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Dynamic bimodal ridesharing and idle vehicle repositioning strategy for smart mobility

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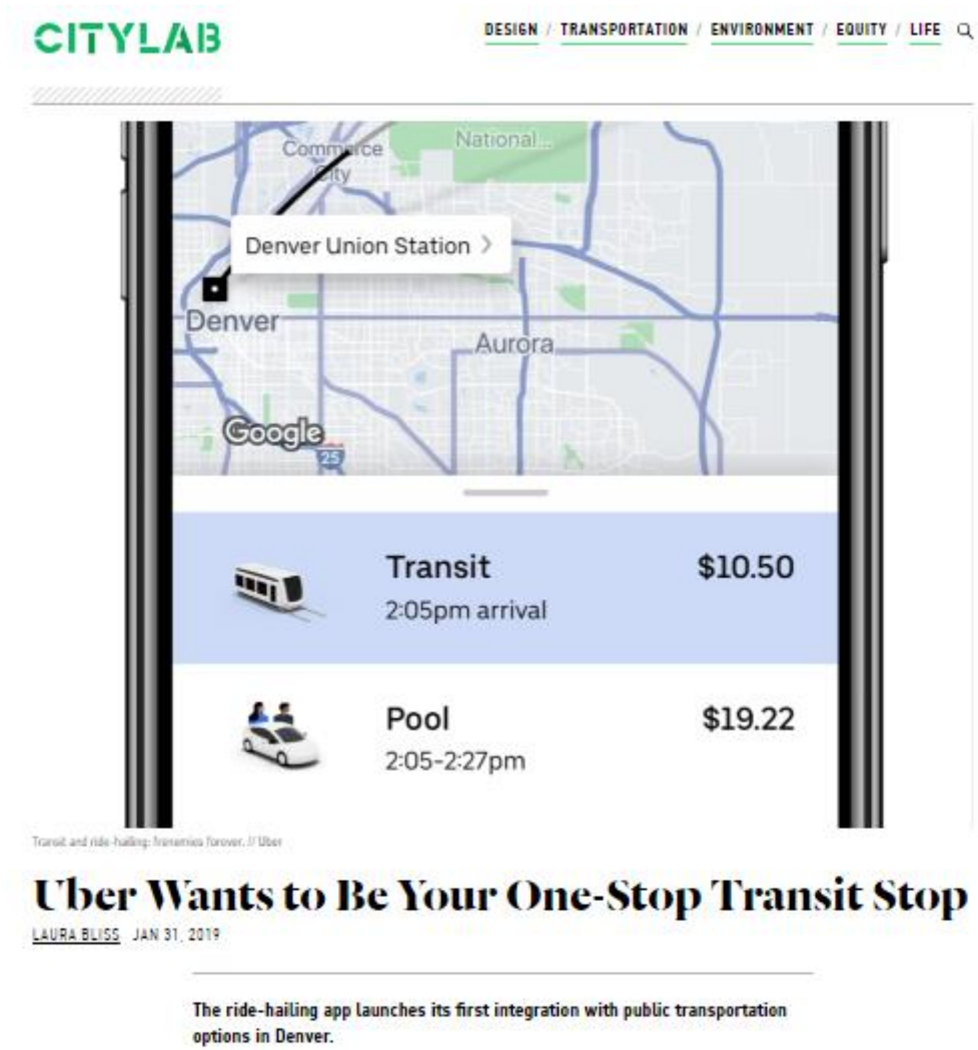
Examples of public-private partnerships with mobility services to address last mile problem

Public agency	Private company	Project	Source
Helsinki	Kutsuplus	On-demand minibus	(Wired, 2013)
Dallas Area Rapid Transit	Lyft	Dallas	(DART, 2015)
JFK Airport	Bandwagon	Cab carpool	(Daily News, 2015)
Kansas City	Bridj	Microtransit service	(Kansas City Star, 2015)
Los Angeles Airport	Lyft	LAX access	(The Verge, 2015)
Metrolinx	RideCo	Last mile	(CBC, 2015)
Amtrak	Lyft	Last mile	(TechCrunch, 2017)
Arlington, TX	Via	On-demand minibus	(TechCrunch, 2018)
San Francisco	Chariot	Private transit	(SF Chronicle, 2018)

The research problem

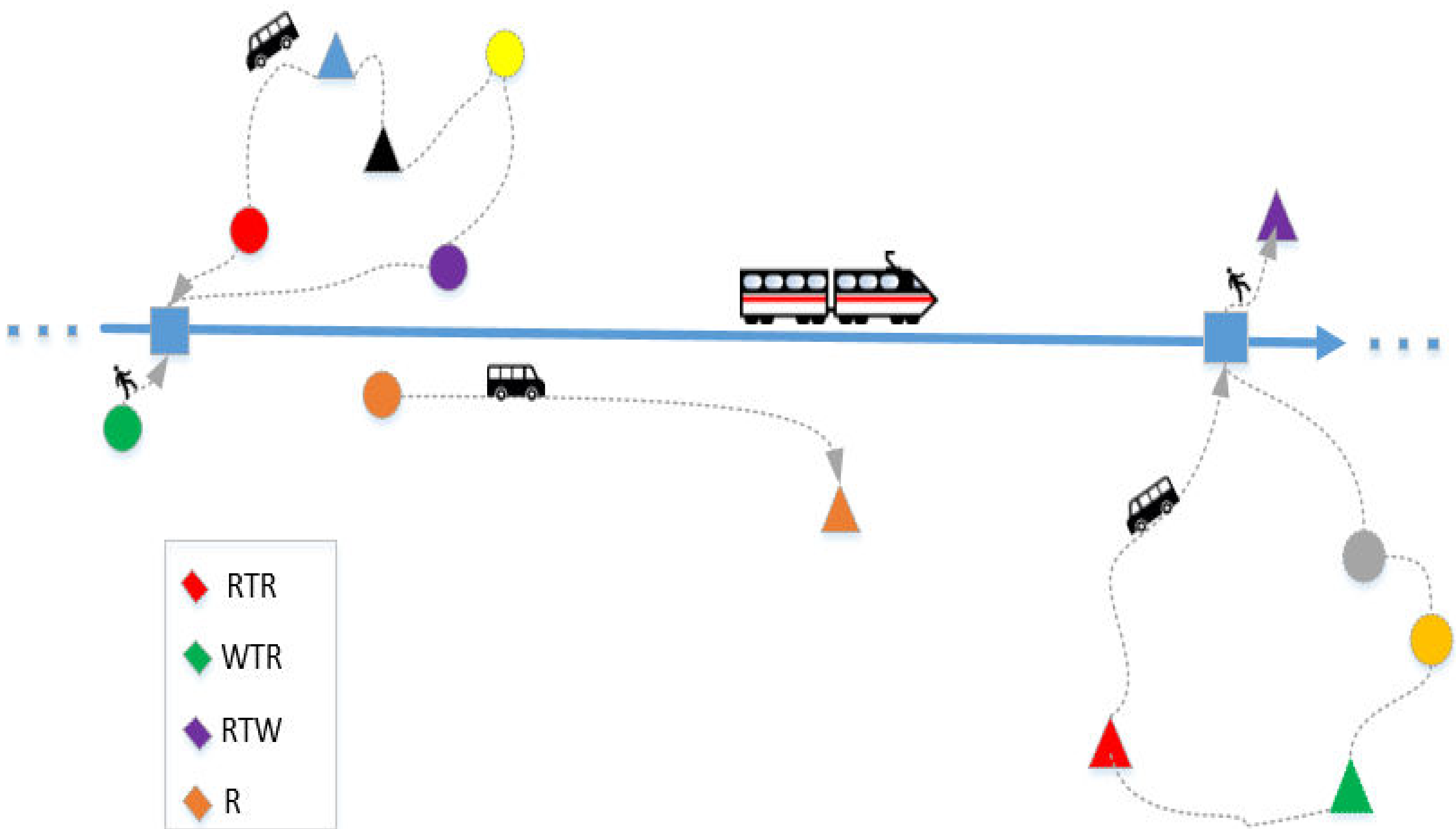
- Motivations
  - ➢ Collaborations between public transport agencies and private transport operators present a huge potential
  - ➢ Multimodal segments of a passenger's trip are not coordinated
  - ➢ There is no integrated dispatch and fleet management algorithm offering a bundled service option from private operators

- Problem: How to design bimodal rideshare system using the Mass Rapid Transit (MRT) ?



Source: https://www.citylab.com/

Illustration of bimodal ridesharing in collaboration with a coexisting transit system



The bimodal dynamic dial-a-ride problem

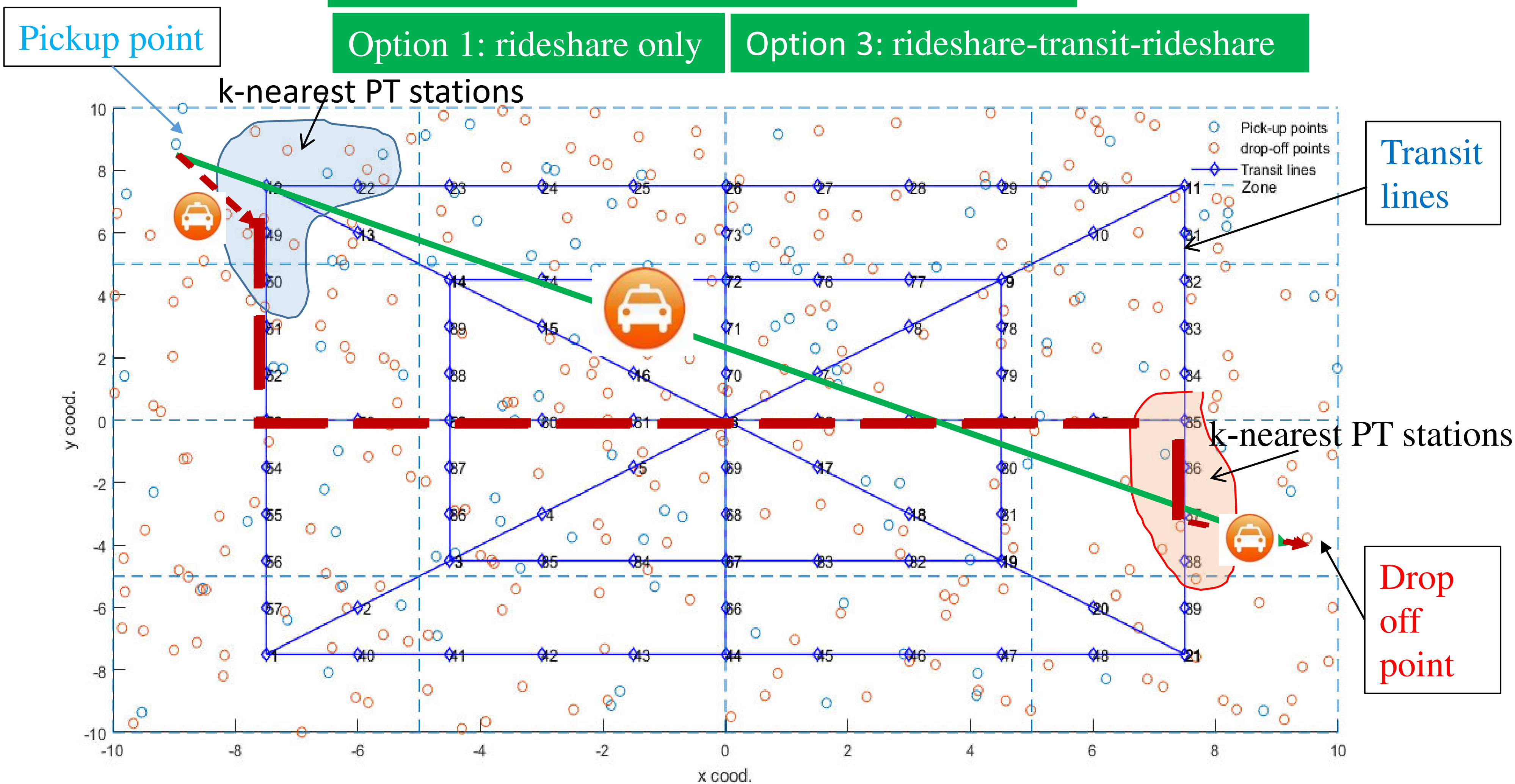
- The problem is modeled on a complete graph $G(N, E)$, $N = N_T \cup N_P \cup N_Z$
- A operator uses a fleet of homogeneous capacitated vehicles $V = \{v_1, v_2, \ldots, v_{|V|}\}$
- Requests arrive in real-time following invariant Poisson process
- All requests must be served, no time windows constraints
- An operator determines dispatch and routing decisions for real-time trip requests (1) using operating vehicles only (direct trip) or by (2) using both operating vehicles (as last mile feeders) and Public Transport (PT) services

Non-myopic bimodal dispatch/ routing **P1**

Option 2: rideshare-transit-walk (and vice versa)

Option 1: rideshare only

Option 3: rideshare-transit-rideshare



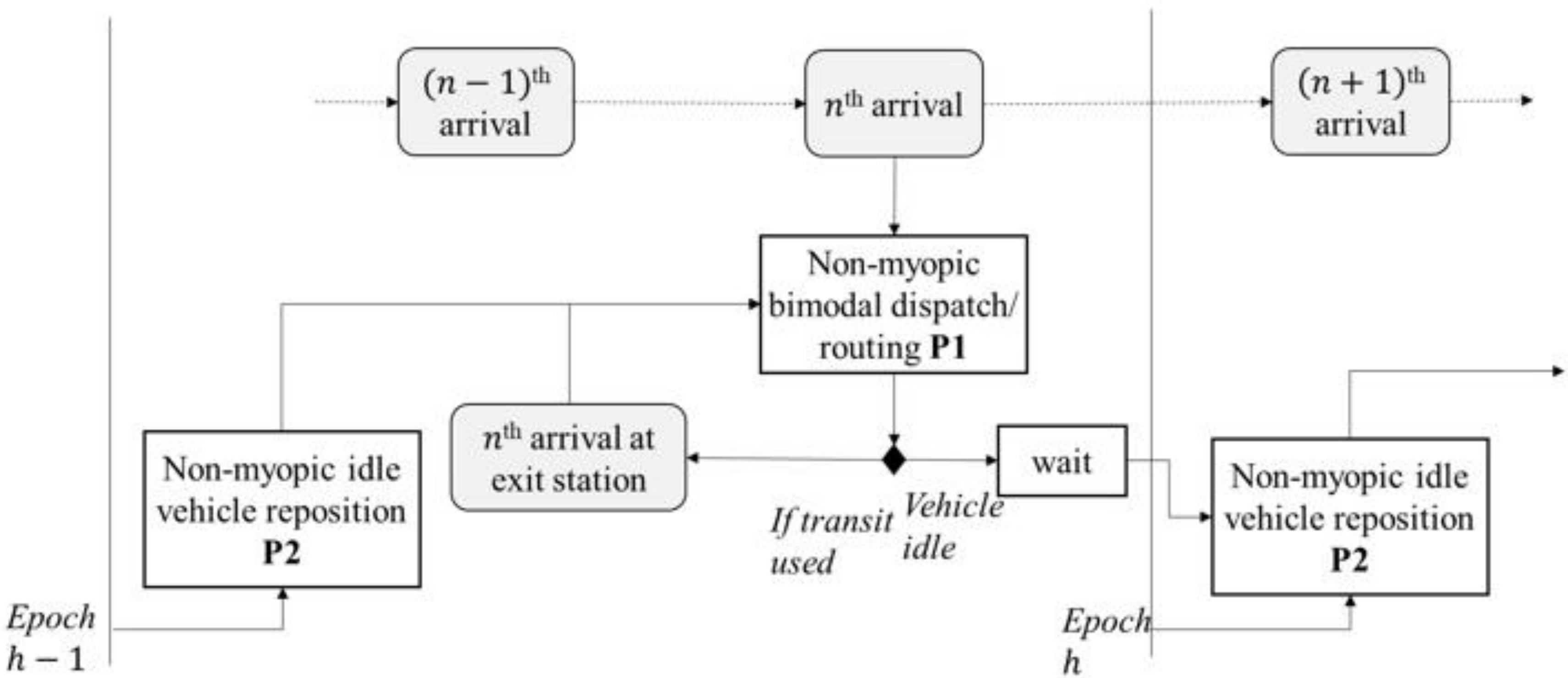
P1: Bimodal non-myopic vehicle dispatching and routing algorithm

1. Upon arrival of a new request n, **update positions and service statuses** of every vehicle from the time of previous request
2. **Compute a fastest option for request n**: Determine the costs of the three service options:
   For rideshre only: dispatch a vehicle with minimal additional operating costs (TSPPD)
   For other options involving transit option, consider each pair of k-nearest entry and exit stations, compute the cost as sum of costs for each trip leg plus transit cost.

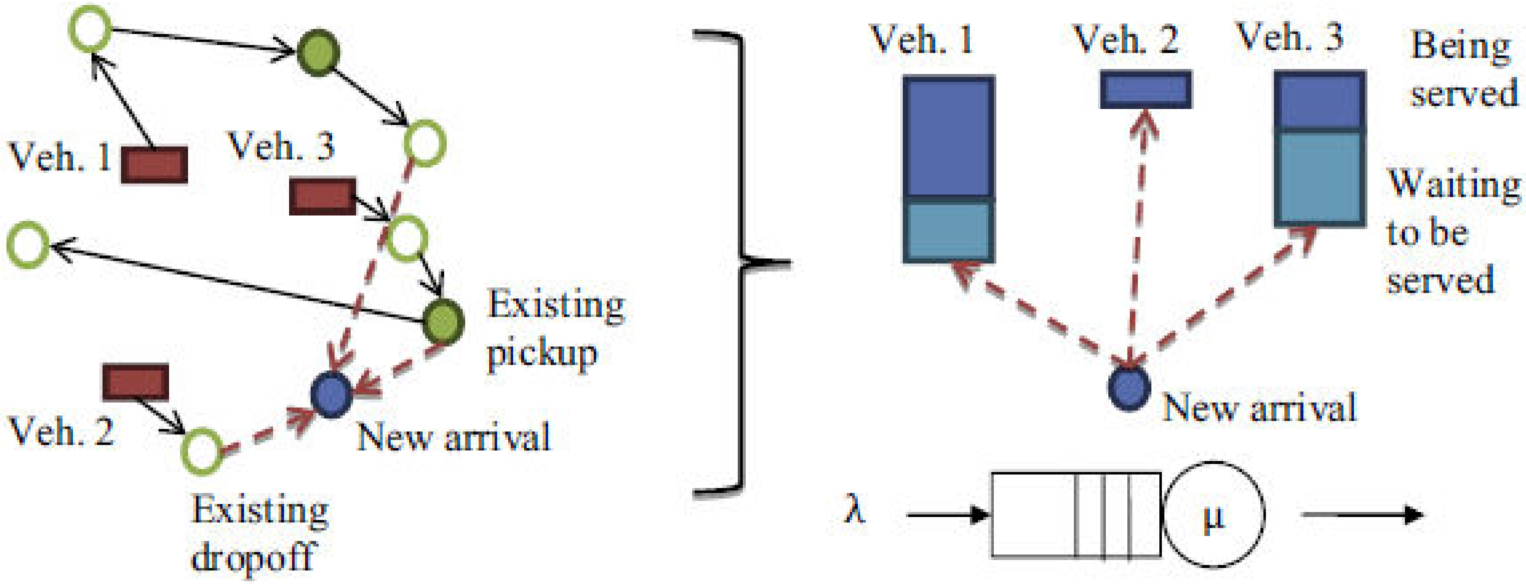
4. Update the pick-up or drop-off point of new request n if transit option is used.
5. Update the new tour for that assigned vehicle, while keeping the other vehicles' tours the same as before.

Integrated strategy with functional components (rectangles) and initiating events (gray rounded rectangles)

- P1: Non-myopic vehicle dispatching policy on a bimodal transport system (M/M/k queueing system)
- P2: Non-myopic idle vehicle relocation policy (a variant of p-median problem)



Non-myopic vehicle dispatching and routing policy (Hyytiä et al., 2012; Sayarshad and Chow, 2015)



$$\boldsymbol{argmin_{v,\xi}[c(v,\xi) - c(v,\xi')]} \quad \mathbf{(2)}$$

ξ' is the current tour of vehicle v. ξ is a new tour after inserting a new request.
$T(v,\xi)$ is the tour length of ξ for vehicle v.

Customers' inconvenience

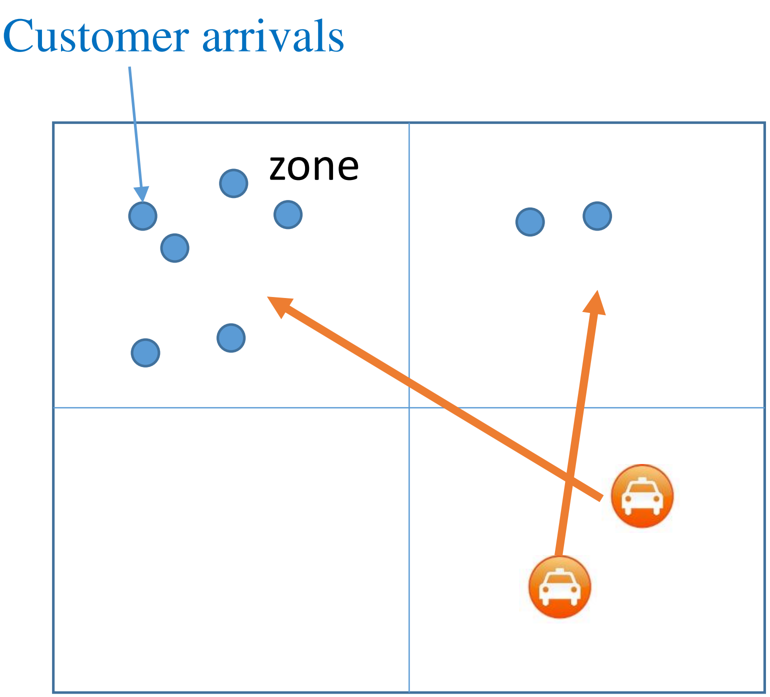
where $c(v,\xi) = \theta T(v,\xi) + (1-\theta)[\beta T(v,\xi)^2 + \sum_{p \in P_v} Y_p(v,\xi)]$

System cost

θ: adjust the system cost versus user cost, β： adjust the degree of look ahead

Dynamic relocation of idle vehicles based on multiple server location-allocation models with queue length constraints (P2)

-Mixed integer linear programming problem (variant of p-median problem)
-Solved by Matlab MIP solver



$$\Phi = \min \sum_{i \in N} \sum_{j \in N} \lambda_i t_{ij} X_{ij} + \theta \sum_{i \in N} \sum_{j \in N} r_{ij} W_{ij} \quad (3)$$

Subject to:

$$\sum_{j \in N} X_{ij} = 1, \quad \forall i \in \bar{N} \quad (4)$$

$$Y_{jm} \leq Y_{j,m-1}, \quad \forall j \in \bar{N}, m = 2,3,\ldots,C_j \quad (5)$$

$$\sum_{i \in N} \lambda_i X_{ij} \leq \mu_j \left[Y_{j1} \rho_{\eta j1} + \sum_{m=2}^{C_j} Y_{jm} \left(\rho_{\eta jm} - \rho_{\eta j,m-1} \right) \right], \quad \forall j \in \bar{N} \quad (6)$$

$$X_{ij} \leq Y_{j1}, \quad \forall i,j \in \bar{N} \quad (7)$$

$$\sum_{j \in N} \sum_{m=1}^{C_j} Y_{jm} = B \quad (8)$$

$$\sum_{j \in N} W_{ij} = S_i, \quad \forall i \in \bar{N} \quad (9)$$

$$\sum_{i \in N} W_{ij} = D_j, \quad \forall j \in \bar{N} \quad (10)$$

$$S_j \leq y_j, \quad \forall j \in \bar{N} \quad (11)$$

$$-D_j - S_j - y_j + \sum_{m=1}^{C_j} Y_{jm} \leq 0, \quad \forall j \in \bar{N} \quad (12)$$

$$X_{ij} \in \{0,1\} \quad (13)$$

$$0 \leq Y_{jm} \leq 1 \quad (14)$$

$$D_j, S_j \geq 0, W_{ij} \in Z^{+} \quad (15)$$

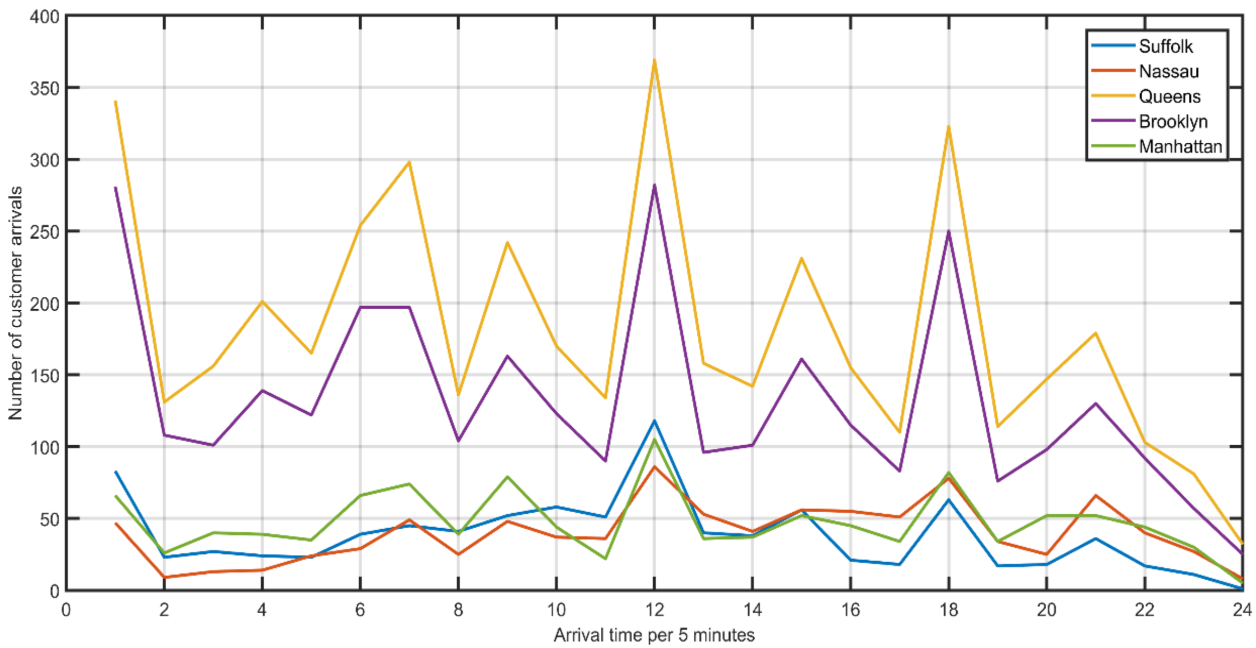
NYC and LIRR case study

Objective: assessing the benefit of the integrated operating policy in the NYC metropolitan region, specifically for commuters traveling to/from Long Island to NYC

- How much better can a system with transit transfers outperform rideshare-only system when operating non-myopic versus myopic algorithms, under different congestion levels?
- Under what conditions is rideshare with integrated transit preferred, and within those conditions when are RTW/WTR preferred over RTR?
- By incorporating transit transfers, how much does the effective service capacity increase?
- How do we use the algorithm to plan for service expansions?

NYC and LIRR case study

- Data: 010-2011 Regional Household Travel Survey of New York metropolitan area
- 72 zones with 10572 customers during 7:00-9:00 a.m.
- Fleet size: 720/1440/2160 (i.e. 10/20/30 vehicles per zone)
- Vehicle capacity=4, initially located at each zone center
- Idle vehicle relocation interval as 15 minutes



● Pickup/drop off points

▬ Long Island Rail Road (LIRR)

Fig 1 Customer arrival times over counties in NYC and Long Island during 7:00 – 9:00 a.m

System characteristic and parameter settings for NYC and LIC case study

Number of customers	10572	β	$4/\bar{T}(v,x)$
Number of zones	72	γ	0.5
Fleet size	720/1440/2160	ρ_η	$\eta = 0.95$, b=0
Capacity of vehicles	4 pers./veh.	Idle vehicle relocation interval	15 min.
Walking speed	5 km/hour	Warming up period	30 min.
Vehicle speed	29.4 km/hour	Headway of train	20 min.
Number of transit stations	124	Simulation time	2 hours

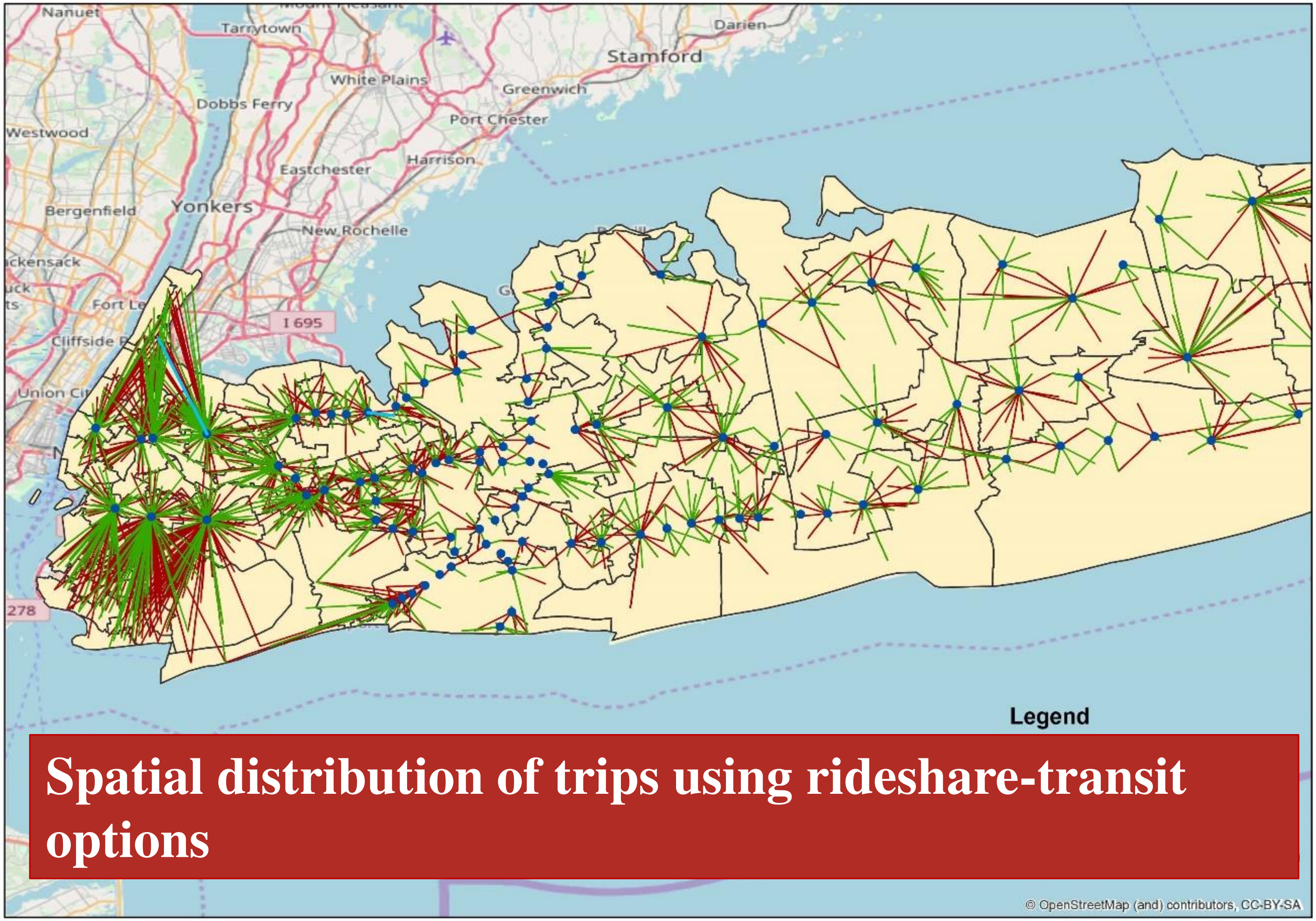
Remarks: 1. $\bar{T}(v,x)$ is mean vehicle travel time without considering transit-rideshare cooperation. 2. Vehicle speed is set up based on the taxicab data during 7:00-9:00 a.m. used in this study.

Benefit of the system with transit-rideshare options compared to that of rideshare only

Number of vehicles per zone	System with rideshare only			System with rideshare-transit options		
	WT	JT	VTL	WT	JT	VTL
10	62.1	133.0	440.5	19.4(-68.7%)	60.8(-54.3%)	175.2(-60.2%)
20	13.2	60.7	210.8	5.6(-57.6%)	41.2(-32.1%)	76.5(-63.7%)
30	8.7	51.7	146.7	5.5(-37.0%)	41.6(-19.6%)	55.7(-62.1%)

Remark: WT: Mean passenger waiting time, JT: Mean passenger journey time, VTL: Mean vehicle travel length. Measured in minutes.

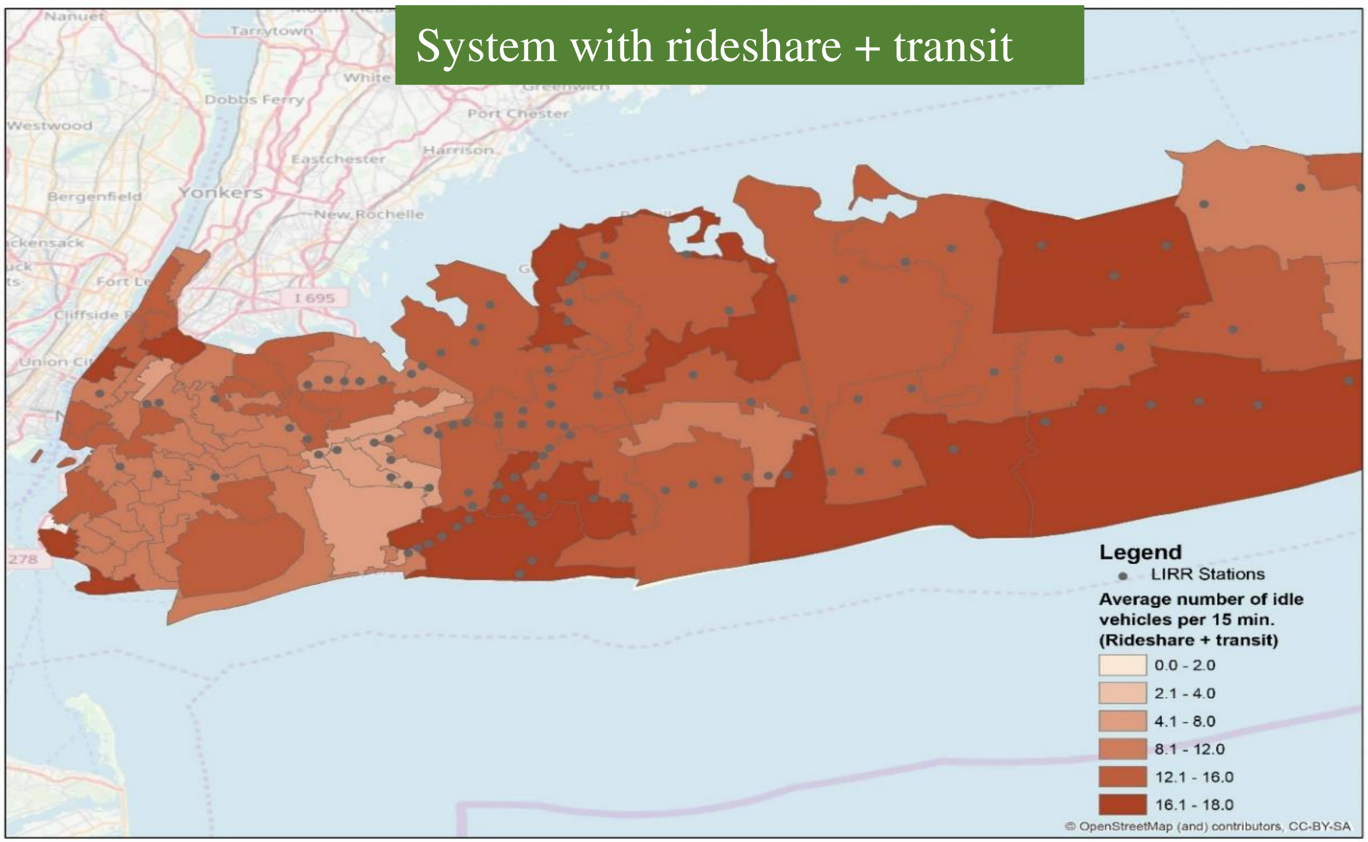
Spatial distribution of trips of the system with bimodal options



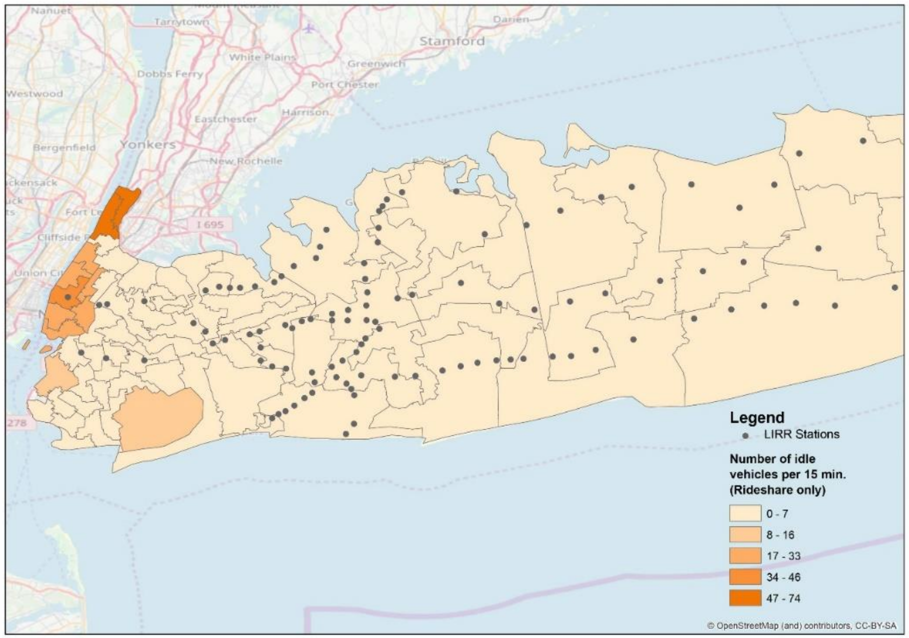
Spatial distribution of trips using rideshare-transit options

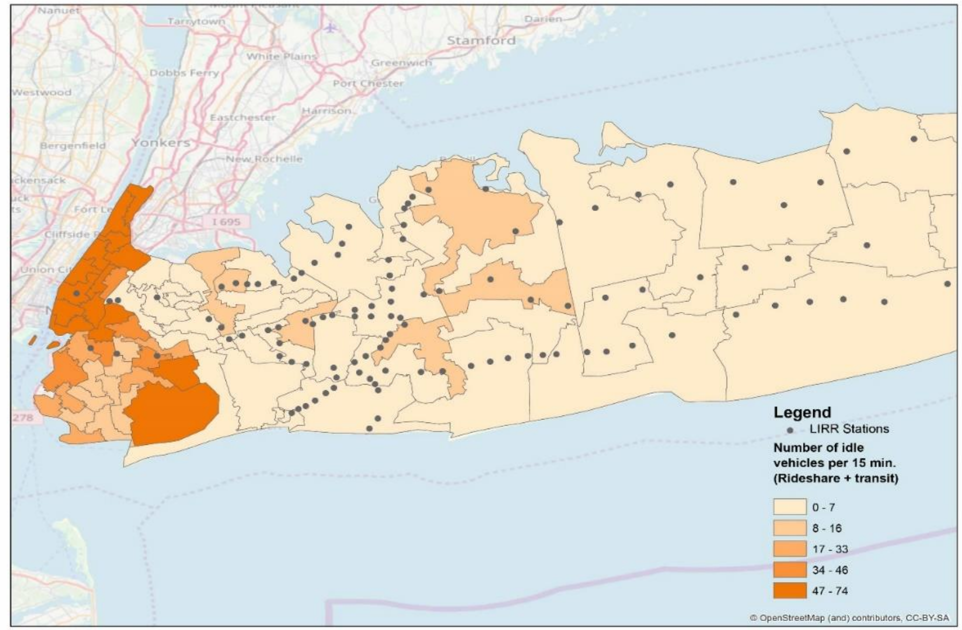
Average number of idle vehicles per zone per 15 minutes

But this number increases to **12.48** for the system with rideshare-transit option



Number of rebalanced vehicles in zones





system with rideshare only

system with rideshare + transit

Ratio of different rideshare-transit options customers for the NYC-LI case study

Number of vehicles per zone	WTR	RTW	RTR	R
10	4.7%	31.0%	4.4%	59.9%
20	0.3%	34.1%	2.7%	62.9%
30	1.0%	36.8%	4.4%	57.9%

Remark: W: Walk, T: Transit, R: Rideshare

Service coverage expansion decision support

Suppose a ridesharing service had to consider between expanding from NYC to either Suffolk County or to Nassau County

- Three scenarios with 500, 1000 and 1500 vehicles, corresponding with 10, 20 and 30 vehicles per zone over 50 zones in the studied area of NYC
- 10% of vehicle fleet are initially deployed at the zone centers of the extension area, corresponding approximately to the demand from/to Suffolk County (8.9%) and Nassau County (14.6%).

Table 10 Demand between OD counties during 7-9 a.m.

O/D	Suffolk	Nassau	NYC	Total
Suffolk	602	214	104	920
Nassau	56	851	44	951
NYC	88	497	8116	8701
Total	746	1562	8264	10572

The impact of extending service

Table 11 Service coverage extension analysis

Number of vehicles		NYC		NYC-Suffolk		NYC-Nassau	
		R	R+T	R	R+T	R	R+T
500	JT	93.3	52.1	151.7	67.8	162.3	69.1
	VTL	286.3	170.0	455.6	206.9	463.8	209.5
1000	JT	44.0	30.5	71.1	38.9	94.2	37.8
	VTL	131.9	76.9	222.2	92.8	216.2	90.0
1500	JT	35.1	29.7	52.3	37.8	48.9	35.6
	VTL	86.4	52.4	150.0	65.0	138.2	61.5

Remark: JT: Mean passenger journey time (in minutes), VTL: Mean vehicle travel time (in minutes).

Table 12 Mean passenger journey time for different service coverage extensions

Number of vehicles	System	NYC	NYC-Suffolk		NYC-Nassau	
			NYC	Suffolk	NYC	Nassau
500	R	93.3	109.9	579.7	114.3	442.3
	RT	52.1	57.1	176.2	58.4	131.5
1000	R	44	48.3	305.0	57.3	309.0
	RT	30.5	30.9	121.1	30.7	79.1
1500	R	35.1	36.2	217.4	36.7	120.5
	RT	29.7	29.8	120.3	29.8	69.6

Remark: R: system with rideshare only, RT: system with rideshare-transit options

Conclusions

- Cost savings can be substantial and benefit both users and operators, although the amount of benefit varies by type of network and demand patterns of the users.
- There is an effective increase in the capacity of the MoD service of 4.05 when linking with the PT network for the LIRR case study
- Future extensions
  - Study an efficient algorithm to solve large-scale idle vehicle relocation problems with a grid-like zoning system
  - Operation policy design using electric vehicles or autonomous vehicles

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