Modeling and Optimizing Paratransit in the Age of TNCs

NUTC Seminar, Northwestern University
26 April 2018

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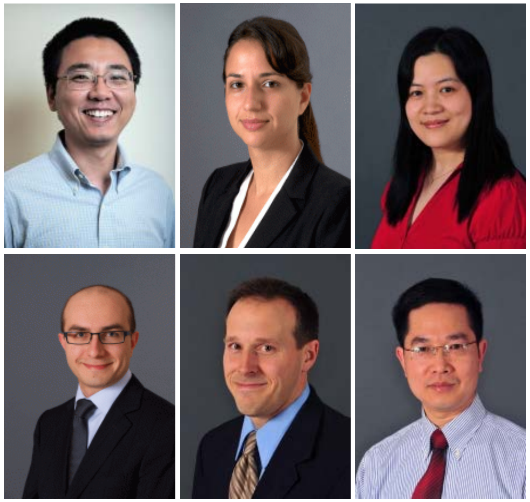
6 Faculty in Transportation Group

- Traffic operations and control
- Public transportation
- Systems analysis
- Transportation safety
- Human factors
- Air traffic modeling and control



UMass Amherst Transportation Center

- Regional Traveler Information Center (RTIC)
- Local Technical Assistance Program (LTAP)
- Transportation Training Institute (TTI)
- Cooperative Research Program
- UMass Traffic Research Safety Program (UMassSafe)
- Aviation Center

Research Motivation

How can transportation systems be designed and managed to respond to users' needs?

- Simple models of system operations provide useful insights for providing efficient service.
- Taxis (and TNCs) have the potential to serve some trips at lower cost.
- Future systems may exploit benefits of multiple services operating together to serve diverse demand.

Outline

1 **Demand Responsive Transit: ADA Paratransit**

2 **Modeling Paratransit Operations**

3 **Operation and Demand Strategies**

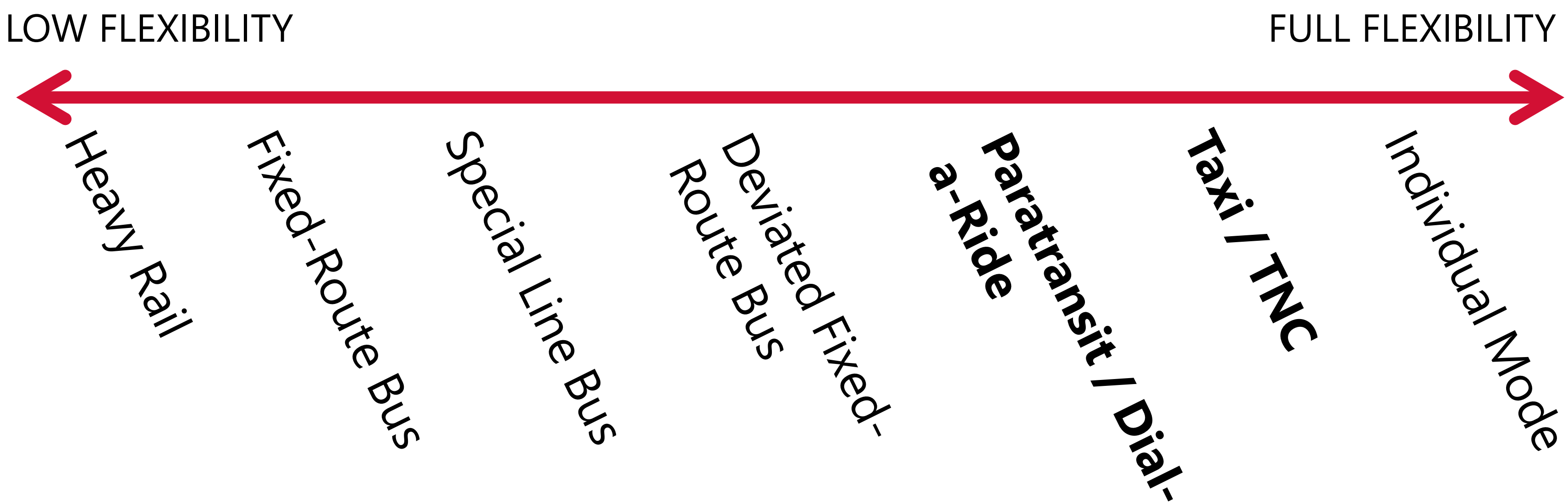
4 **Coordination with Taxis and TNCs**

1 ADA Paratransit

Demand Responsive Transit

DRT includes modes of transportation that serve the public, which adapt to passenger demands by changing routes, stops, and/or departure times.

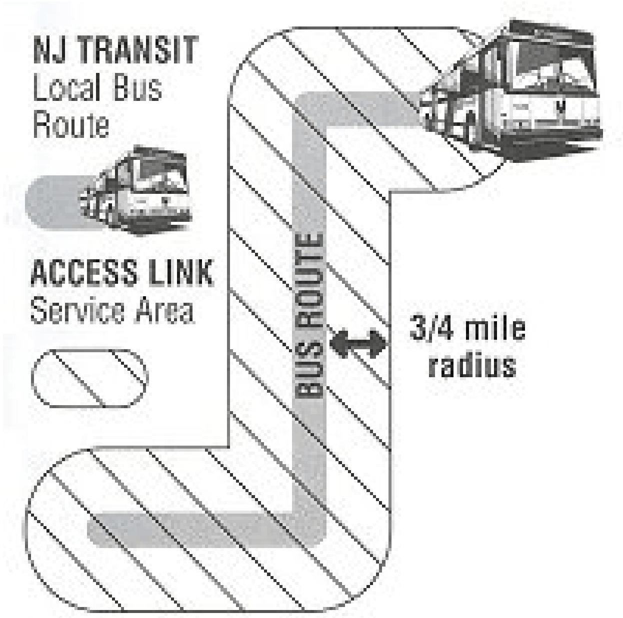
How Much Route and Schedule can Change



ADA Paratransit

Required Service for People with Disabilities

- Required by Americans with Disabilities Act of 1990
- Required for agencies to receive federal funding
- Customers who are unable to navigate public bus system, or are unable to access the system are eligible
- Transit operators must provide paratransit service to destinations with 3/4 mile of fixed routes, same hours of operation.



ADA Paratransit

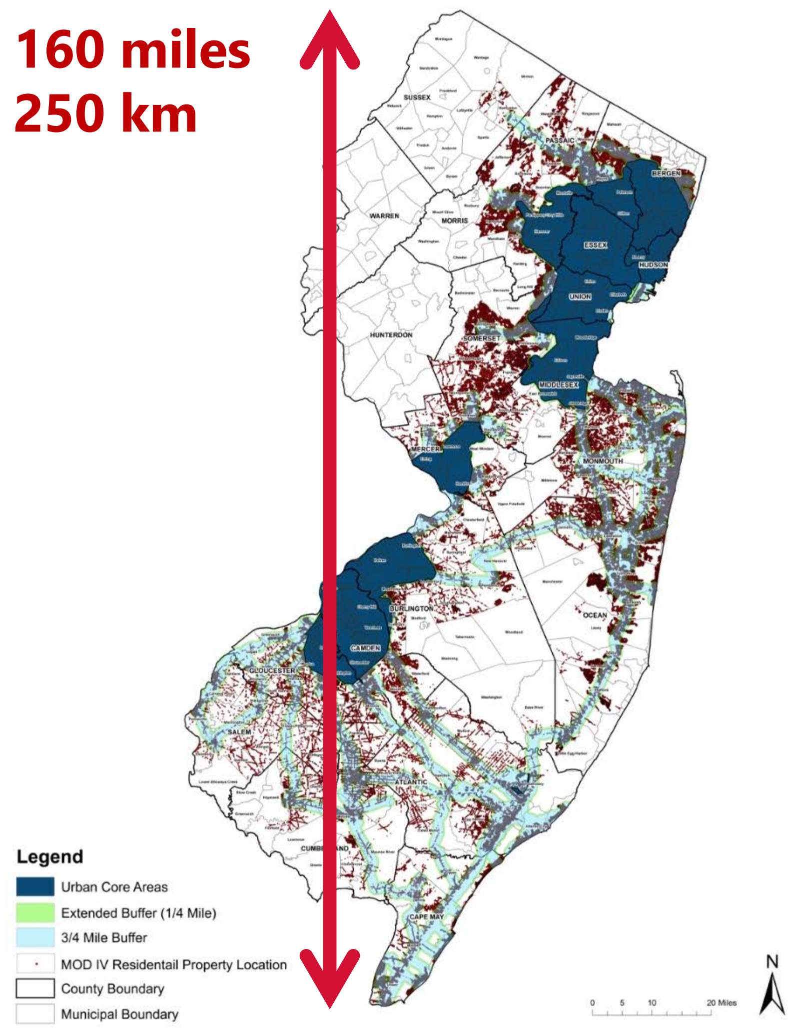
Requirements

- Trips are reserved at least 24 hours in advance
- Scheduled pick-up is within 1 hour of requested pick-up; Actual pick-up is within 20 minutes of scheduled pick-up
- Travel time is within 1.5×, and fare within 2× conventional mode

New Jersey Transit: Access Link

Statewide Paratransit Service

- Annual Trips: 951,000 trips/yr
- Service Region: 18,000 km^2
- Vehicle Fleet: 372 veh
- Urban core areas provide contiguous coverage
- ¾ mile buffers provide service around outlying bus routes



New Jersey Transit: Access Link

Statewide Paratransit Service

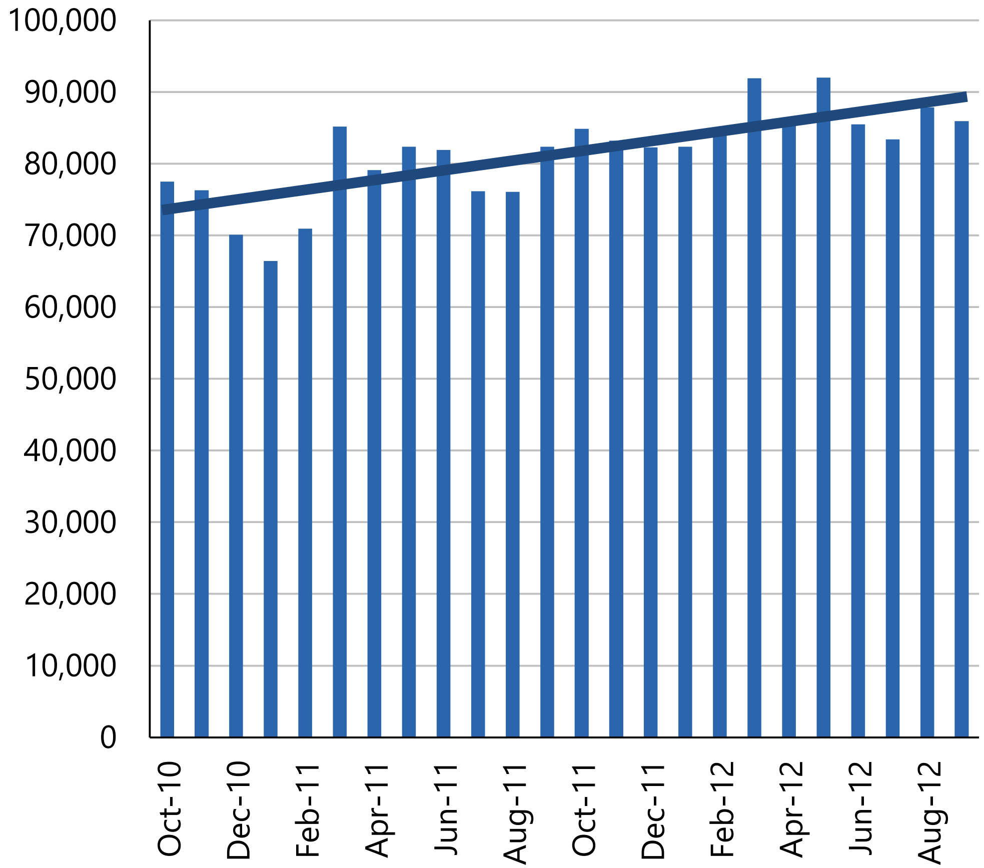
- State is divided into 6 overlapping service regions
- Trips are served without transfer within each region. Travel between regions requires a transfer.
- Service in each region is operated under a separate contract, with separate fleet and facilities

Growing Demand for ADA Paratransit

National Trends

- Demand increased by 41% from 2000 to 2010.
- Paratransit customers are 5-7% of demand, but 20-25% of operating costs. (National Transit Database)
- Aging population will cause this increase to continue.

Access Link Passenger Pick-Ups per Month



Low Density Development

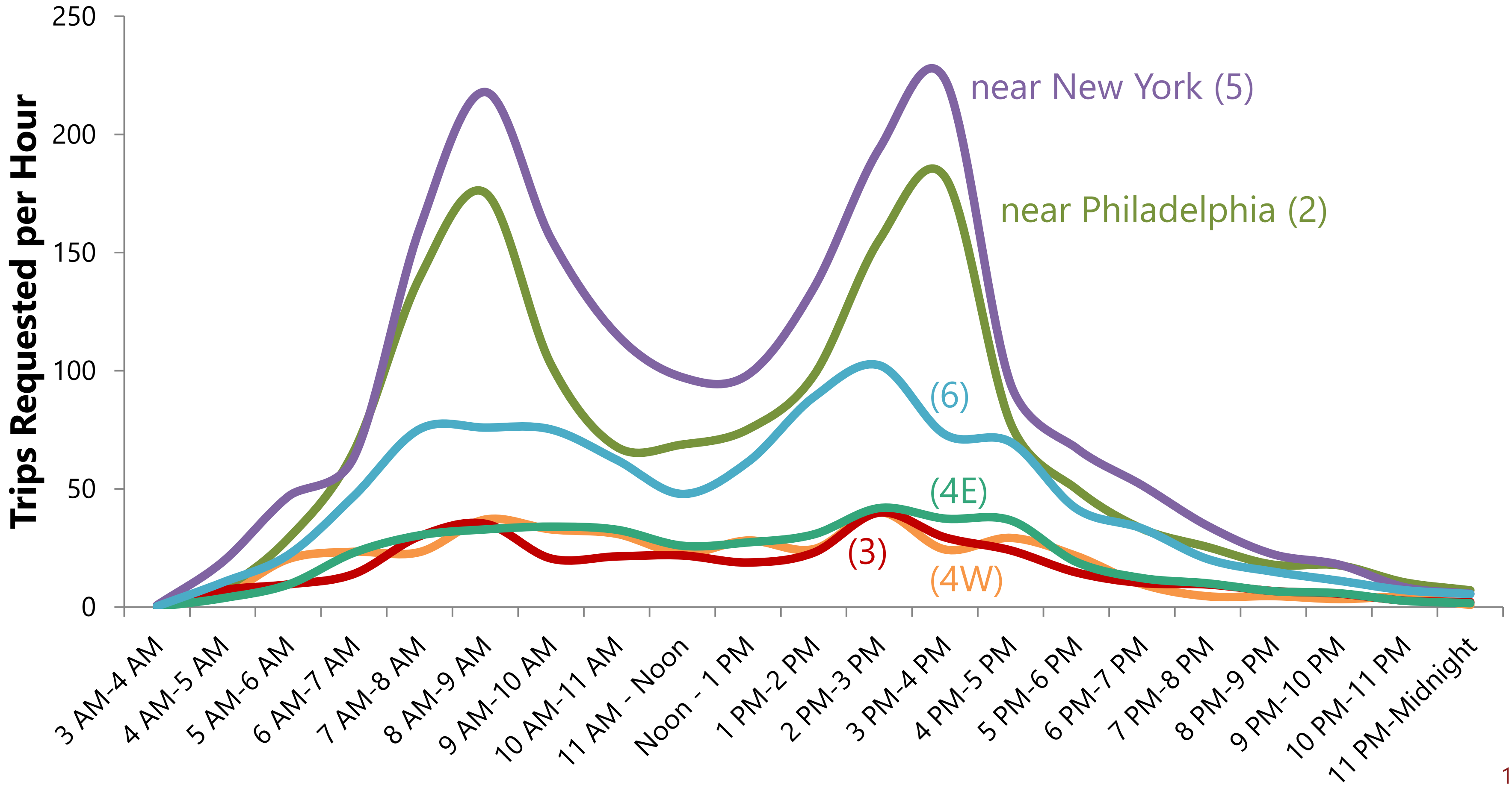
The average American lives in a neighborhood with 2,440 people/km^2.

Source: http://www.citylab.com/housing/2012/10/americas-truly-densest-metros/3450/

Avenel, New Jersey

Peaked Demand

Demand is very peaked at certain times of day. Vehicles and drivers are costly when only used for a short time period.



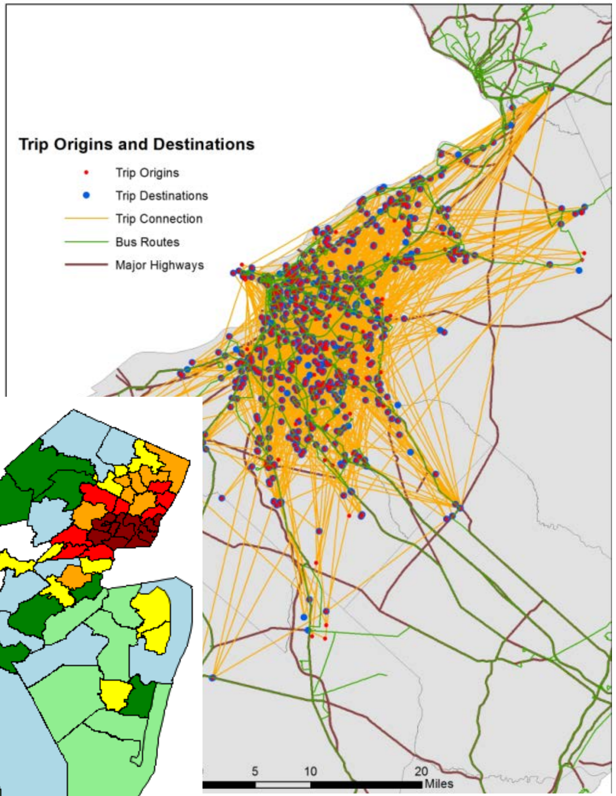
2 Modeling Paratransit Operations

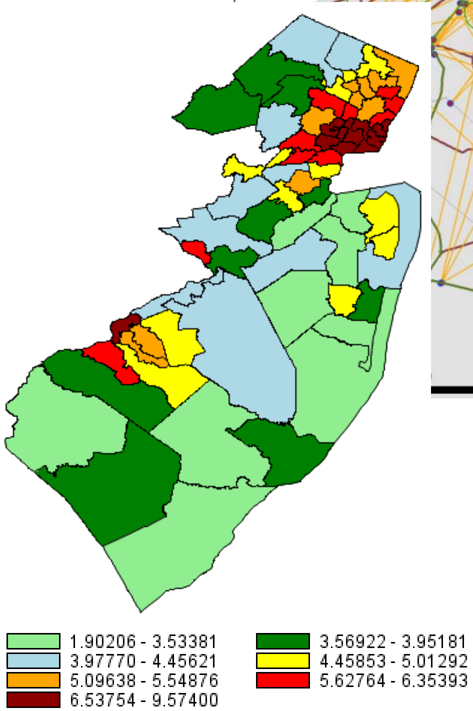
Data Sources

Records of All Trips
October 2010 – September 2012: ~2 million trips

- Pick-up/Drop-off Locations
- Pick-up/Drop-off Times
- Passenger ID
- Vehicle ID

Average Vehicle Speeds (min/mile)

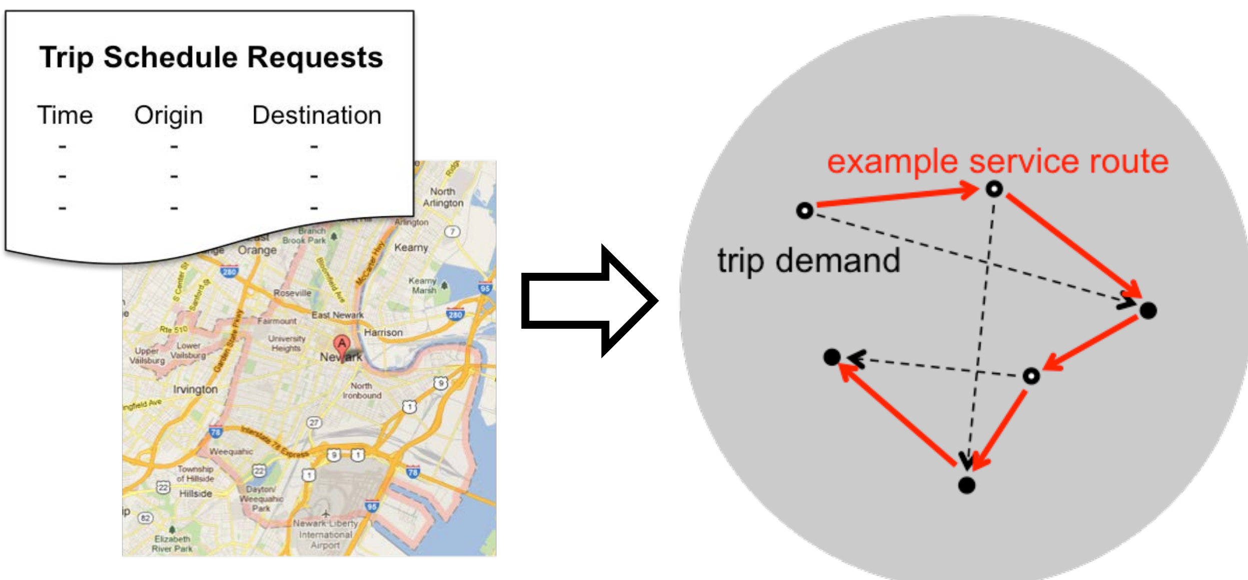




Continuous Approximation Model

Continuous approximation is a technique to treat integer variables (e.g., number of vehicles, number of passengers, etc.) as continuous values so that simple equations can define general relationships.

For each region i, and each time period j:



Data Inputs
Region Area
Demand
Time-Window Constraint
for Pick-up
Travel Time Constraints

Data Outputs
Total Vehicle Miles
Total Vehicle Hours
Required Fleet Size

Continuous Approximation Model

Specific origin-destination demands and corresponding routes vary from day to day. For planning purposes, a **continuous approximation** model is useful for modeling aggregate operations and costs.

Operation Model **Cost Model**

λ **Demand Rate**

T **Time Window**

A **Service Area**

v Traffic Speed

n Vehicle Occupancy

b Duration of Stop

VMT **Vehicle Miles**

M **Fleet Size**

VHT **Vehicle Hours**

Cost per Pick-up

Total Annual Cost

Rahimi and Gonzales (2015)

Operation and Cost Model

Vehicle Miles Traveled (VMT)

$$VMT = r_1 \frac{\lambda\sqrt{A}}{2}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)$$

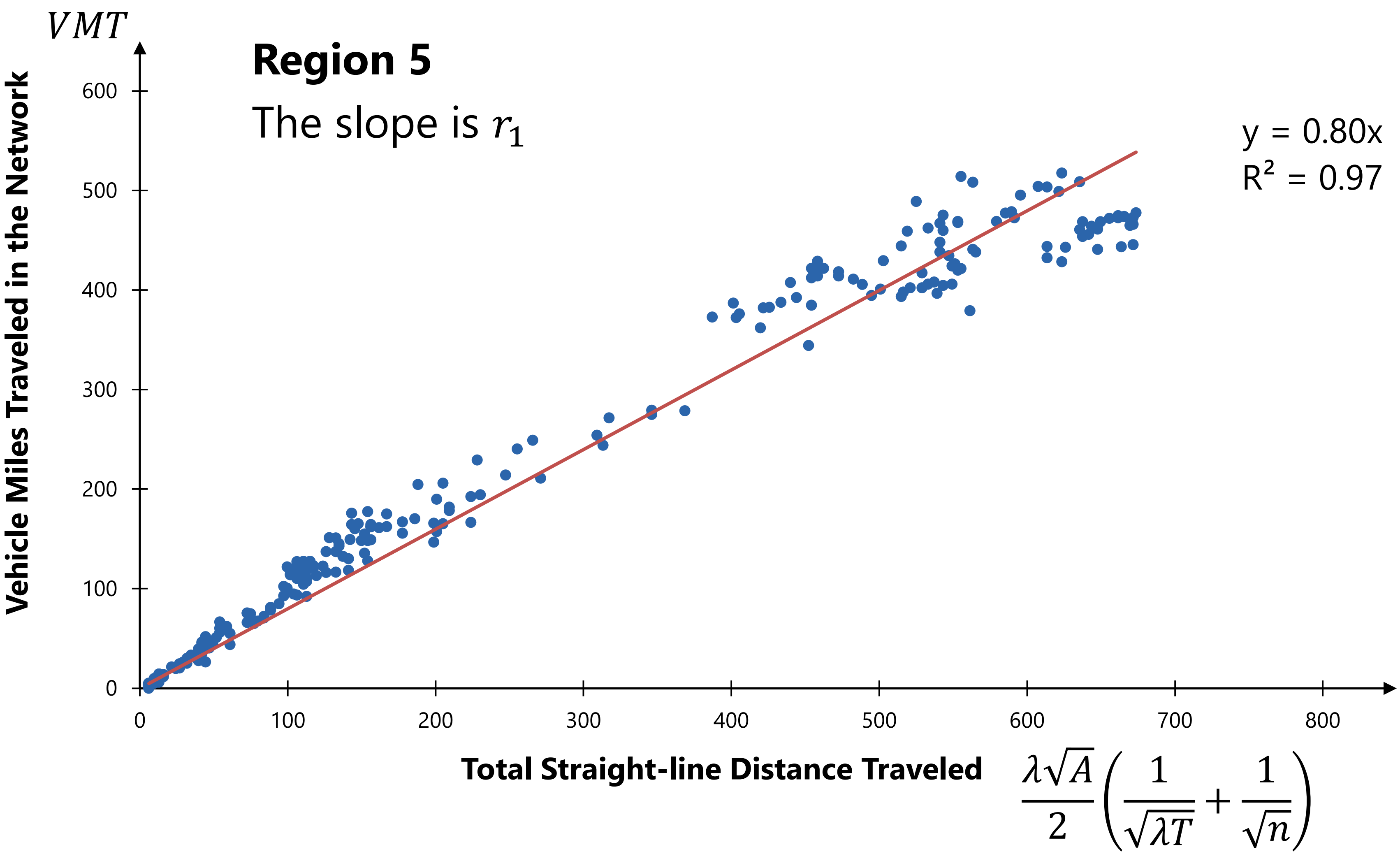
- λ Demand Rate [pick-ups/time]
- A Area of Service Coverage [dist^2]
- T Time Window (maximum difference from schedule) [time]
- n Vehicle Occupancy [passengers]

Vehicle Hours (VHT) and Fleet Size (M)

$$VHT = Mt_p = \lambda t_p\left(b + r_2 \frac{\sqrt{A}}{2v}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)\right)$$

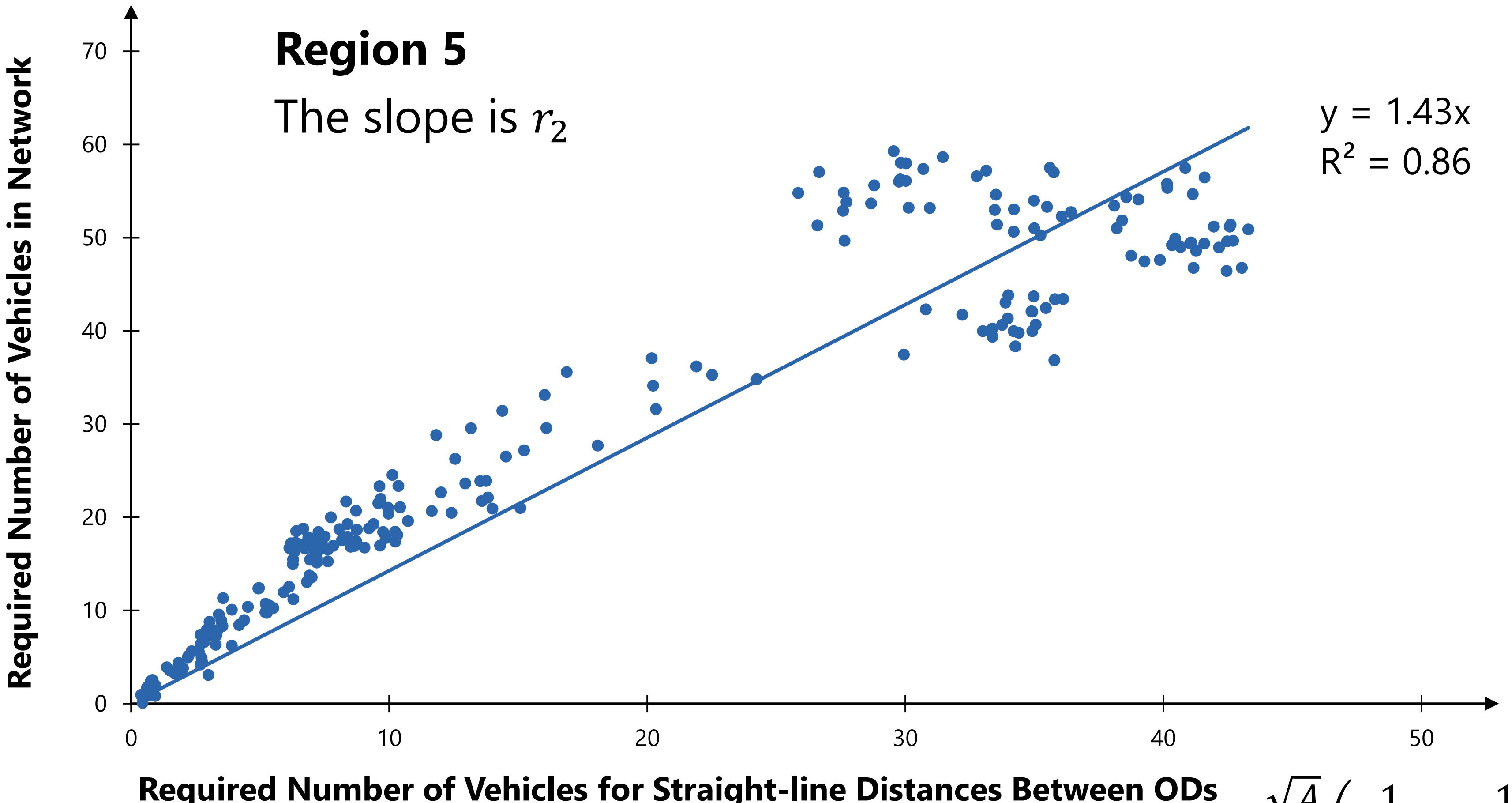
- t_p Duration of Time Period [time]
- b Average Boarding & Alighting Time [time]
- v Average Traffic Speed [dist/time]

Operation Model: Vehicle Miles Traveled (*VMT*)



Operation Model: Vehicle Hours Traveled (*VHT*)

$M - \lambda b$



$$\lambda \frac{\sqrt{A}}{2v}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)$$

Comparing Efficiency in Service Regions

The r factors provide an indication of how efficiently resources are used. The VHT value will always be greater than VMT because extra waiting time in the schedule increases its value.

Region	r_{VMT}	r_{VHT}
2	0.86	1.65
3	1.19	2.22
4E	0.99	1.58
4W	1.25	4.08
5	0.80	1.43
6	0.95	1.61

Operation and Cost Model

Vehicle Miles Traveled (VMT)

$$VMT = r_1 \frac{\lambda\sqrt{A}}{2}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)$$

Vehicle Hours (VHT) and Fleet Size (M)

$$VHT = Mt_p = \lambda t_p \left(b + r_2 \frac{\sqrt{A}}{2v}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)\right)$$

Total Cost of Paratransit (TC)

$$TC(\lambda) = \alpha_0 + \alpha_1 \frac{r_1 \lambda\sqrt{A}}{2}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right) + (\alpha_2 t_p + \alpha_3)\left[b\lambda + \frac{r_2 \lambda\sqrt{A}}{2v}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)\right]$$

- λ Demand Rate [pick-ups/time]
- A Area of Service Coverage [$dist^2$]
- T Time Window (maximum difference from schedule) [time]
- n Vehicle Occupancy [passengers]
- t_p Duration of Time Period [time]
- b Average Boarding & Alighting Time [time]
- v Average Traffic Speed [dist/time]

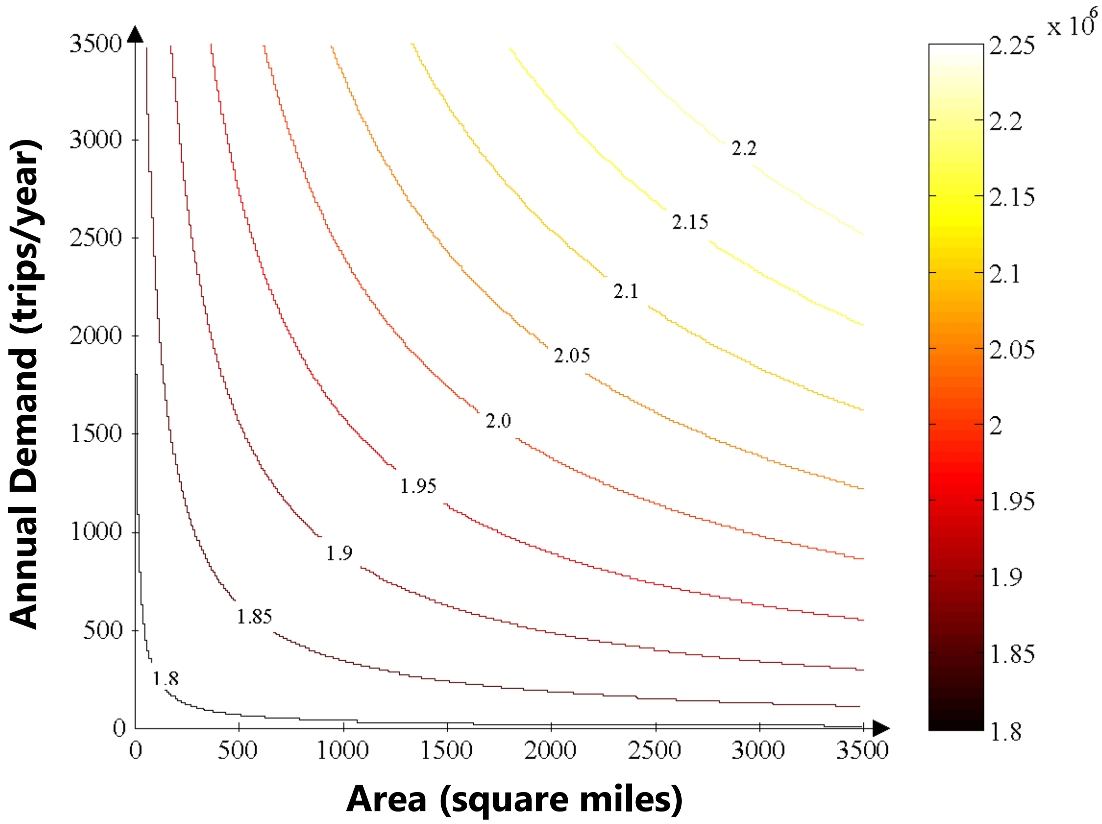
Model for Access Link Region 5

Parameter	Value		Fit (R^2)
Area of Service Coverage, A	559	mi^2	
Travel Demand, λ	381,049	pax/yr	
Vehicle Occupancy, n	1.26	pax/veh	
Average Traffic Speed, v	23.6	mi/hr	
Fleet Size, M	99	veh	
Boarding & Alighting Time, b	4.0	min	
Travel Distance Parameter, r_1	0.80		0.97
Travel Time Parameter, r_2	1.43		0.86
Fixed Annual Cost, α_0	1,780,000	$	
Cost per Vehicle Mile, α_1	0.46	$/veh-mile	0.91
Cost per Vehicle Hour, α_2	14.35	$/veh-hr	0.92
Annual Cost per Vehicle, α_3	37,879	$/veh	0.93

Characteristics of Total Annual Operating Cost

Annual operating cost increases with demand and with coverage area. Growing demand means increasing costs for agencies.

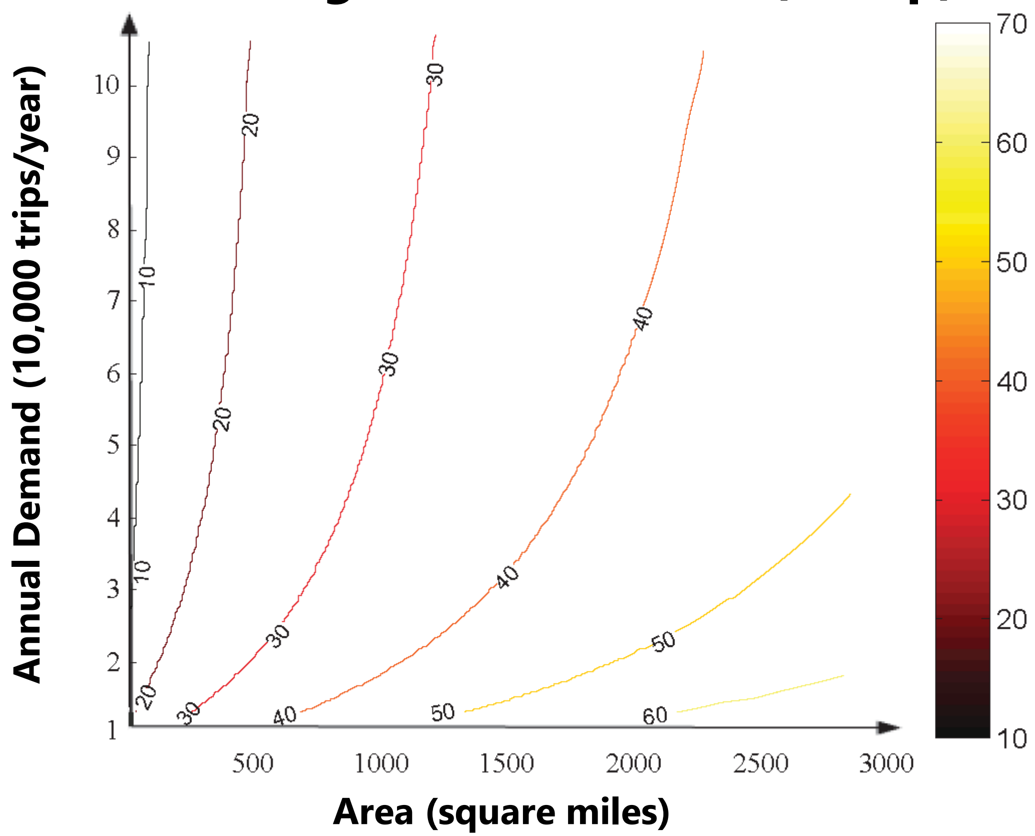
Annual Cost Contours (Million $)



Characteristics of Average Operating Cost per Trip

Average cost per trip increases with area, but decreases with demand. More dense demand makes the system more efficient.

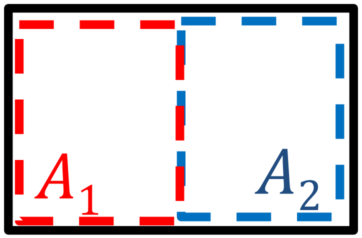
Average Cost Contours ($/Trip)



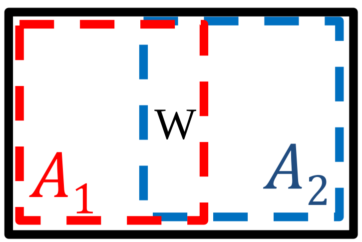
3 Operation and Demand Strategies

Cost Comparison of Zoning Strategies

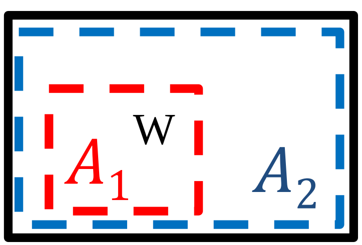
Symmetric Non-Overlapping

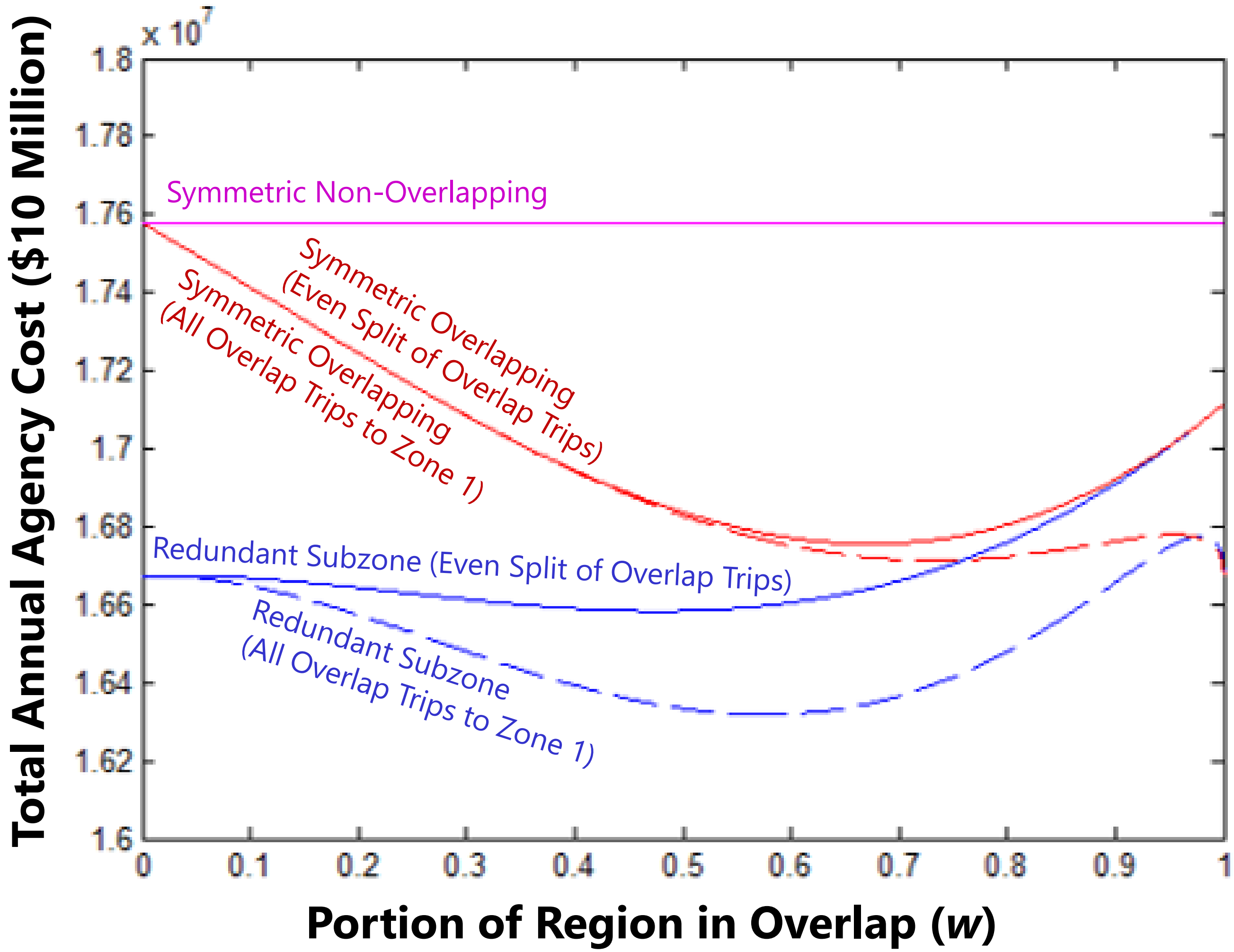


Symmetric Overlapping



Redundant Subzone





Effect of Transfers on Operations and Demand

Many agencies split large operating areas into multiple zones. Travel from one zone to another requires a transfer that delays travelers and requires an extra vehicle trip.

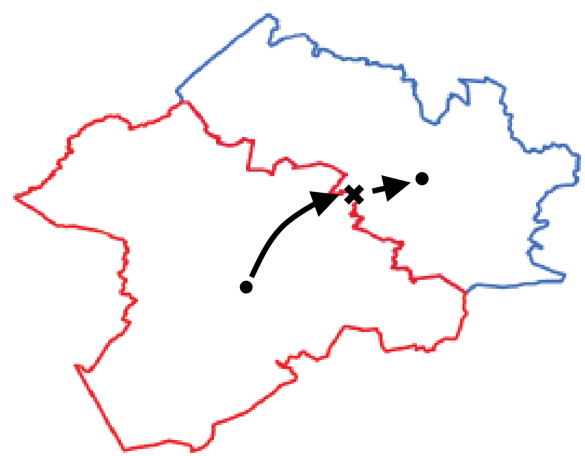
Access Link Region 5

Single Region

$$t_{od} = md_{od} + b + w_o$$

Access Link Region 5

2 Zones



$$t_{od} = md_{od} + b + w_o + X$$

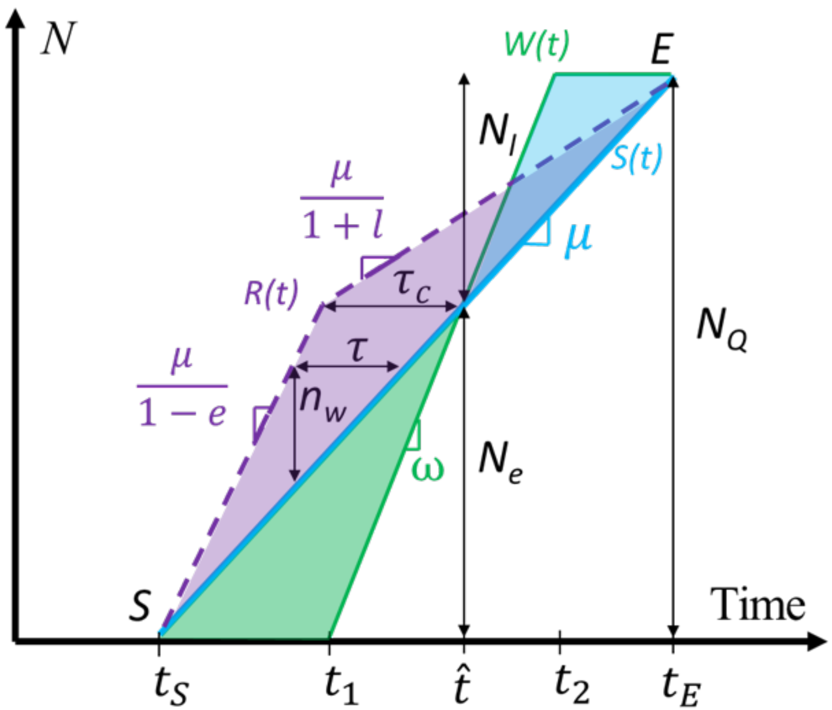
Transfer Time, $X = 9.6$ min

Time-Dependent Pricing to Spread Demand

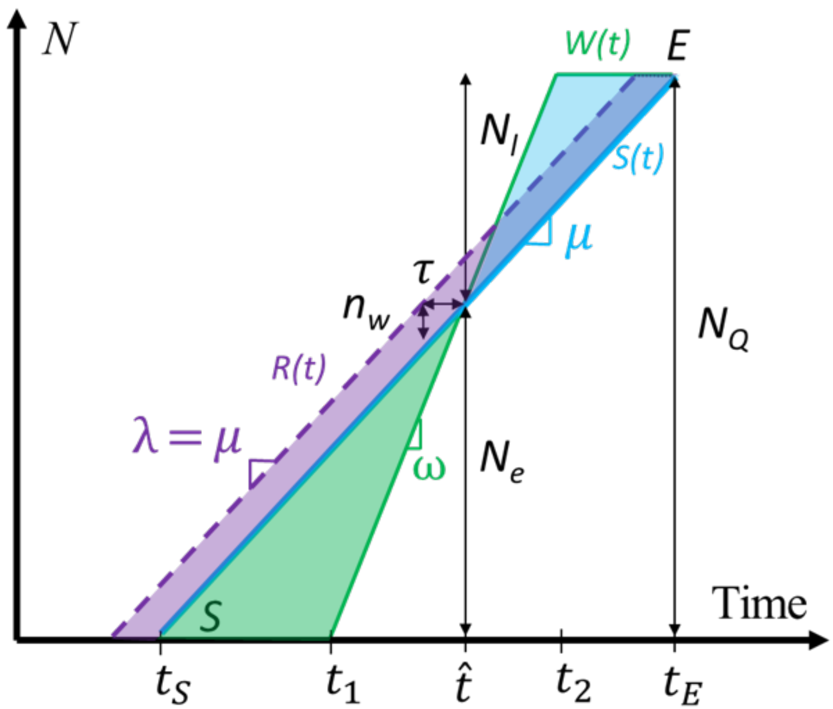
(Amirgholy and Gonzales, 2015)

The capacity of DRT service depends on the number of waiting customers. Adaptation of bottleneck pricing optimizes operations.

Optimizing Capacity Without Pricing



Optimizing Capacity With Pricing

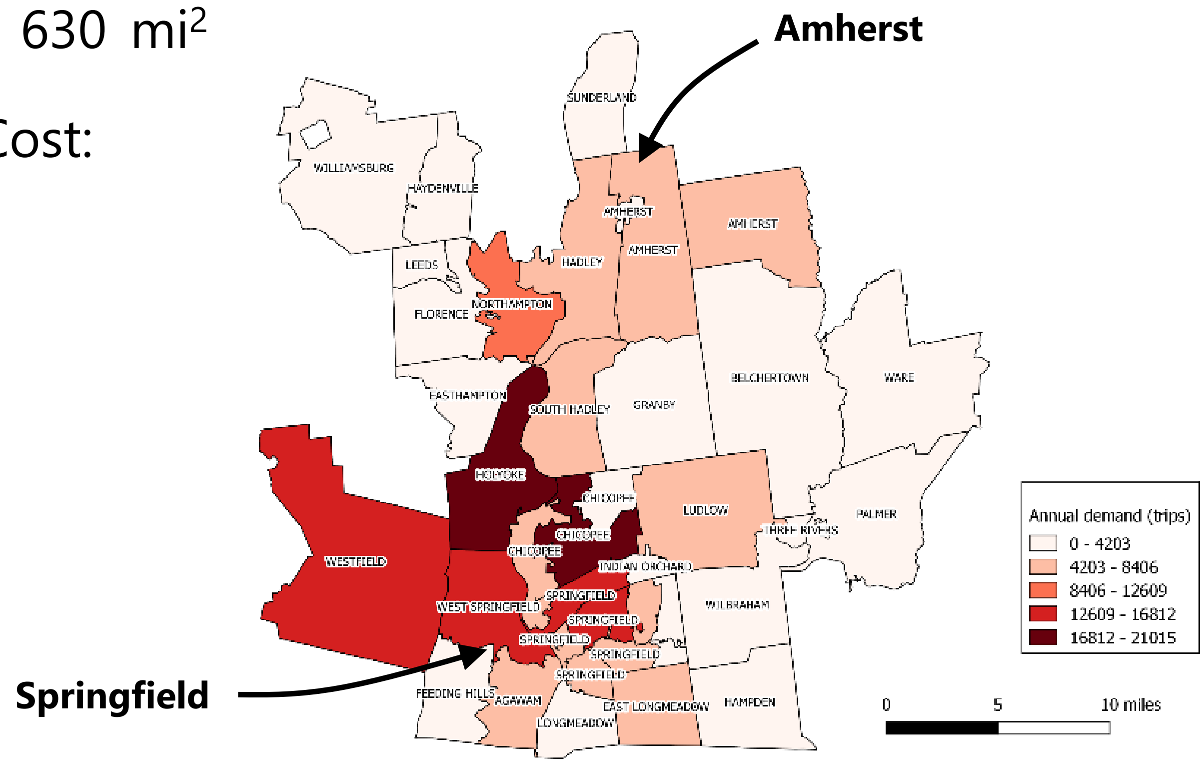


4 Coordination with Taxis and TNCs

Pioneer Valley Transit Authority (Springfield, MA)

Regional Paratransit Service

- Annual Trips: 215,000 trips/yr
- Service Region: 630 mi^2
- Average Operating Cost: $28.66 per trip



Pioneer Valley Transit Authority (Springfield, MA)

Regional Paratransit Service

- Annual Trips: 215,000 trips/yr
- Service Region: 630 mi^2
- Average Operating Cost: $28.66 per trip

Records of All Trips

June 2015 – June 2017: 432,830 trips

- Pick-up/Drop-off Locations
- Pick-up/Drop-off Times
- Passenger ID Type of Disability
- Vehicle ID
- Network Distance Traveled by Paratransit Vehicles

Model of Paratransit

Specific origin-destination demands and corresponding routes vary from day to day. For planning purposes, a **continuous approximation** model is useful for modeling aggregate operations and costs.

Operation Model

Time Window, $T = 40$ min

Service Area, $A = 627$ mi^2

Traffic Speed, $v = 20.5$ mi/hr

Vehicle Occupancy, $n = 1.2$ pax/veh

Duration Loading and Unloading, $b = 10$ min

Vehicle Miles, VMT

Fleet Size, M

Vehicle Hours, VHT

Operation Model

Vehicle Miles Traveled (VMT)

$$VMT = r_1 \frac{\lambda\sqrt{A}}{2}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)$$

Travel Distance Parameter
r_1 = 0.82 (R^2 = 0.97)

Vehicle Hours Traveled (VHT) and Fleet Size (M)

$$VHT = Mt_p = \lambda t_p\left(b + r_2 \frac{\sqrt{A}}{2v}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)\right)$$

Travel Time Parameter
r_2 = 0.90 (R^2 = 0.96)

- λ Demand Rate [pick-ups/time]
- A Area of Service Coverage [$dist^2$]
- T Time Window (maximum difference from schedule) [time]
- n Vehicle Occupancy [passengers]
- t_p Duration of Time Period [time]
- b Average Boarding & Alighting Time [time]
- v Average Traffic Speed [dist/time]

Cost Function for ADA Paratransit

Total Cost of Paratransit (TC_p)

$$TC_p(\lambda) = \alpha_0 + \alpha_1 \frac{r_1 \lambda \sqrt{A}}{2}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right) + \left(\alpha_2 t_p + \alpha_3\right)\left[b\lambda + \frac{r_2 \lambda \sqrt{A}}{2v}\left(\frac{1}{\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)\right]$$

Marginal Cost of Paratransit (MC_p)

$$MC_p(\lambda) = \alpha_0 + \alpha_1 \frac{r_1 \sqrt{A}}{2}\left(\frac{1}{2\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right) + \left(\alpha_2 t_p + \alpha_3\right)\left[b + \frac{r_2 \sqrt{A}}{2v}\left(\frac{1}{2\sqrt{\lambda T}} + \frac{1}{\sqrt{n}}\right)\right]$$

Parameter	Value		Fit (R^2)
Fixed Annual Cost, α_0	135,135	\$	
Cost per Vehicle Mile, α_1	0.518	\$/veh-mile	0.80
Cost per Vehicle Hour, α_2	19.89	\$/veh-hr	0.86
Annual Cost per Vehicle, α_3	55,044	\$/veh	0.93

Cost Function for Taxicab

The cost of taxi, by comparison, is governed by a meter rate that depends on distance and travel time.

$$AC_t = \beta_0 + \beta_1 l + \beta_2 d$$

l distance traveled [dist]

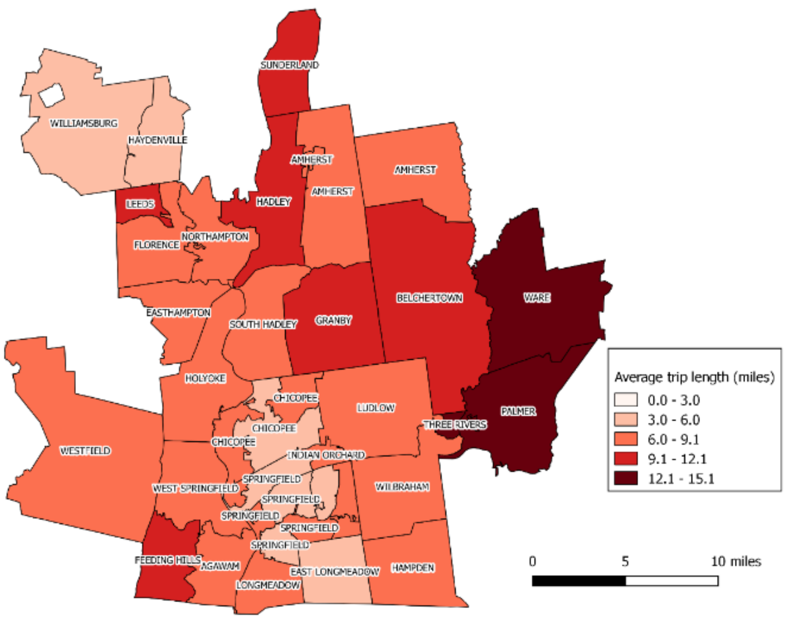
d delay (time exceeding travel at 25 mph) [time]

Parameter	Value	
Fixed Cost, β_0	2.40	\$/trip
Cost per Distance, β_1	2.50	\$/mile
Cost per Delay Time, β_2	21.00	\$/hr

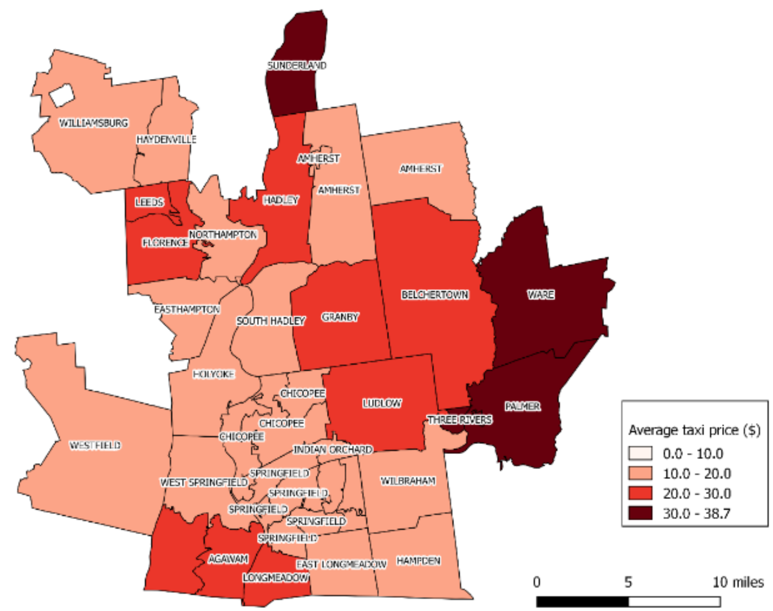
Source: Yellow Cab of Springfield

Identifying Opportunities to Reduce Cost

Average Trip Length



Estimated Average Taxi Fare



Which trips should be incentivized to switch to taxi or TNC to minimize total cost of paratransit operations and subsidies?

Optimizing Paratransit and Taxis

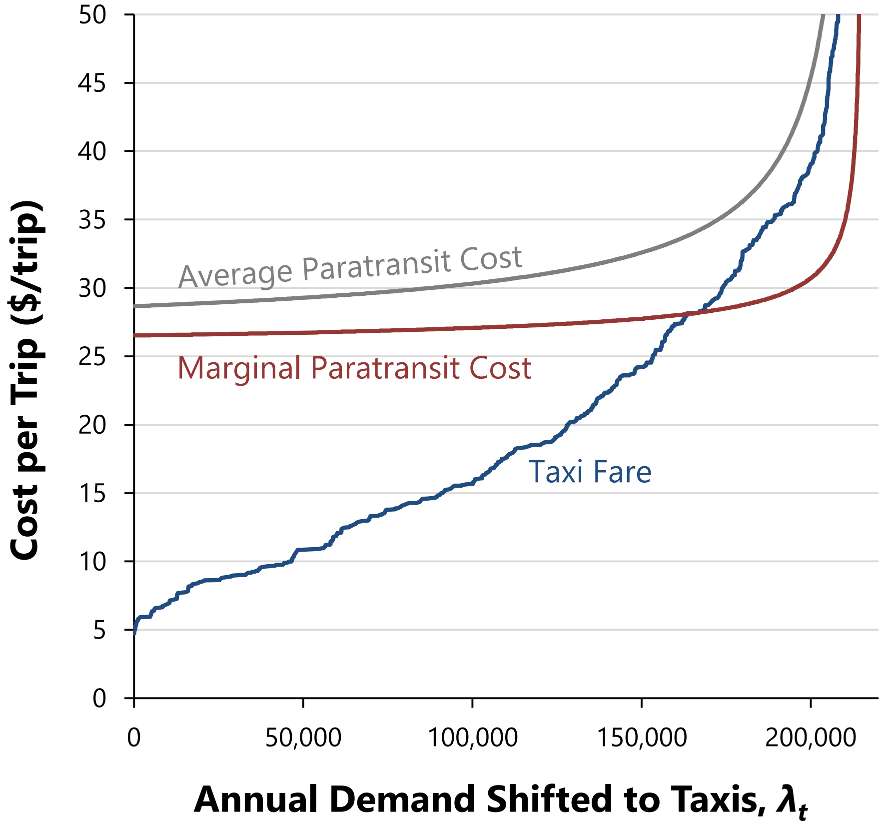
System cost is minimized by transferring trips that can be served by taxi at less than the marginal cost of paratransit.

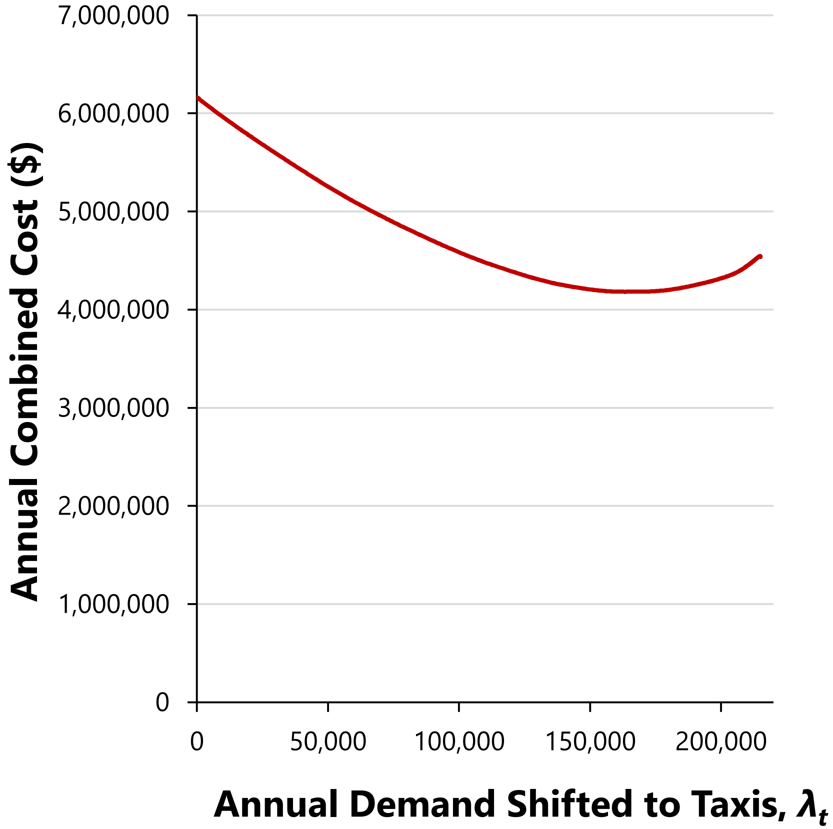
1) Sort trips from lowest to highest expected taxi trip cost
2) Plot against marginal cost of paratransit trips in order of decreasing demand
3) Identify threshold cab fare which matches marginal cost of paratransit; all lower fares would be more cost on taxi

Suppose customers can be incentivized to switch to taxi by offering a subsidized fare.

Case 1: All Customers Potentially Use Taxi

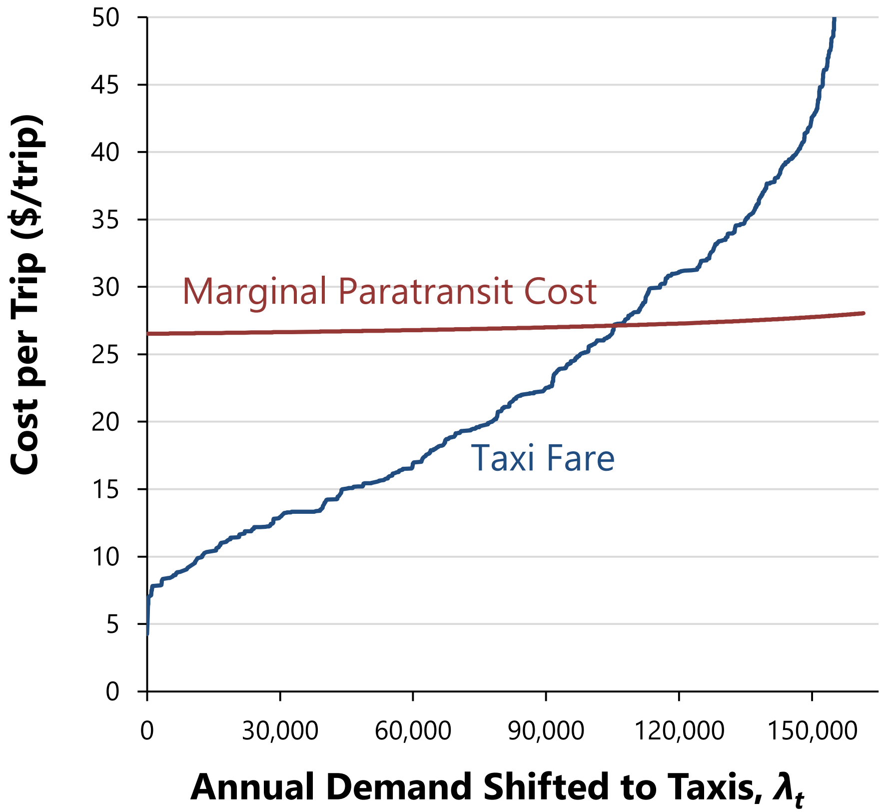
Consider the whole day as a single time period

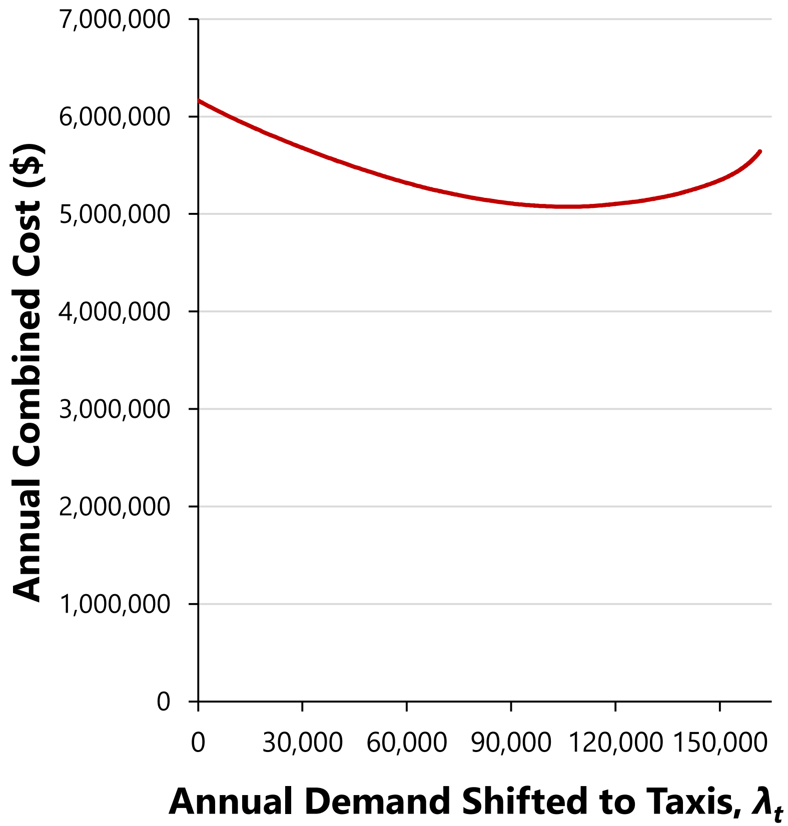




Case 2: Only Ambulatory Customers Can Use Taxi

75% of PVTA's customers are ambulatory (not in wheelchair)

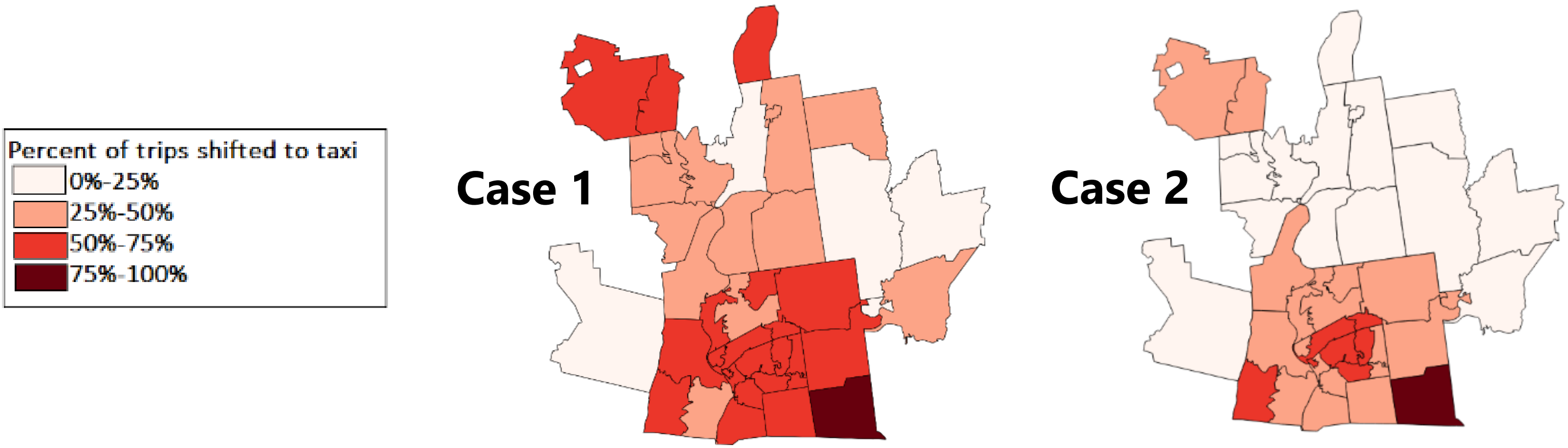




Comparing Existing and Coordinated Systems

Case	Threshold Price	Taxi Demand	Paratransit Demand	Annual Cost*
All Paratransit		0	206,100	$6,163,000
All Taxi		206,100	0	$4,537,000
Case 1	$28.09	162,700	43,400	$4,182,000
Case 2	$27.13	105,400	100,700	$5,074,000

*Considering the whole day as a single time period



Case 3: Consider Varying Demand by Time of Day

The marginal cost varies by time of day, because demand varies by time of day.

- Separate trip data into time periods reflecting changing demand and traffic congestion
- Marginal cost is greatest during peak demand, when more vehicles would need to be purchased to serve more trips
- During off-peak periods, marginal cost depends only on operating costs of VMT and VHT (not fleet acquisition).

Optimizing Paratransit and Taxis

Time Period	Threshold Price	Taxi Demand	Paratransit Demand	Required Fleet Size
6am – 9am			45,165	30
9am – 12pm			43,898	29
12pm – 3pm			44,474	29
3pm – 6pm			72,559	47
All Trips Served by ADA Paratransit				*$6,760,000 per year*
6am – 9am	$19.51	14,503	30,662	20
9am – 12pm	$19.51	19,329	24,569	16
12pm – 3pm	$19.56	17,447	27,027	18
3pm – 6pm	$31.35	42,826	29,733	20
Optimized Taxi and Paratransit (Case 3)				*$4,890,000 per year*

Insights and Observations

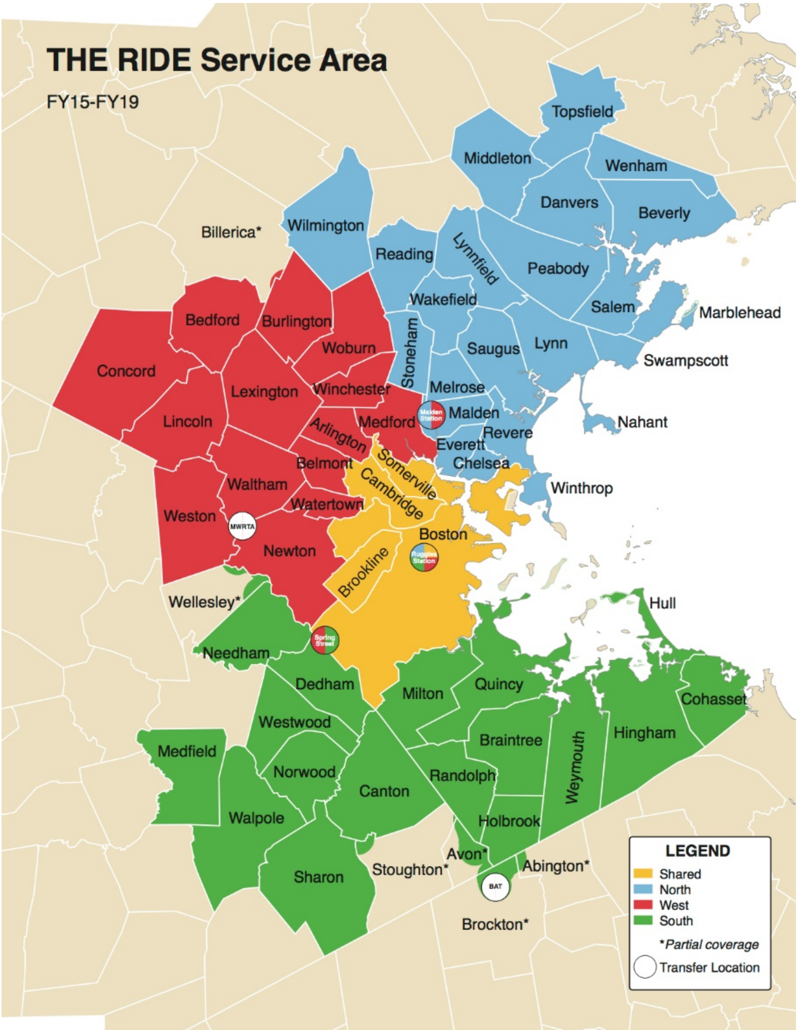
- Extensive data about demand and operations allows demand responsive transit services to be optimized
- There are large opportunities to **reduce costs through strategic partnerships** with taxis and TNCs (~28% based on analysis of time-varying demand).
- In Springfield, incentivized trips to divert to taxi are typically in the urban core (i.e., **divert shorter trips**)

MBTA The Ride (Boston, MA)

Regional Paratransit Service

- Annual Trips: 2,188,000 trips/yr
- Service Region: 630 mi^2
- Average Operating Cost: $46.62 per trip

Fare to customers: $3.15



MBTA TNC Pilot Program (Boston, MA)

October 2016 400 initial participants allocated 20 trips/month
Customer pays $2; MBTA pays the next $13

January 2017 Trip allocation assigned based on previous usage:
2, 20, 25 trips/mo

March 2017 Opened to all The Ride customers
Customer pays $1 on UberPool

June 2017 Allocation tiers adjusted to
2, 10, 20, 30, 40 trips/month

October 2017 MBTA subsidy increased to $40 limit per trip

Initial Developments

Support for the Pilot

- Allows faster, cheaper, same-day service → Customers are pleased with improved service
- Political support and momentum from as high as Governor Baker.

Risks and Challenges

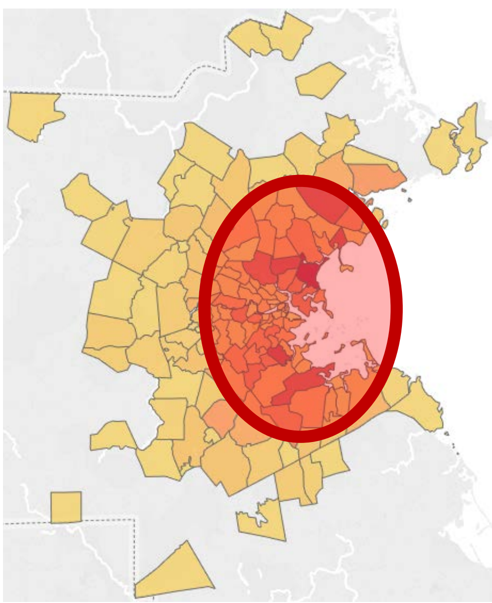
- Customers make more 43% more trips on TNCs, undercutting savings; currently pilot reduces costs by about 1% per customer.
  - ADA does not allow limiting trips or restricting purpose
- Uber and Lyft are platforms not operators
  - Not enough Wheelchair-Accessible Vehicles (WAV)
  - Lower levels of driver screening and training

Coordinating Paratransit and Other Services

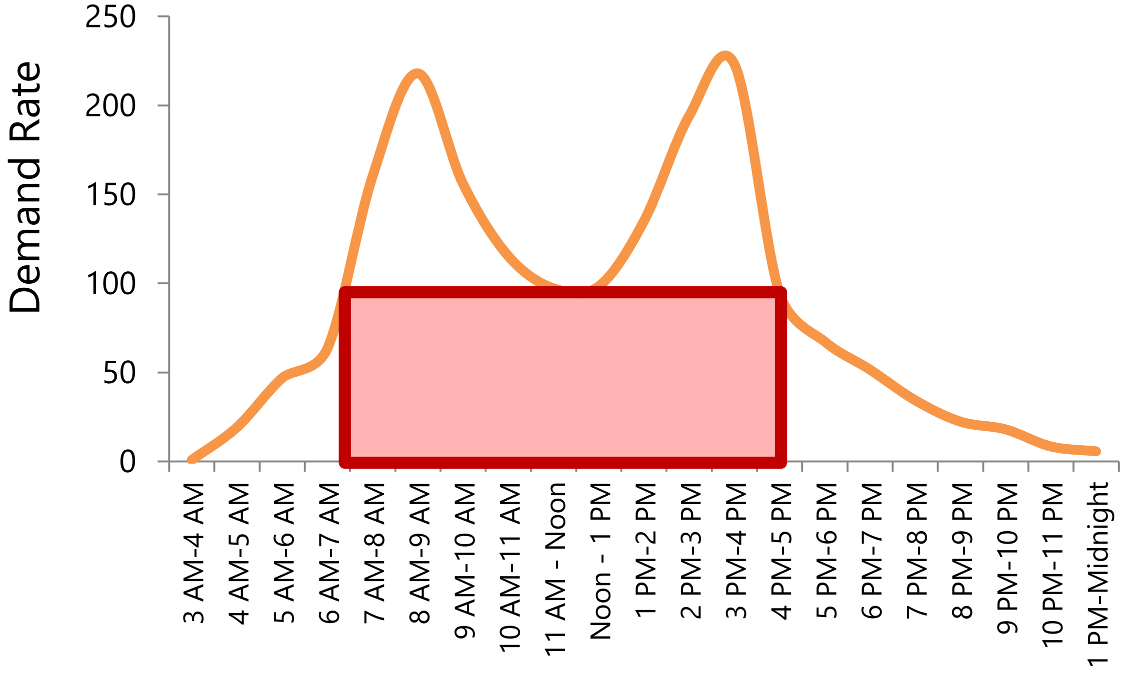
Dense, stable demand is most efficient for paratransit.

Alternative providers are best suited for serving:

Spatial Fringe



Temporal Fringe & Peaks



Research Questions

- How do TNCs (same-day service) affect demand?
  - Who is using these services?
  - How many trips are they making?
  - Where are they going?
- How should the remaining van service be organized, if it continues to operate at all?
- What changes in regulation or incentive policies should be made to utilize current and emerging technologies?

Questions

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Related Publications

Turmo, V., Rahimi, M., Gonzales, E.J., Armstrong, P. (2018). Evaluating potential demand and operational effects of coordinated ADA paratransit and taxi service. *Transportation Research Record*. [In Press]

Rahimi, M., Amirgholy, M., Gonzales, E.J. (2018). System modeling of demand responsive transportation services: Evaluating cost efficiency of service and coordinated taxi usage. *Transportation Research Part E*, 112:66-84.

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