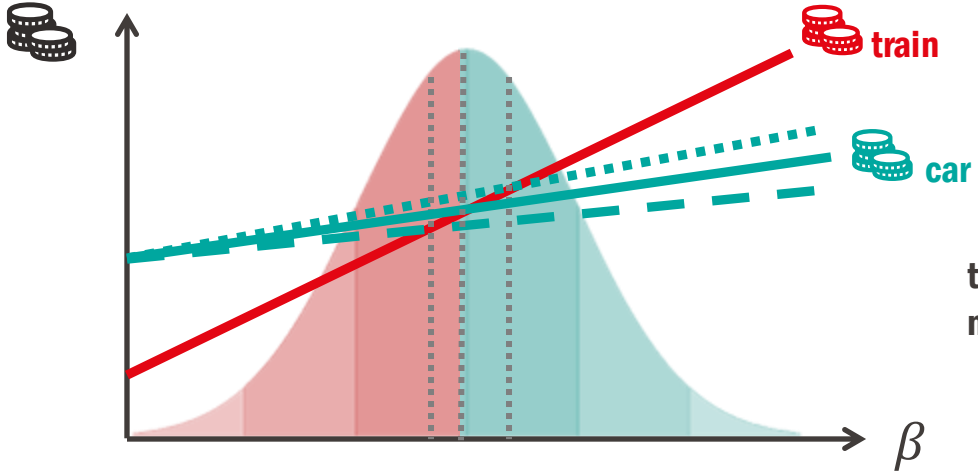


travel time decrease thanks to higher capacity

A1 highway expansion

- A simple model to analyze highway expansion
  - Mode choice in daily commute

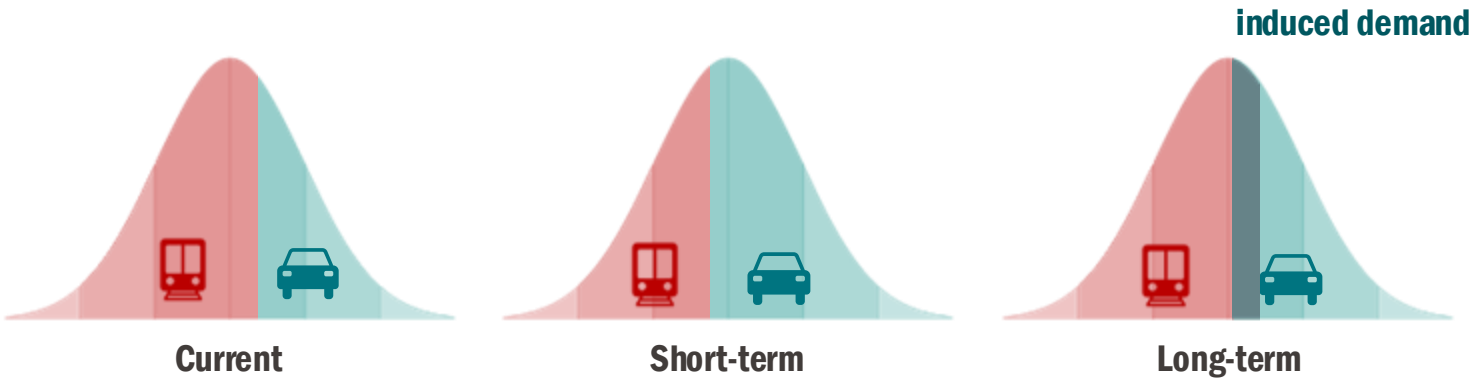




travel time increases due to more traffic

A1 highway expansion

- A simple model to analyze highway expansion
  - Mode choice in daily commute

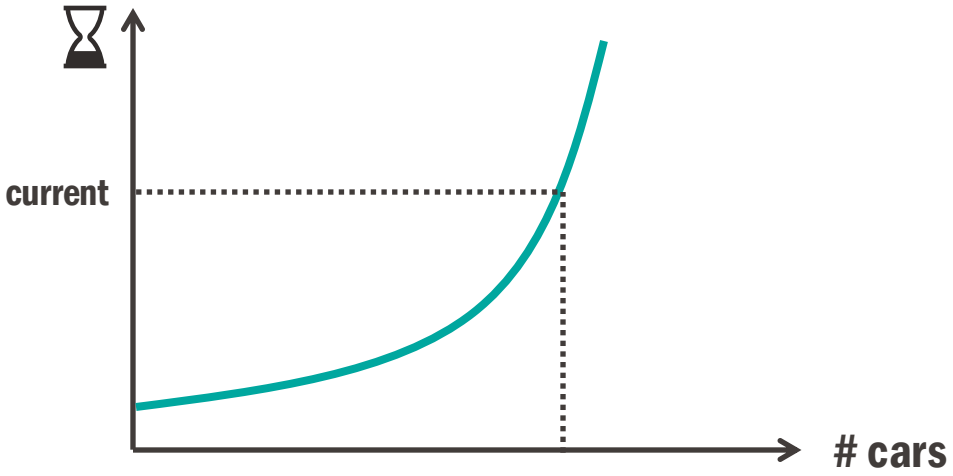


How does the induced demand affect highway congestion?

A1 highway expansion

- A simple model to analyze highway expansion
  - Highway travel time

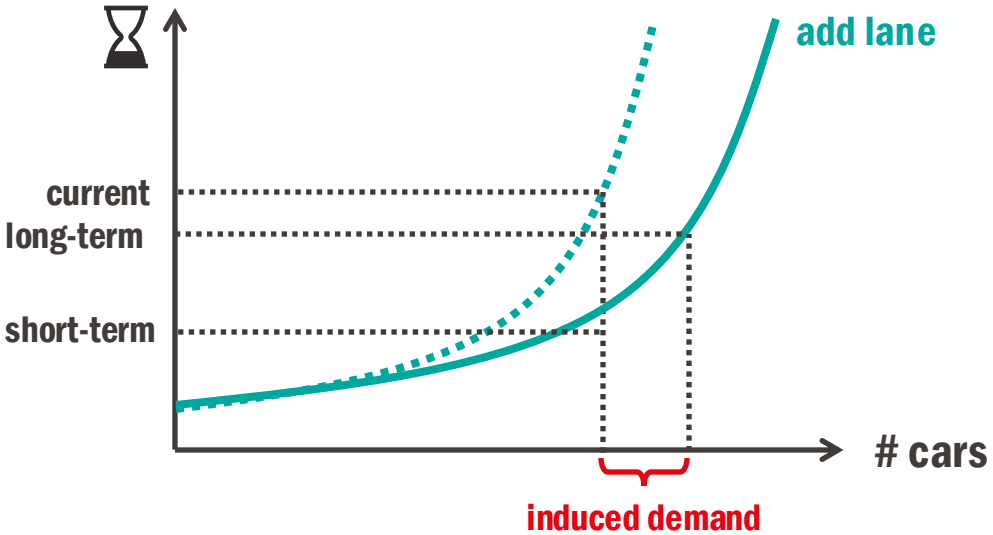
$$\text{⧗} = f\left(\frac{\#\ \text{cars}}{\#\ \text{lanes}}\right)$$



A1 highway expansion

- A simple model to analyze highway expansion
  - Highway travel time

$$\text{⧗} = f\left(\frac{\#\ \text{cars}}{\#\ \text{lanes}}\right)$$



A1 highway expansion

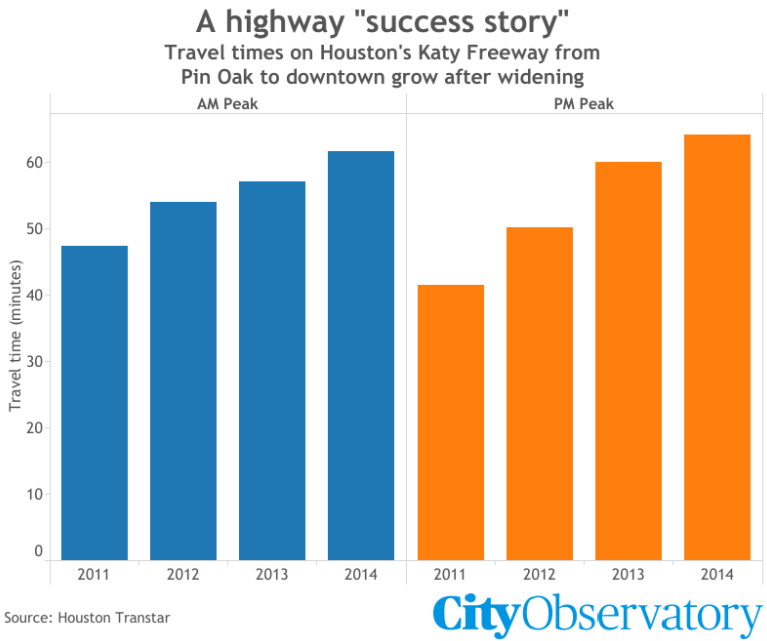
- Lessons from other countries
  - Highway expansion in Texas, U.S.

Katy freeway (2004)

Katy freeway (2016)

A1 highway expansion

- Lessons from other countries
  - Highway expansion in Texas, U.S.



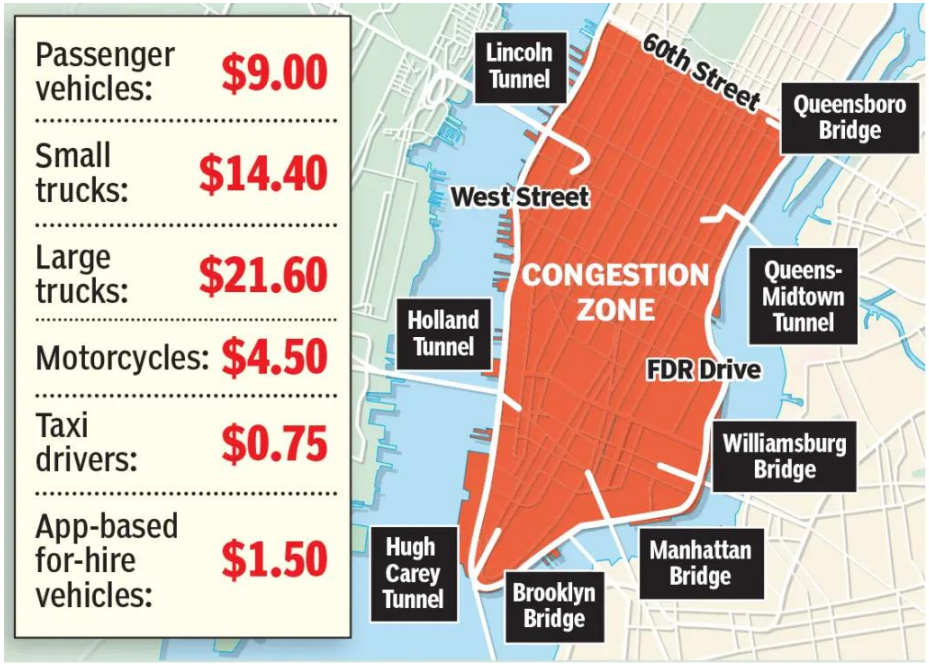
Katy freeway (2016)

Why taking this course?

- Better understand real-world problems
  - Explain contradictory phenomena
    - e.g., Braess paradox
  - Answer what-if problem
    - e.g., A1 expansion
  - Estimate long-term impact
    - e.g., NYC congestion pricing

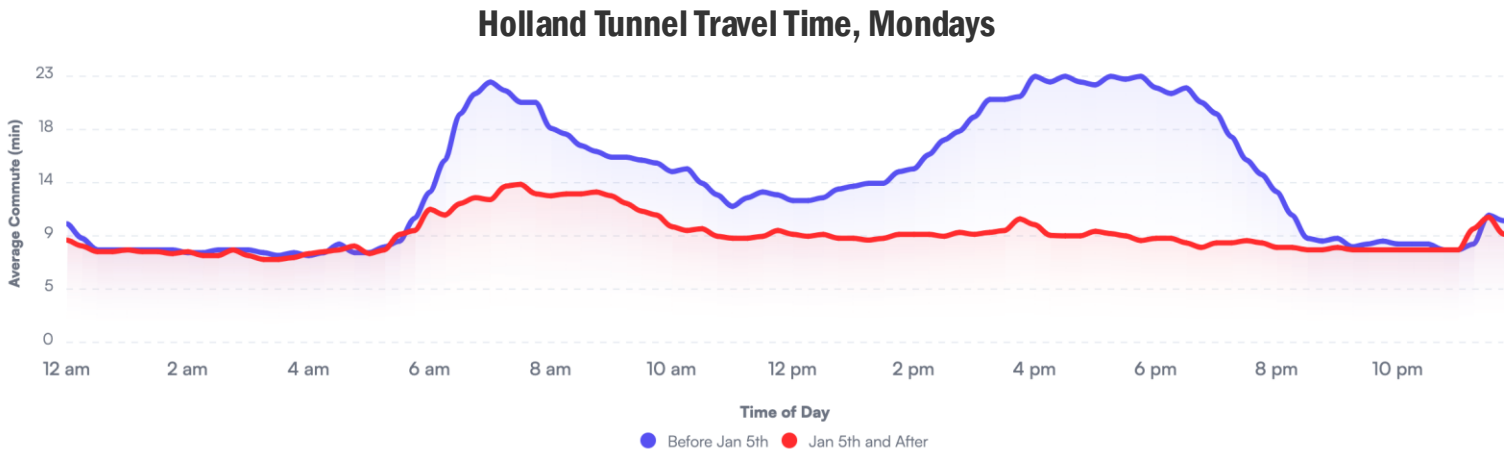
NYC congestion pricing

- Finally launched in January 2025 after multiple rounds of debates
  - 24/7, discount outside peak (9 am – 9 pm)



NYC congestion pricing

- Effectively reduce traffic entering Manhattan



https://news.climate.columbia.edu/2025/02/18/congestion-pricing-benefits-new-york-city/

NYC congestion pricing

- How about traffic inside Manhattan?
  - The answer is not conclusive

CONGESTION PRICING

Congestion pricing impacts: Fewer cars in Manhattan and fewer crashes, MTA finds

The MTA released new numbers showing that despite some perceptions, the controversial tolling program has made a big impact on the number of vehicles in Manhattan

By **Andrew Siff** • Published January 24, 2025 • Updated on January 24, 2025 at 11:31 pm

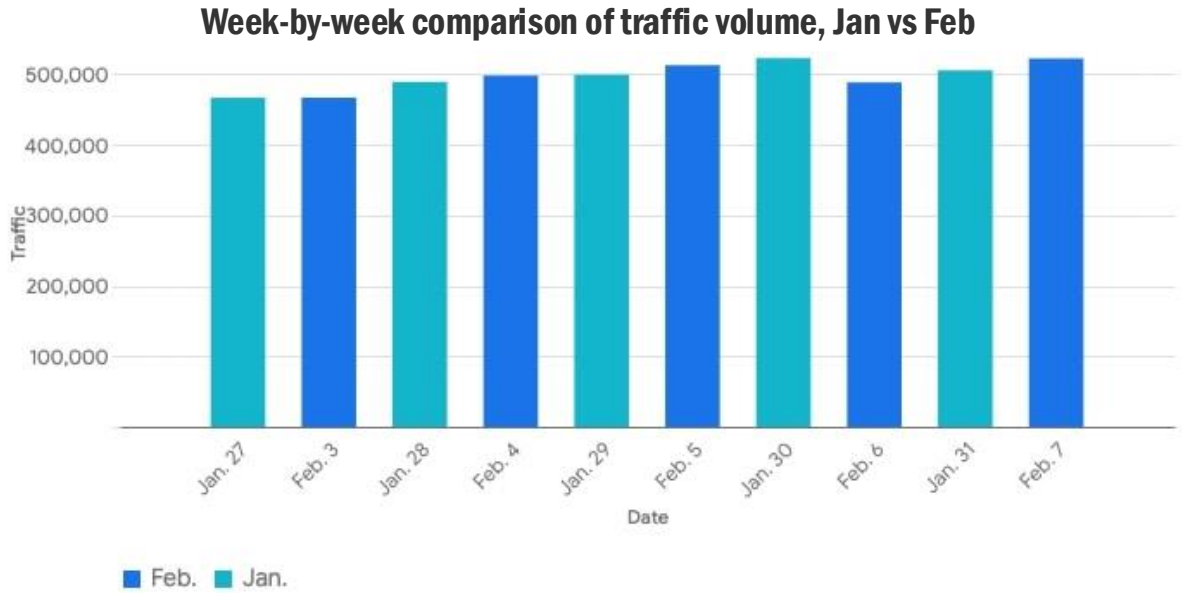
TRANSPORTATION

Congestion toll cuts time on tunnel crossings, but few effects on NYC traffic

BY: **NIKITA BIRYUKOV** - JANUARY 13, 2025 7:07 AM

NYC congestion pricing

- Will the traffic reduction last long?



https://www.amny.com/nyc-transit/congestion-pricing-traffic-creeps-up-manhattan-february-2025/

NYC congestion pricing

- What is happening outside Manhattan?
  - Trains entering Manhattan are packed, and congestion emerges on the way to train stations

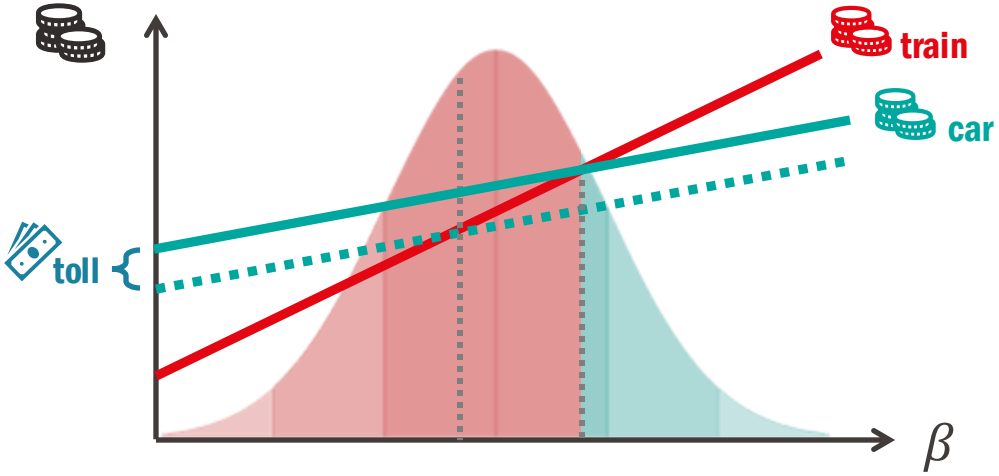
    https://www.yahoo.com/news/jersey-transit-commuters-report-crowded-224457761.html

- How should the toll revenue be used?
  - Improve transit service in Manhattan, and share with its “neighbor” to compromise the negative externality

    https://www.fastcompany.com/91272434/a-million-cars-have-disappeared-what-nyc-is-like-after-one-month-of-congestion-pricing
    https://www.cbsnews.com/newyork/news/new-jersey-congestion-pricing-opposition/

NYC congestion pricing

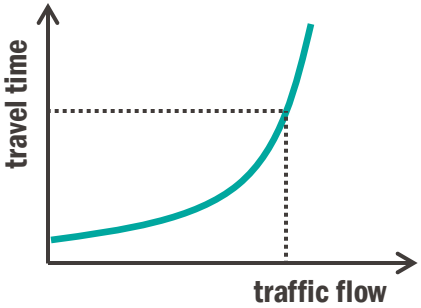
- How to explain congestion pricing using model?
  - Mode choice in daily commute



Questions?

What are expected in course?

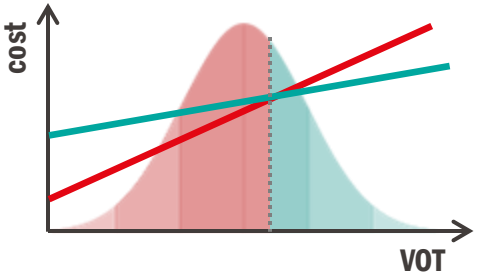
- Mathematical models



BPR function

$$t(x) = t_0\left(1 + 0.15\left(\frac{x}{c}\right)^4\right)$$

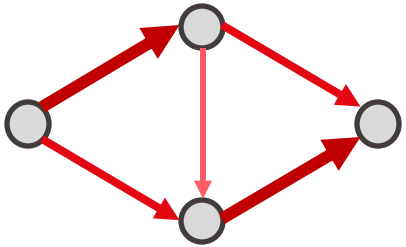
- Optimization problems



VI formulation

$$\langle c(x^*), x - x^* \rangle \geq 0, \forall x \in \Omega$$

- Algorithms



Frank-Wolfe