Fusing Confusing Data Streams

Insight into Seattle's Transportation System

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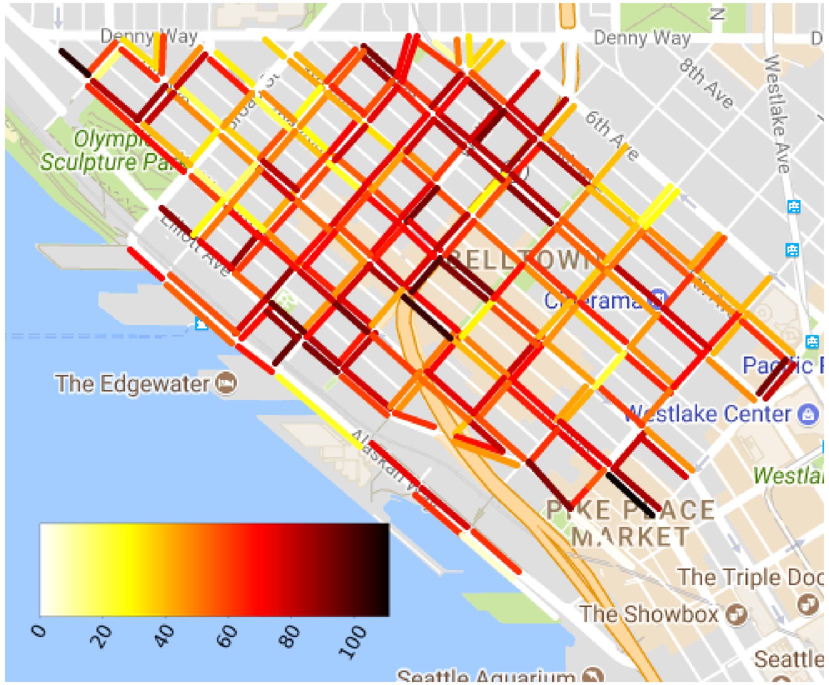
PNNL is operated by Battelle for the U.S. Department of Energy

Talk outline

How can we use multiple data streams to improve core business district curbside performance?

1. Project motivation
2. Fusing multiple data streams for curb use insight
3. Abstracting data fusion across multiple sources
4. Ongoing project goals and implementation



Digital paid parking transactions are an example of emerging data sources; above is afternoon demand for paid curbside parking in Belltown, Seattle (2016); units are % hourly occupancy

A changing mobility landscape

- Rapidly evolving transportation landscape. We need to rethink land use of the curb as the interfacing layer of a more dynamic transportation network.
  - Curbside EV charging in Seattle now operational
  - Walking and dining sidewalks/streets in response to COVID-19
  - Rapidly increasing urban freight/delivery
  - Partial autonomy will increase utilization of courier services with lower costs/overheads

A dynamic curb's impact on network performance

We can take an *extreme* and contextual example to see how exogenous factors like curb policy influence the shape of a fundamental diagram: a multi-lane road with no stopping along the curb (left, I-5 in Seattle), and a multi-lane road with dedicated short pick-up drop-off stopping (right, Seattle-Tacoma airport)

Image Credit: KUOW

Image Credit: Port of Seattle

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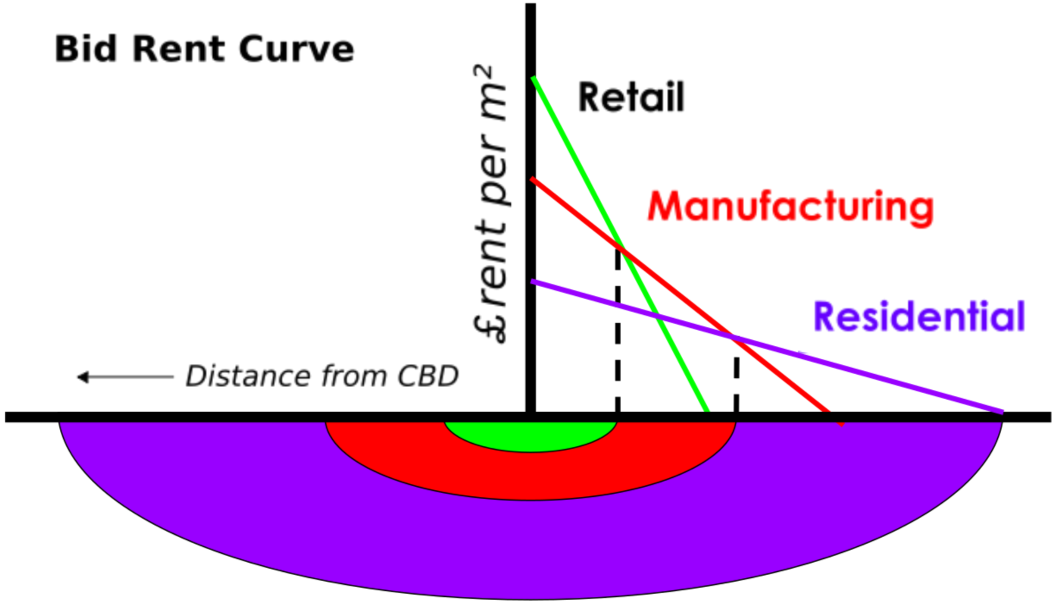
Data-informed curb management policy

- Multiple data streams can potentially be combined to paint a complete picture of what is happening at the curb and on the adjacent roadway.
- Data and example sources include:
  - Digital transactions for paid parking (e.g. Seattle Department of Transportation)
  - Traffic camera data (e.g. Automotus in Los Angeles)
  - Curb proximity sensors (e.g. the City of Melbourne)
  - Loop detectors and magnetometers
  - Manual observation and study (e.g. UW’s Urban Freight Lab)
  - OEM vehicle GPS signals and telematics

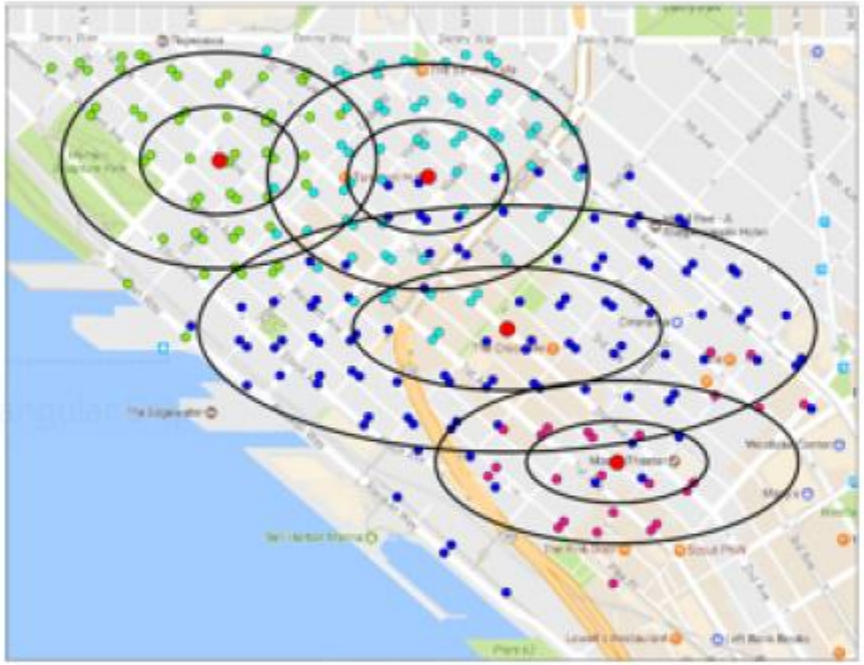
Suppose we have a complete picture of curb and adjacent roadway activity; how would we best use this information to better inform network usage?

1. Henao et al. *Municipal adaptation to changing curbside demands* (2020) Transport Policy

Bid-Rent Theory



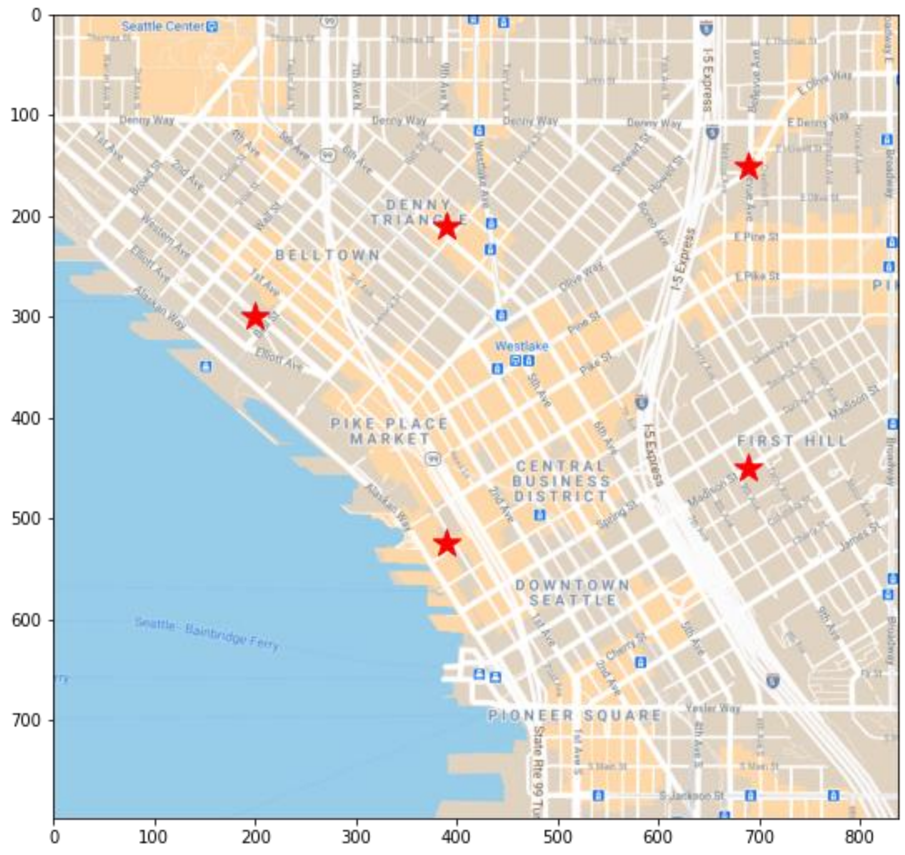
Canonical bid-rent theory modeling the price of real-estate by land use

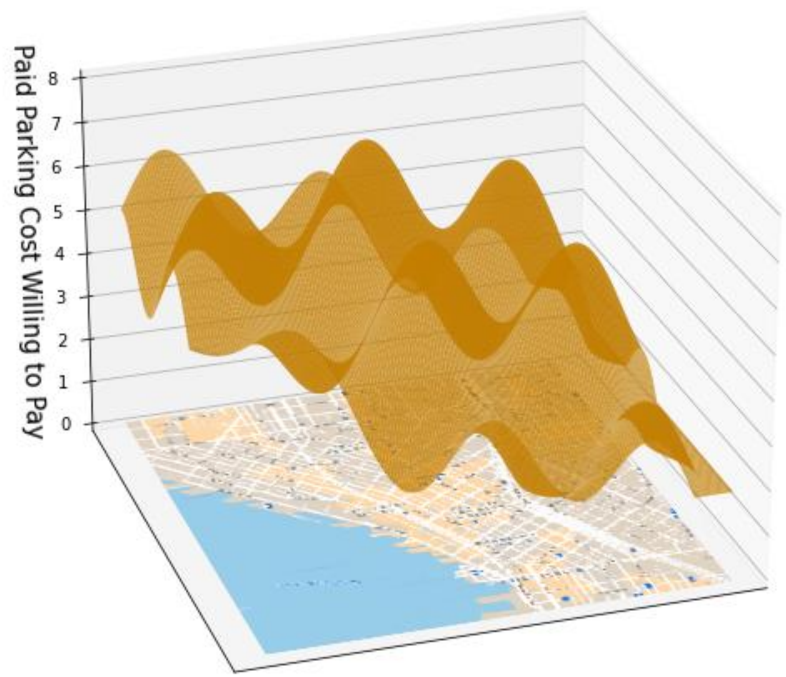


Centralized patterns of demand for private parking[2] in Belltown, Seattle

2. Fiez et al. *Gaussian Mixture Models for Parking Demand Data* (2019) IEEE ITS

Bid-Rent Theory applied to curb real estate





A hypothetical function of curb demand for a single modality at a single time[2]

3. Dowling et al. *Turning curb data into curb policy via a bid-rent framework* (2021) In Review

Bid-Rent Theory applied to curb real estate

If we have a description of demand for curb real estate by modality over time, then we can select an optimal zoning or space allocation subject to

1. Performance objectives (emissions, throughput, productivity, access, etc)
2. Policy constraints (distance between zone types, number of zone types)

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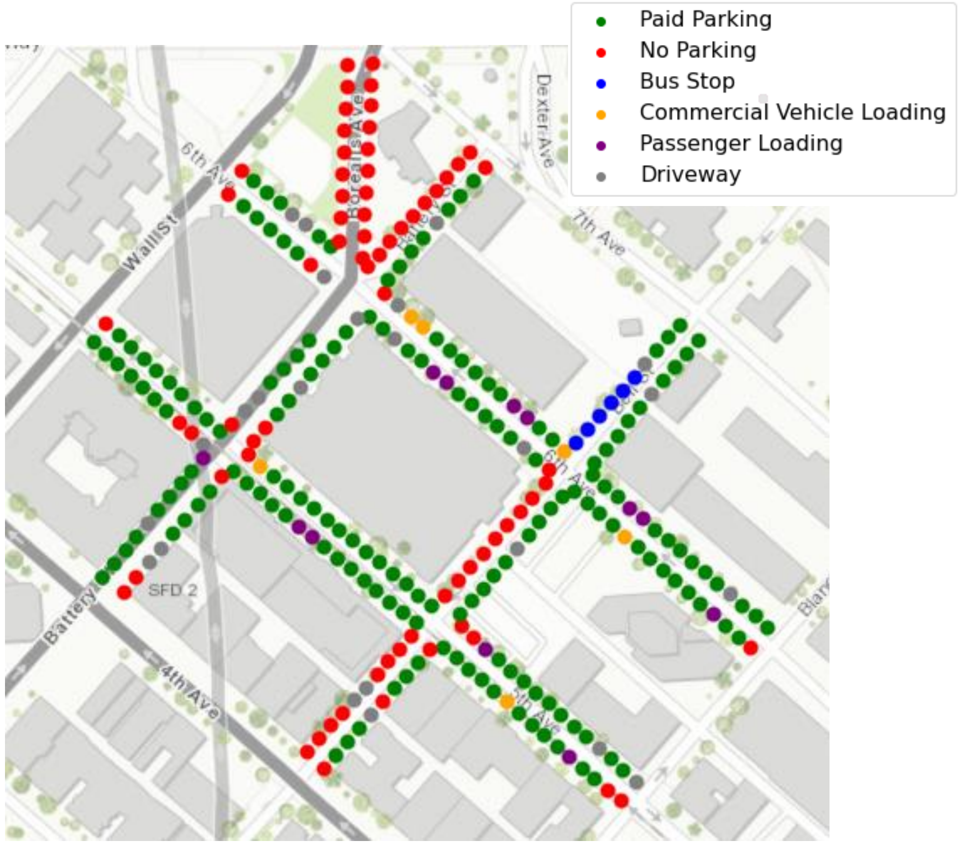
Empirical estimation of demand by modality

We combine 4 curb data sources (in addition to global estimations of emissions, fuel efficiency, value of time, etc) to paint a holistic picture of what is happening at the curb in space and time:

1. Digital paid parking curb transactions (Seattle Department of Transportation)
2. Manual observation of commercial loading/unloading activities (Giron-Valderrama et al. *Freight and the Seattle CBD* (2019) TRR)
3. Bus alighting studies by route and time (automated passenger counting, King County Metro)
4. Manual observation of transportation network company activities (e.g. Lyft/Uber) (Ranjbari et al. *Testing Curbside Management Strategies* (2020) TRR)

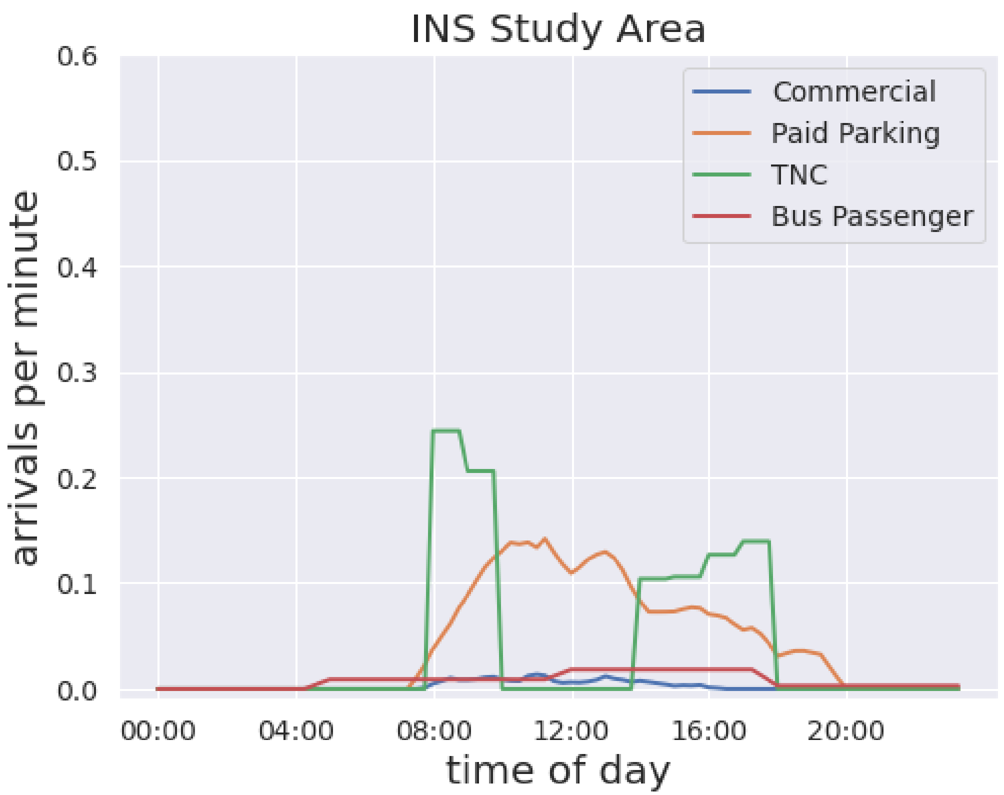


Curb zoning of Insignia Towers Apts between 5th and 6th Ave's, and Battery and Bell St's.

3. Dowling et al. *Turning curb data into curb policy via a bid-rent framework* (2021) In Review

Empirical estimation of demand by modality

- Compute a per-minute arrival rate by modality per hour and per block-face; this involve time alignment, and matching units between time deltas between arrival and departure (commercial), *estimated departure* (parking data and TNC), and number of arrivals/departures at a fixed point in time (bus passengers)



Study area total *measured* arrivals per minute over the course of a Winter 2017 day

Objective function and policy constraint design

- Given an estimation of demand by modality, we can optimize a block-faces curb zoning strategy.
- Optimize with respect to:
  - **Costs paid by users** (access/equity by breaking down modalities)
  - Revenue generated by curb (parking transactions, curb reservations)
  - Productivity of curb (packages or passengers per unit time)
  - Energy efficiency of curb (preference for vehicle charging or efficient productivity)
- Constrained by:
  - Number of certain zoning types (minimum or maximum number of spaces)
  - Space between zoning types (e.g. ¼ mile distance between Seattle bus stops)
  - Number of zone changes over time

Optimizing user costs w/o policy constraints

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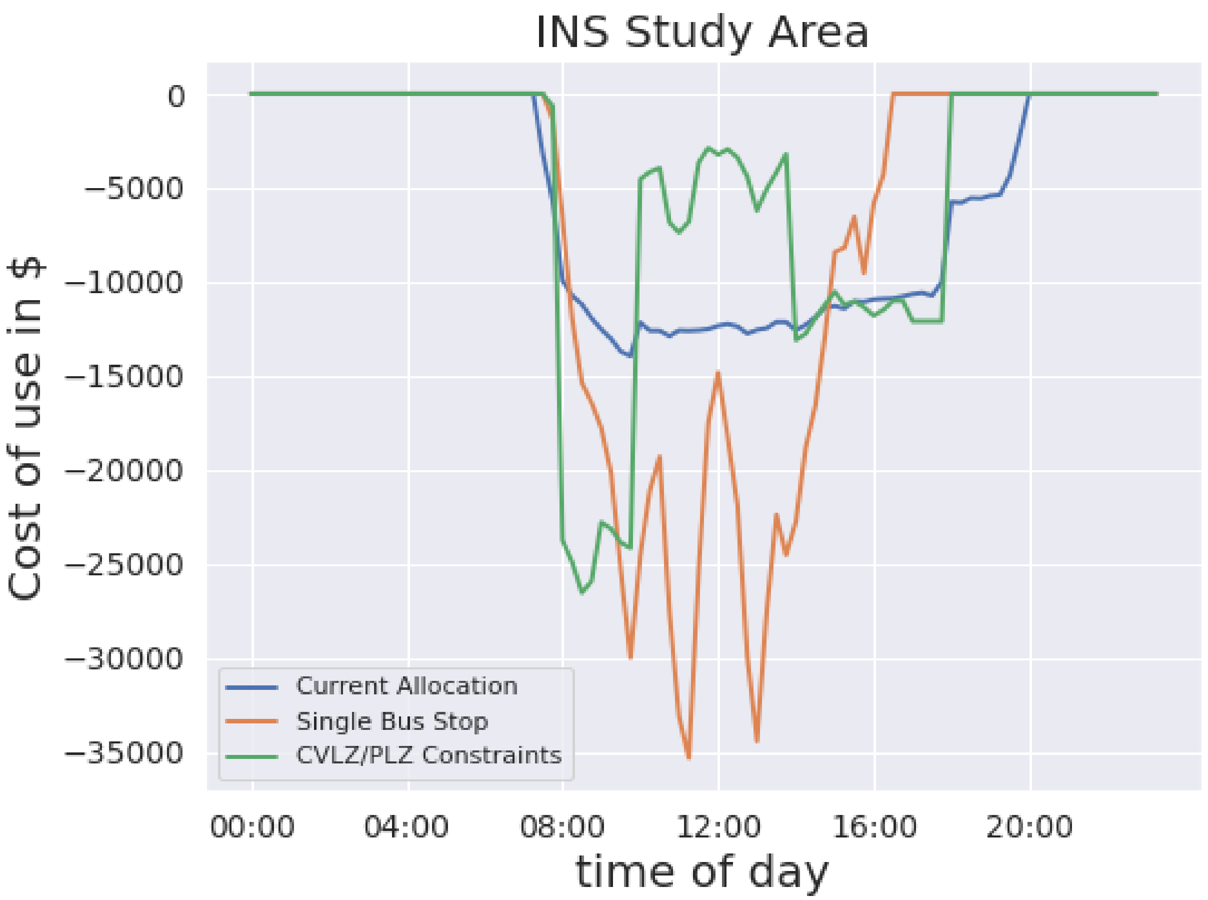
Optimize user costs with cardinality constraints

Measuring cost savings across modalities

- Unconstrained zoning can potentially create thousands in savings across all modalities, but not realistic or even useful
- Can measure the costs across modalities of programmatic policies that reflect current demand data



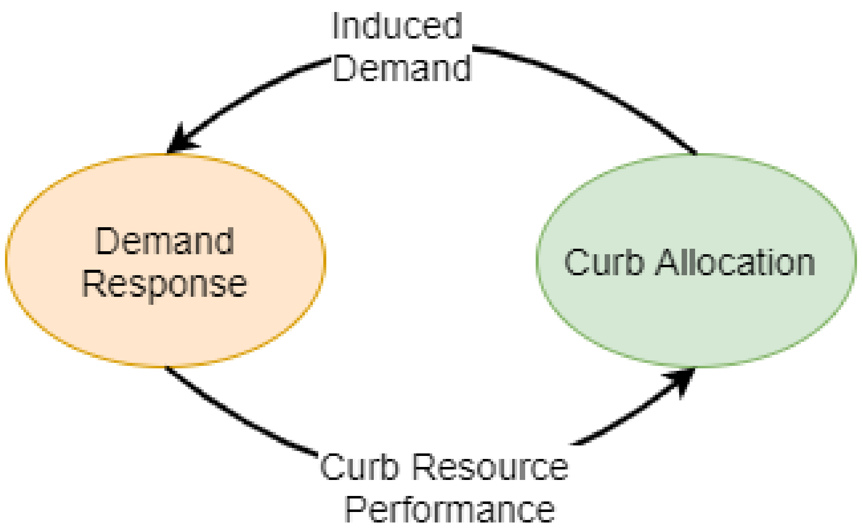
Next steps for dynamic zoning basic research

Getting inside the demand response loop: how do changes in zoning or zone control affect curb demand?

- Large price changes in Amsterdam
- Large zoning changes due to COVID19

Solving the optimal allocation problem over time

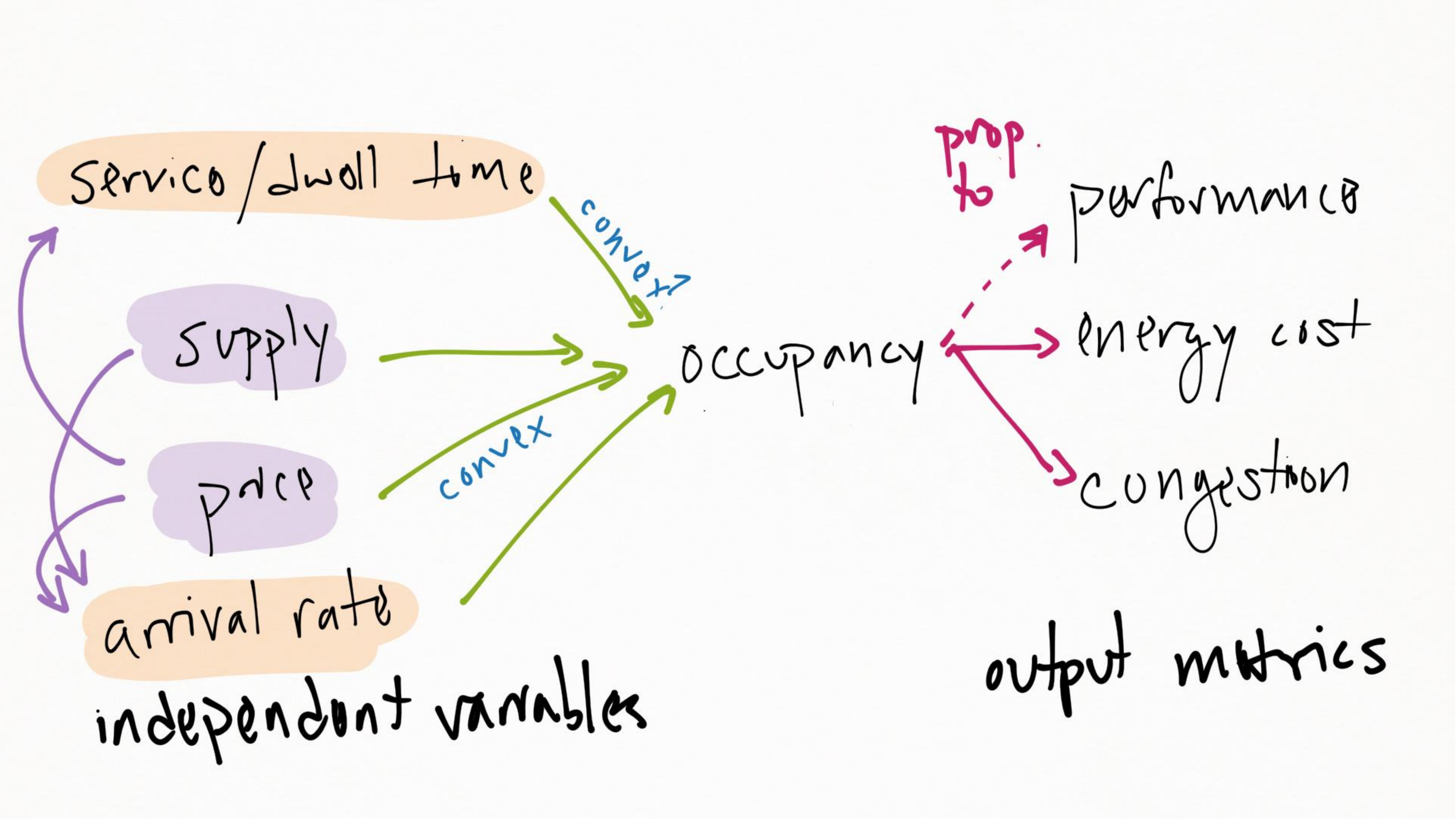
- Turning a central, municipal authorities optimal zoning problem into a dynamic programming problem
- Comparing externalities with *decentralized* market-based reservation systems (e.g. Flex Zones)



Lessons Learned

- Established economic and engineering theories and methods can be used as a lens to focus disparate data sources and paint more complete pictures
- Wealth of municipal data can be used to programmatically adjust curb policy; *more* data required to factor in impact on roadways adjacent to curb zoning changes
- Manual data curation and fusion was extremely time consuming
  - Different data standards across studies (addressing with Lacuna’s open source smart city data stream schema)
  - Different levels of data quality (manual curation)
  - Converting all input data types to least common denominators (identify least common denominator (e.g. arrivals per minute), then bespoke transformation of individual data sources)

Abstracting the data fusion problem



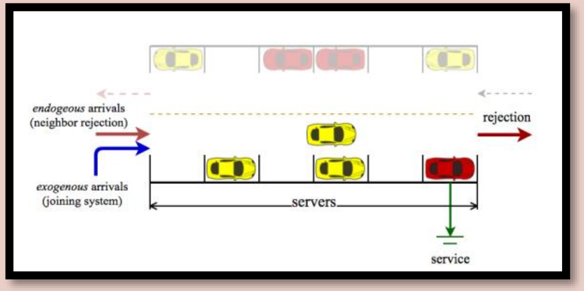
Implementation

The Department of Energy's Vehicle Technologies Office wants to put explorations of novel curb use strategies into practice, not the least of which is curbside EV charging, as well as measuring curb zoning's impact of traffic flow **and associated energy costs incurred by congestion**. This requires:

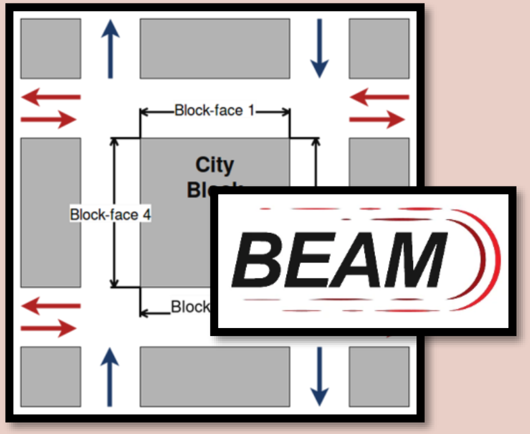
1. The ability to A/B test different curb control policies (UW Urban Freight Lab is building a curb physics engine)
2. The ability to extrapolate curb-level impacts to through-traffic at city-wide scale (LBNL's macroscopic transportation network model BEAM)
3. Selecting optimal zoning strategies (PNNL) according to curb performance and access metrics (NREL) measured by varied data streams, and communicating these zoning changes to users (Lacuna)

Overall Project Goals

Curb Simulation



Curb Physics Engine



City Scale Network Effects

Stakeholder Engagement

Municipality / Market Operator

Optimal Online/Market-based Space Allocation Controller

Sensor/Historical Data

Communications Platform

Online Learning Objectives

Given currently available data this will require a number of ML-oriented tasks

1. Predicting vehicle modality (commercial, transit, private parking, etc.) through either proximity sensors or video data
2. Estimation of demand surface by modality in response to changes in allocation, or at least unsupervised estimation of key centers of mobility demand accessed via the curb
3. Regression of fundamental diagrams (functions that describe roadway flow) as a function of exogenous information, specifically curb zoning and usage (but also things like weather, topography, etc)

Questions and Suggestions?

4: Seinfeld: “The Parking Spot” (S3, E21)

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