JUNE 2021

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

DYNAMIC CURB ALLOCATION (EEMS100)

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Argonne National Laboratory | Berkeley Lab | Idaho National Laboratory | NREL National Renewable Energy Laboratory | Oak Ridge National Laboratory | Pacific Northwest National Laboratory

OVERVIEW

Timeline:
- Start: August 20, 2020
- End: September 30, 2023
- 25% complete

Budget:
- $2.95 million (all federal)
- National Lab: 65%
- Subcontract: 35%
- Funding for FY2020: $11k
- Funding for FY2021: $1.11m

Barriers:
- Curb management increasingly difficult across US cities w/ new users and technologies
- A/B testing & pilots are expensive; microscopic simulation gives cities affordable mechanism to explore alternative curb allocation
- Curb congestion impacts on system energy efficiency
- Need for principled application of data-driven congestion measurement for energy supply chain optimization (e.g. power grid impacts)

Partners
- Pacific Northwest National Laboratory
- Lawrence Berkeley National Laboratory
- National Renewable Energy Laboratory
- University of Washington Urban Freight Lab
- Lacuna

RELEVANCE

Curb use is a significant local policy issue; why does *DoE* care?

Curb management is a ubiquitous example of transportation engineering municipalities are grappling with; this and other roadway configuration features and environment factors impact travel speed vs vehicle flow (i.e. **fundamental diagrams**). Understanding exogenous factors like curb use as case-in-point will be critical for optimizing energy supply chains including power distribution for electrified vehicles

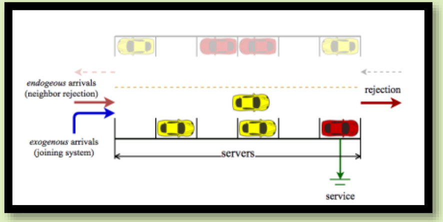
I-5 looking south toward Seattle[1]

The Seattle-Tacoma Airport departures curb drop off[2]

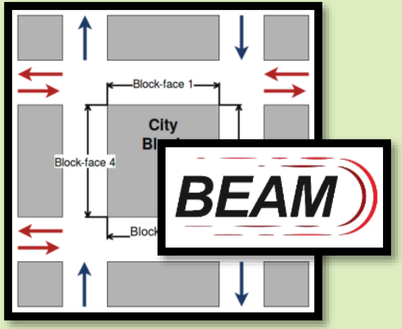
1. Image Credit: SounderBruce CC 2, via Wikimedia Commons
2. Image Credit: Port of Seattle, CC 0

APPROACH (~YEAR 1)

Curb Simulation



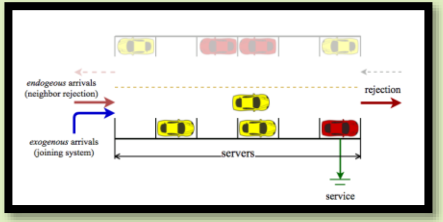
Microscale Simulator



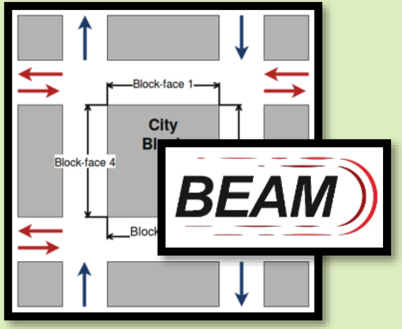
Macroscale Simulator

APPROACH (~YEAR 1)

Curb Simulation



Microscale Simulator



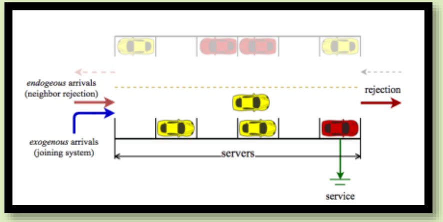
Macroscale Simulator

Using microscale simulations(Milestone 1) we developed a novel *stateful* fundamental diagrams (FDs) (Milestone 2)

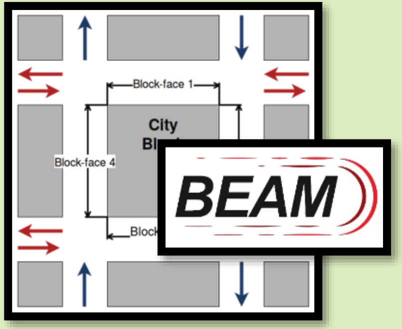
- Stateful FDs account for the time-dependent states of the environment, network, and travel demand to more dynamically measure roadway flow
- Stateful FD methods can be applied to different exogenous variables; here, we are focused on curb configurations and their resulting efficiencies (productivity, energy, access, etc.)

APPROACH (~YEAR 1)

Curb Simulation



Microscale Simulator



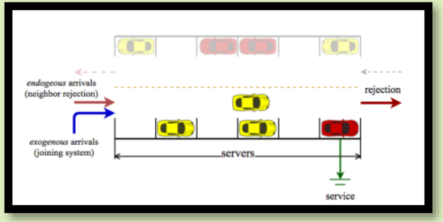
Macroscale Simulator

Agent-based transportation system models (LBNL's BEAM) will accept *stateful* FD's as a function curb configuration (Go-No/Go 1)

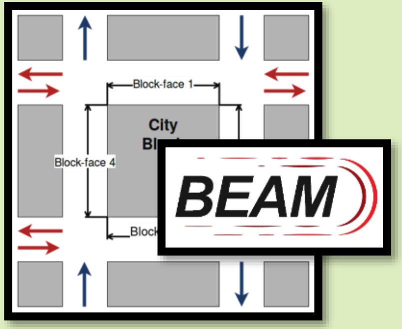
- SMART needs to measure how curb configuration (e.g. transit vs EV charging vs parking) impacts system energy efficiency

APPROACH (~YEAR 2)

Curb Simulation



Microscale Simulator



Macroscale Simulator

Stakeholder Engagement

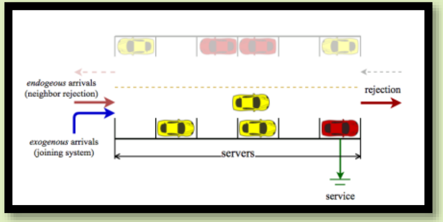
Municipality / Market Operator

Optimal Online/Market-based Space Allocation Controller

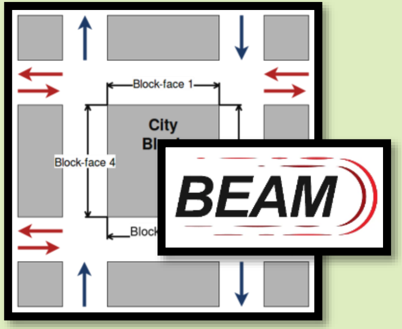
Sensor/Historical Data

APPROACH (~YEAR 3)

Curb Simulation



Microscale Simulator



Macroscale Simulator

Stakeholder Engagement

Municipality / Market Operator

Optimal Online/Market-based Space Allocation Controller

Sensor/Historical Data

Communications Platform

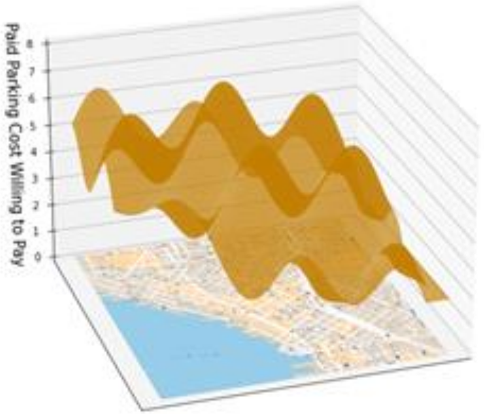
MILESTONES & GO/NO-GO

Date	Status	Description
1/31/20	Complete	(M1) Microsimulation tool specified and selected
4/30/21	Complete	(M2) Microsimulation results by vehicle type
7/30/21	In-progress	(M3) Ground truth validation planned and scoped
9/30/21	**In-progress**	**(G1) Microscale simulation outputs integrated into BEAM (Go/No-Go)**
12/30/21	On-track	(M4) City and commercial partner engagements documented and scoped
5/30/22	On-track	(M5) Test simulations of optimal curb allocation policies

CURB METRICS FOR OPTIMAL DYNAMIC CONTROL

To define an objective function, we use SMART 1.0 curb performance metrics to define a net utility, either from the user or system perspective

Net User Utility	Utility	Disutility
Internalized	Value of access to space to user (e.g. number of food truck sales)	Cost to access the space (e.g. time spent cruising, parking fare)
Externalized	Value of services provided by user (e.g. foot traffic at local business)	Congestion and emissions created by user accessing the space



Hypothetical cost-willing-to-pay surface for a given zone type projected over curb real estate in downtown Seattle

DYNAMIC CONTROL FORMULATION

Solving with respect to a centralized controller first

- Solved for the centralized control case (from municipal perspective) using dynamic programming
  - Can account for switching constraints (e.g. at right)
  - Can account for cardinality constraints
  - Currently addressing distance constraints
  - Assume noise in realized demand, addressing non-stationary noise

$$\text{maximize} \ \mathbb{E} \sum_{t=1}^{T} [F_t(u_t) + \epsilon_t]$$

$$\text{subject to} \ \sum_{t=1}^{T-1} \frac{1}{2} ||u_{t+1} - u_t||_1 \leq b.$$

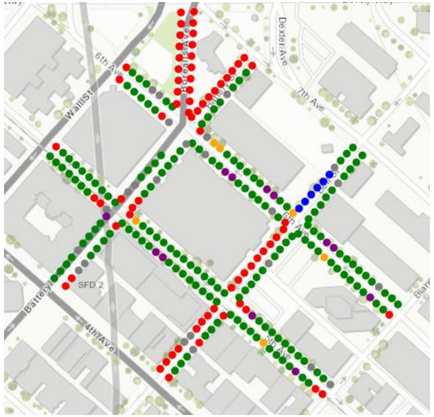
F is a net utility measure for a single curb space; *u* is an allocation signal, with the resulting utility being subject to non-IID noise. This example constraint limits the number of zoning changes over time horizon *T*

SINGLE TIME STEP REALLOCATION

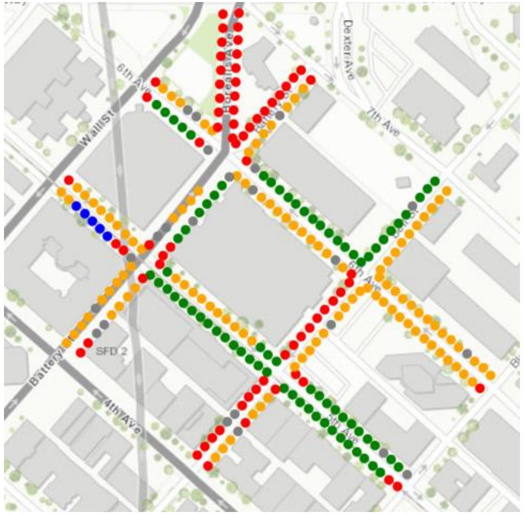
Using carefully regressed objective functions and available data, we can begin to compute new optimal allocations with and without constraints

- Paid Parking
- No Parking
- Bus Stop
- Commercial Vehicle Loading
- Passenger Loading
- Driveway

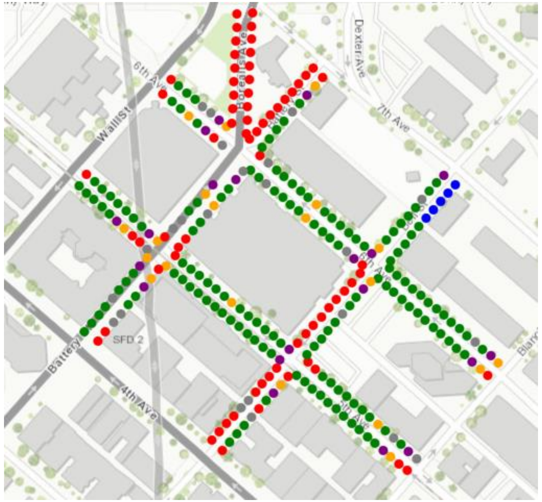
6th & Battery in Seattle



Current allocation



Unconstrained optimization



Cardinality constrained optimization

MICROSCALE SIMULATOR PROGRESS

Vehicle types and curb allocations are defined (Milestones M1 & M2)

- **Curb Allocations:**

  bus stop, passenger load zone (PLZ), commercial vehicle load zone (CVLZ)

- **Vehicle Types:**

  (built-in) passenger cars, buses, heavy goods vehicles +

  (added) TNCs, commercial vans

CVLZ PLZ Bus stop *Rest are paid parking

Passenger vehicle TNC Bus
commercial vans Heavy goods vehicle

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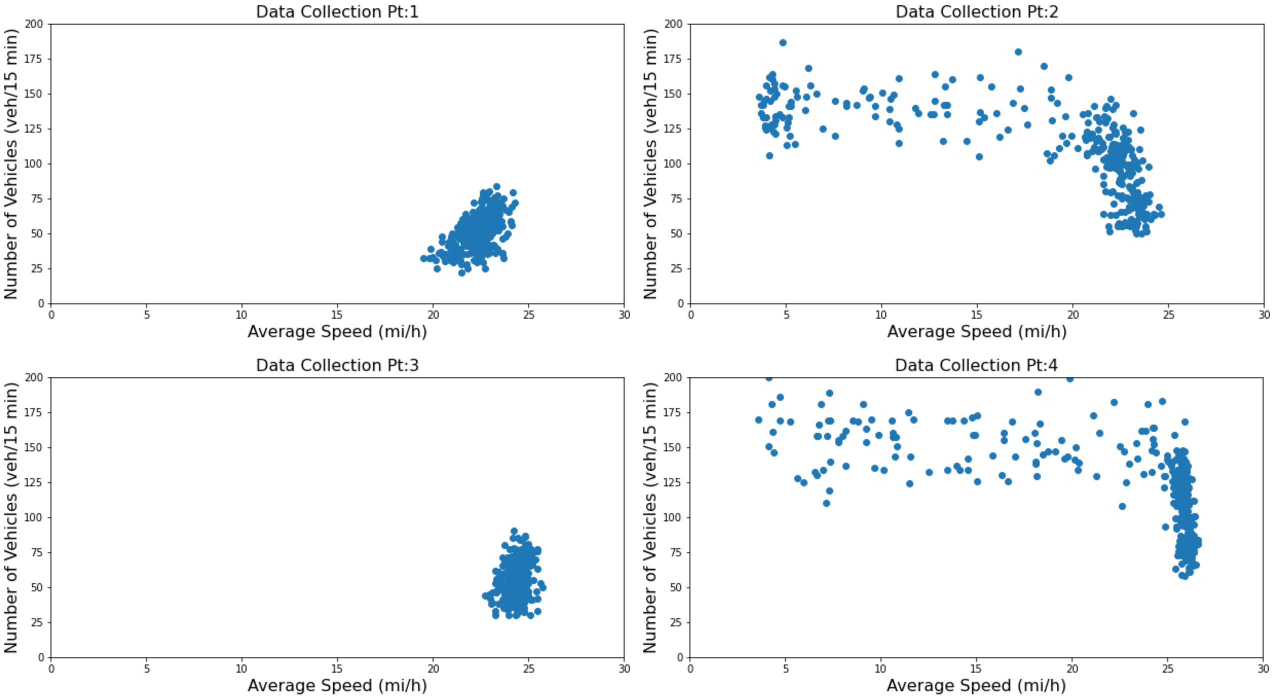
INITIAL STATEFUL FUNDAMENTAL DIAGRAMS FOR BASELINE SCENARIO

- Curb rules: Paid parking for passenger cars, Passenger loading zones (LZ) for TNCs, and commercial vehicle LZs for commercial vans.
- Dwell times are defined as distributions for each vehicle type.
- Percentage of drivers looking to park: 30%
- Stateful fundamental diagrams for BEAM integration (Milestones M2 & G1)

Numbered traffic flow sensor points and corresponding flow diagrams at right



Fundamental diagram simulations; each point is a single simulation

RESPONSE TO PREVIOUS YEAR REVIEWERS' COMMENTS

This project is in its first year.

COLLABORATION & COORDINATION

Collaborating institutions form a uniquely broad covering set of curb stakeholders (cities, commercial fleets, and startups); project-wide biweekly meetings with high frequency task-specific meetings between collaborators as needed

- **Pacific Northwest National Laboratory**
  – PNNL is responsible for developing fundamental diagram learning techniques, research and implementation of dynamic control algorithms, and managing systems integration
- **University of Washington Urban Freight Lab**
  – The Urban Freight Lab is responsible for microscale simulator design and specification for curb configuration analysis
- **Lacuna**
  – An urban mobility startup developing the communications systems and data pipeline utilizing an open source Mobility Data Specification (MDS)
- **Lawrence Berkeley National Laboratory**
  – Developers of the mesoscopic transportation system simulator BEAM, which will accept stateful fundamental diagrams to measure system wide energy impacts of curb configuration
- **National Renewable Energy Laboratory**
  – Developers of SMART 1.0 curb performance metrics that form the basis of an objective function for online optimization of curb allocation

REMAINING CHALLENGES

We will need to address non-trivial technical issues that cut across transportation and economics literature

- To achieve meaningful practicality, any dynamic allocation of curb space will require a serious treatment of **induced demand** and **user elasticities**
  - **Induced demand:** we are exploring predictive performance in sequential decision making problems to model induced demand
  - **User elasticity:** we are working with researchers actively investigating user sensitivities to price and availability[3]
- To maximize the micro-to-meso transferability of stateful fundamental diagrams, we will need to develop an effective sampling strategy across canonical curb configurations and learn sets of diagrams, or possibly a more general governing function
- Achieving milestones M4 with prospective micro- and mesoscale simulation users requires careful coordination with municipal stakeholders. Our first prototype working group including Seattle and Bellevue, WA has already been formed to test run information dissemination and network with other municipalities. These stakeholders are providing access to specialized data to help validation efforts for milestone M3

3. Ostermeijer et al. 2021 “Citywide parking policy and traffic: Evidence from Amsterdam”

PROPOSED FUTURE RESEARCH

The project is well positioned to explore more powerful solutions

- Initial results (M1 & M2) paint a compelling picture of the impact of exogenous factors on the fundamental diagram of an adjacent roadway.
  - We are well positioned to meet originally proposed categorical search of typical configurations using classical regression techniques
  - Stateful FD's will be integrated into BEAM (G1) to capture system-wide energy impacts
  - We will then investigate physics-informed machine learning techniques to learn differential equations that cover wider ranges of curb configurations
- Stateful FD's have broad applicability beyond curb design
  - Other exogenous factors like weather, topography, and vehicle composition could also be studied in future work

PROJECT SUMMARY

Technical deliverables on schedule and municipal engagement proceeding at an aggressive pace.

- Curb performance metrics developed during SMART 1.0 have been adapted to defining an objective function for online optimal curb zoning
- A microscale simulator has been developed to simulate various curb configurations utilized by multiple vehicle types, and associated fundamental diagrams can be measured
- These diagrams are being prepared to be integrated into BEAM to measure system wide impacts
- Leading a curb working group with Seattle and Bellevue to test run future municipal and partner engagement plans (milestone M4)

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MOBILITY FOR OPPORTUNITY

FOR MORE INFORMATION

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OAK RIDGE National Laboratory

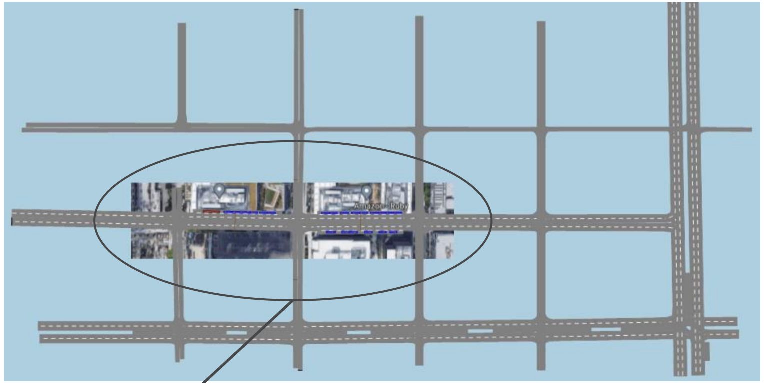
Pacific Northwest NATIONAL LABORATORY

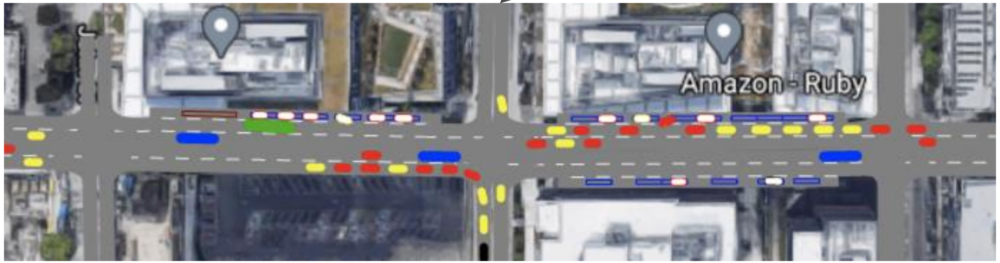
TECHNICAL BACKUP SLIDES

DIVIDER SLIDE

VISSIM SIMULATION SCALE

The study network is built off a real road network in the core business district of Seattle, but several adjustments have been made to the number of lanes and signal controls.





- **Two main blocks** to implement various curb allocations
- **Larger roadway network** to allow for additional vehicle maneuvers and to not constrain vehicles to the four study blockfaces

DATA COLLECTION POINTS ARE PLACED

Speed and Volume data:
in each direction on study blocks

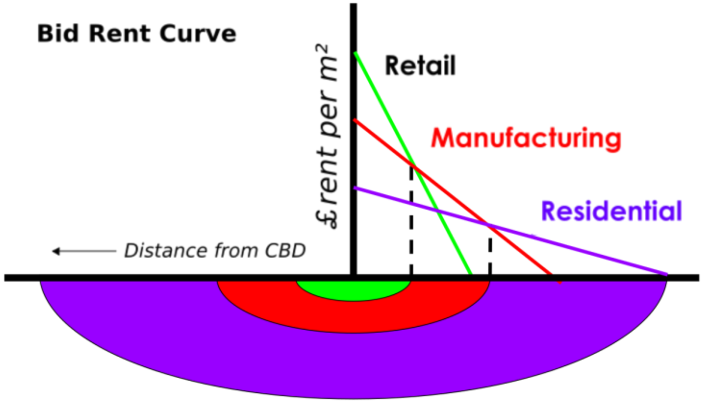
Speed-flow fundamental diagrams

Curb Space data:
in each curb space

Space occupancy, turnover, throughput, etc.

BID-RENT THEORY OF CURB SPACE

Applying SMART 1.0 curb performance metrics to understanding the utility of curb space to users and to the transportation system



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

Centralized patterns of demand for private parking[4] in Belltown, Seattle

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

ESTIMATED NET UTILITY OVER TIME

Slide 12 looks at a potential static reallocation of curb space at a specific point in time given price estimates, value of time, cost of emissions, etc. At right is the net utility of the optimal allocation (where slide 12 is a single time of day) over the course of a typical weekday, corresponding to space cardinality constraints.