Connecting E-Hailing to Mass Transit Platform

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Transportation Center Seminar Series, Northwestern University, 2016

Outline

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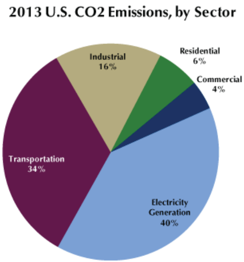
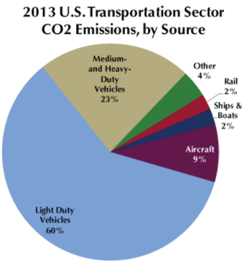
Challenges

Chronic traffic congestion (Over \$ 100 billion/year for wasted time and fuel in the US)

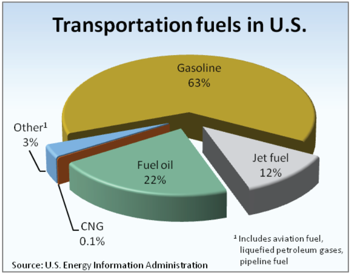
Challenges





Elevated environment impacts of travel (about a quarter of green house gas emissions)

Challenges



Added vulnerability to energy insecurity (60% petroleum in the US)

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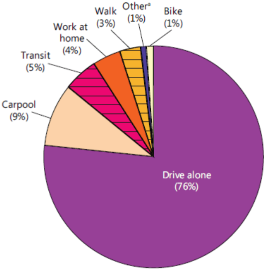
Challenges



Limited mobility options for those who cannot drive.

Towards sustainable transportation

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- Analyzing new mobility services

Disruptive technologies

- Mobile computing and communication technologies

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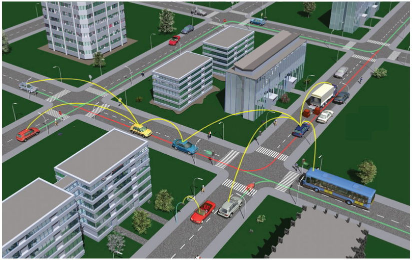
Disruptive technologies



- New vehicle technology

Disruptive technologies

- Ridesourcing and ridesharing

Disruptive technologies

- Social network

Future of personal mobility

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What do we need to get there?

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What do we need to get there?

- New strategies for design and operation
- New theories for regulations and policies
- New mathematical models for forecasting and planning

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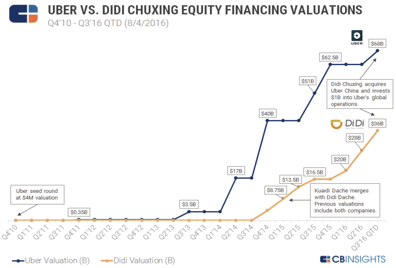

- Transportation Network Companies are touted as a strong contender as the future personal travel provider.
- Car manufacturers and tech giants are busy building partnership with them.
- Uber and Didi Chuxing are valued currently at $68B and $36B, respectively

Case of Transportation Network Companies

- Uber lost $1.27B in the first half of 2016, and Didi Chuxing lost about $1.6B in 2015 based on some estimation.

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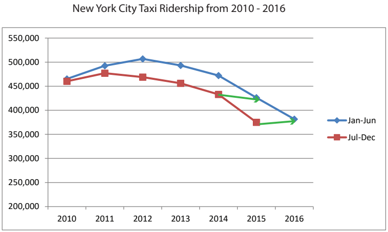

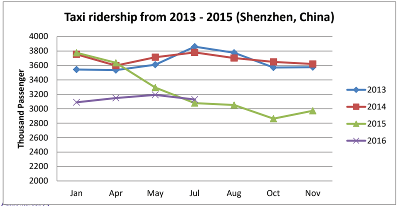

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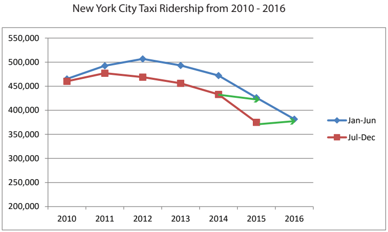

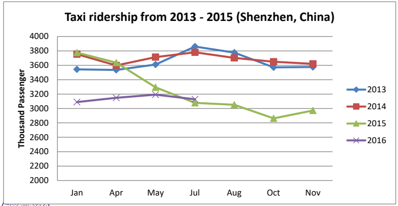

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- There are signs that TNCs' expansion in the market has slowed in recent months.
- TNCs' current business model, built on e-hailing, economy of scale and aggressive pricing, can only go so far (Nie, 2016)

Case of Transportation Network Companies

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Case of Transportation Network Companies

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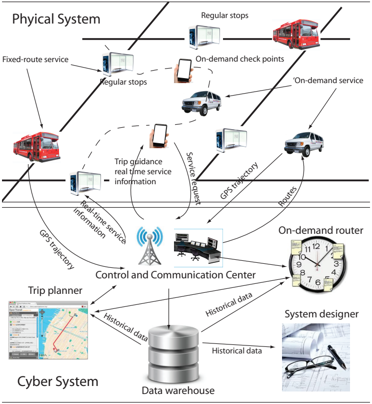
- But can driverless cars solve all the problems?
- Much greater ride consolidation/sharing must be achieved.
- Structured routes must be put in place, along with flexible routes.

What is CREDIT



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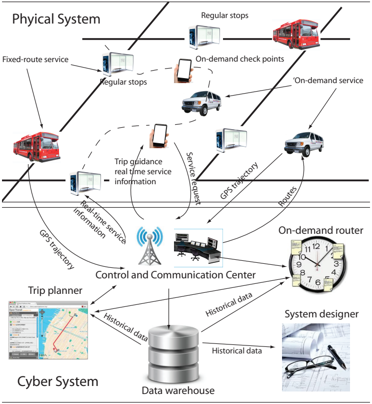

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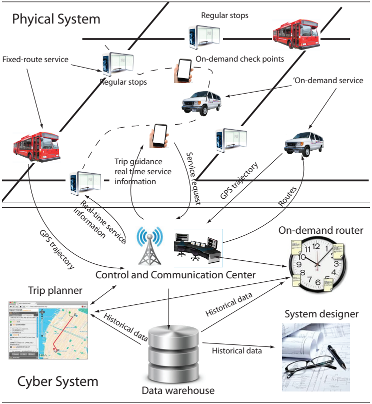

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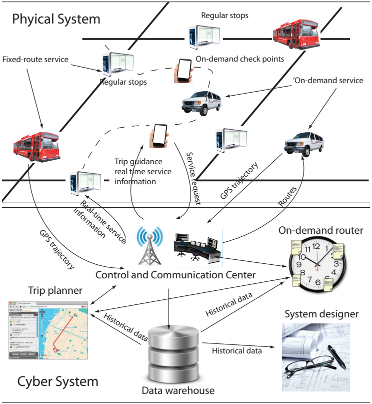

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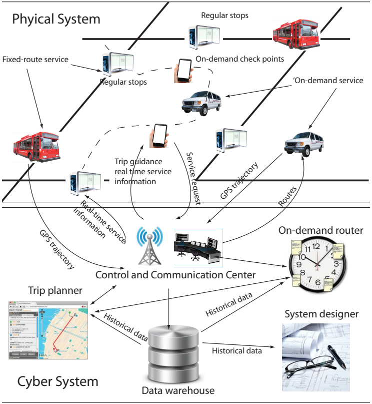

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CREDIT is a prototype of futuristic mass transit platforms.

Research agenda

- Hybrid design
- Vehicle routing - sequencing, ride sharing etc.
- Operational strategies - headway control, coordination etc.
- Trip planning - personalized service and pricing

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The remaining of this talk will focus on hybrid design

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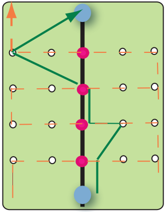
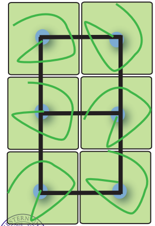
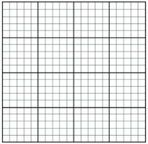
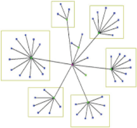
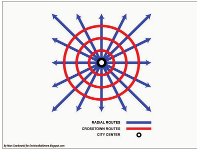
Research question: hybrid design





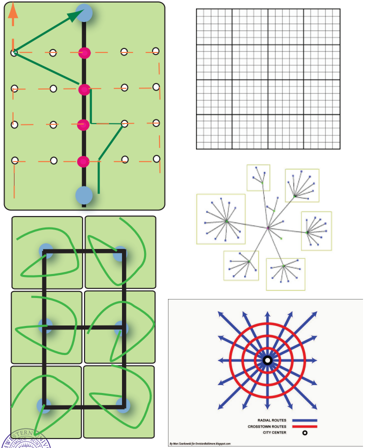






- What is the best hybrid strategy from a macroscopic perspective?

Research question: hybrid design



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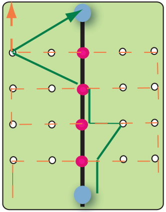

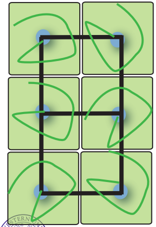

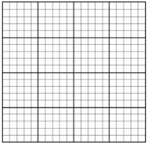

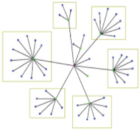

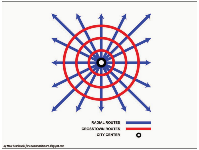

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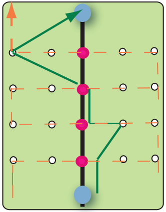

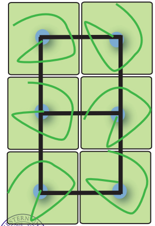

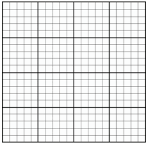

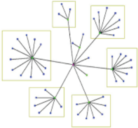

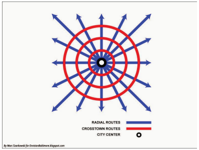

- What is the best hybrid strategy from a macroscopic perspective?
- What is the optimal route structure?
- How to estimate optimal design parameters?
- How to perform a detailed design based on local characteristics?

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Design concepts

- Sketchy design models under idealized conditions

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  - It only serves passengers whose access distance exceeds certain threshold, which itself is a design parameter.

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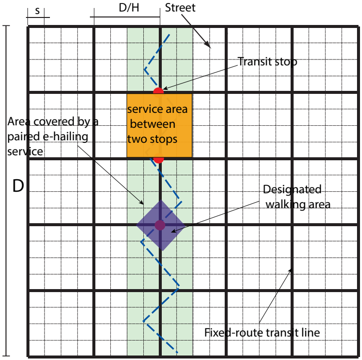
  - Flexible routes are operated in parallel with paired fixed-route transit lines using smaller vehicles.
  - It only serves passengers whose access distance exceeds certain threshold, which itself is a design parameter.
  - Design of flexible and structured routes is tightly integrated.

Sketchy design model



- Square service area of side length D and street spacing of s.

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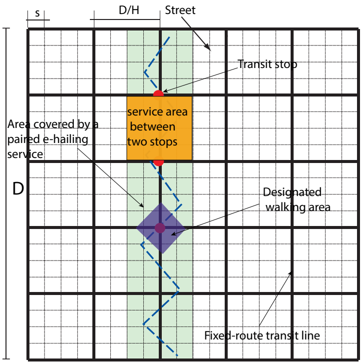

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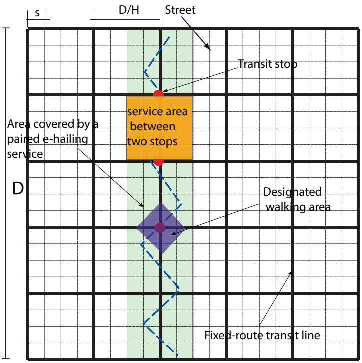

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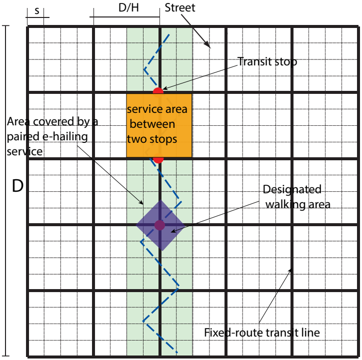

- Square service area of side length D and street spacing of s.
- Demand generation rate λ as a homogeneous spatial Poisson process.
- Structured routes operate in both directions, while flexible routes only operate in one direction.
- Flexible routes serve passengers outside the designed waking area.

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Assumptions

- Passengers always use the stops closest to their origin and destination. If the access distance is less than $\beta D/N$ (where $\beta \in (0, 1]$ is a design variable), passengers will choose walking; otherwise, passengers will request e-hailing.

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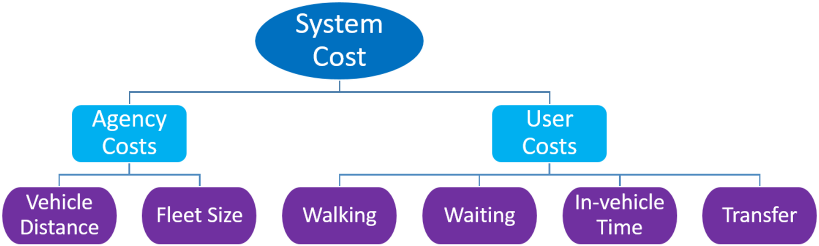
- Passengers travel between these stations with the least possible number of transfers and as directly as possible.
- When transfer is needed, passengers randomly choose the initial direction of travel.

System Cost


System Cost
Agency Costs
User Costs
Vehicle Distance
Fleet Size
Walking
Waiting
In-vehicle Time
Transfer

Formulation for the grid paired-line system

$$\min z(N, H_1, H_2, \beta) \quad (1)$$

$$= \pi_Q Q + \pi_M M + W + A + T + \frac{\delta}{v_w} e_T \quad (2)$$

$$\text{s.t. } H_1 > 0, H_2 > 0 \quad (3)$$

$$N \in \{1, 2, \ldots, \left\lfloor \frac{D}{s} \right\rfloor\} \quad (4)$$

$$0 < \beta \leq 1. \quad (5)$$

where
N - number of lines;
H_1 - headway of structured routes;
H_2 - headway of flexible routes;
β - Walking threhold
are decision variables.
$\pi_Q, \pi_M, \delta, v_{c1}, v_{c2}$ are given parameters.

$$Q = Q_1 + Q_2 \frac{4ND}{H_1} + \frac{5ND}{2H_2} + \frac{2p_y \lambda D^3}{3N} \quad (6)$$

$$M = \frac{Q_1}{v_{c1}} + \frac{Q_2}{v_{c2}} \quad (7)$$

$$A = p_n \frac{2l}{v_w} \quad (8)$$

$$W = p_y H_2 + \frac{H_1}{2} \left[1 + \frac{(N-1)^2}{N^2} \right] \quad (9)$$

$$T = \frac{E_1}{v_{c1}} + \frac{E_2}{v_{c2}} \quad (10)$$

$$E_1 = \frac{0.34D(2N^2 - 2N + 1)}{N^2}; E_2 = \frac{p_y l_y Q_2 H_2}{ND} \quad (11)$$

Q - total distance traveled
M - total fleet size
A - walking time
W - waiting time
E - In-vehicle travel distance

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where

$$p_n = \begin{cases} 2\beta^2, & 0 < \beta \leq 0.5, \\ 1 - 2(1-\beta)^2, & 0.5 < \beta \leq 1. \end{cases}$$

$$p_y = 1 - p_n$$

is walking probability

$$e_T = \frac{(N-1)^2}{N^2}$$

is transfer probability, and

$$l = \begin{cases} \frac{2\beta D}{3N}, & 0 < \beta \leq 0.5, \\ \frac{3-4(1-\beta)^2(1+2\beta)}{6-12(1-\beta)^2} \frac{D}{N}, & 0.5 < \beta \leq 1. \end{cases}$$

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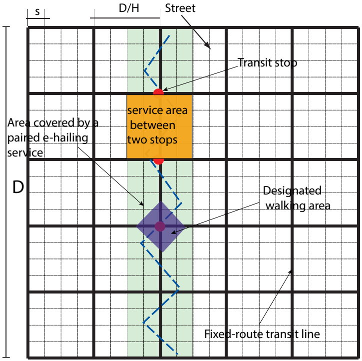
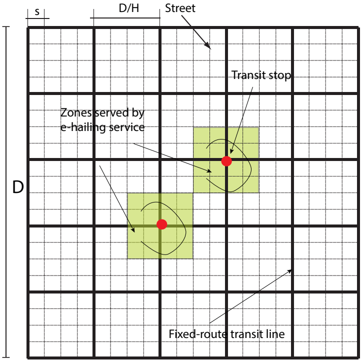
Alternative hybrid design

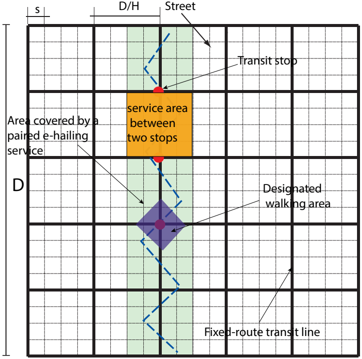


Paired-line system

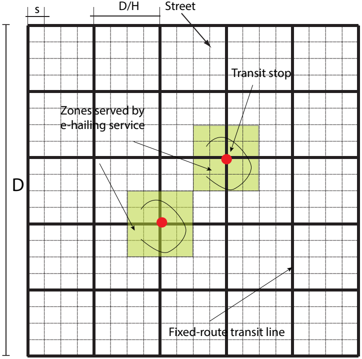


Zone-based system

Alternative hybrid design



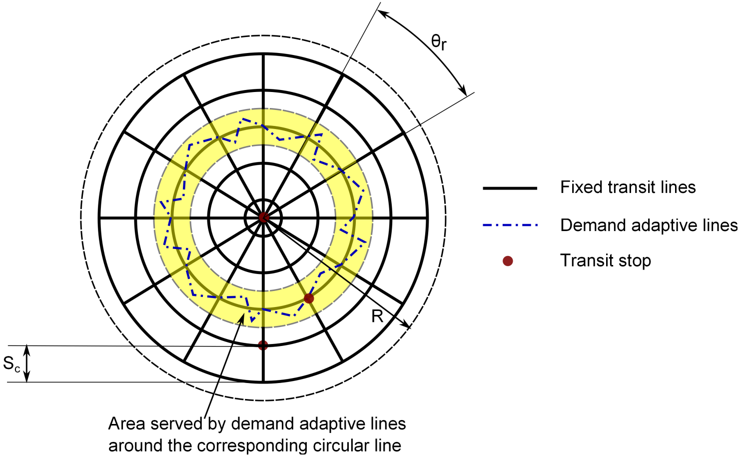
Paired-line system



Zone-based system

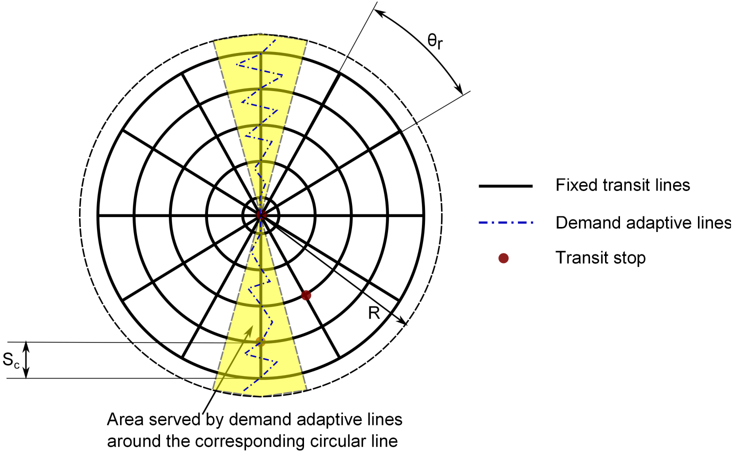
Which one is better?

Alternative route structure



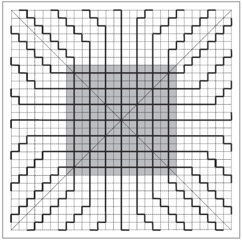
Radial paired-line with flexible routes running on circular lines.

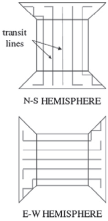
Alternative route structure



Radial paired-line with flexible routes running on radial lines.

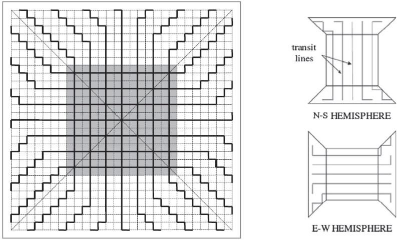
Non-hybrid systems





Fixed-route transit system (Daganzo 2010)

Non-hybrid systems



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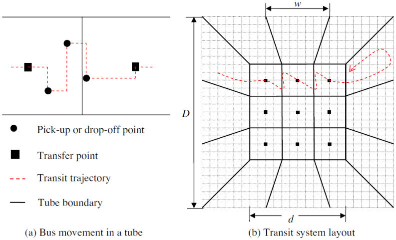


(a) Bus movement in a tube (b) Transit system layout

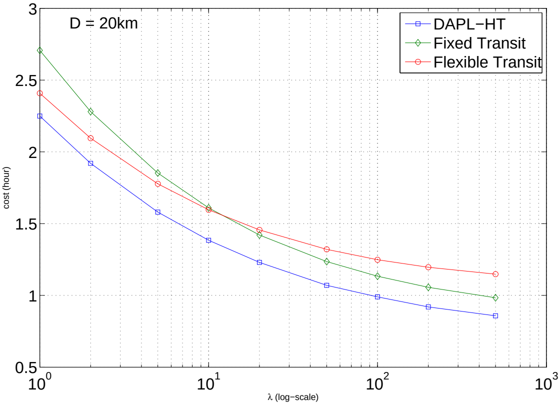
Flexible-route transit system (Nourbakhsh & Ouyang 2012)

Parameters

- The optimization problem is solved by Matlab's built-in genetic algorithm.
- Parameters used in the numerical experiments are listed below.

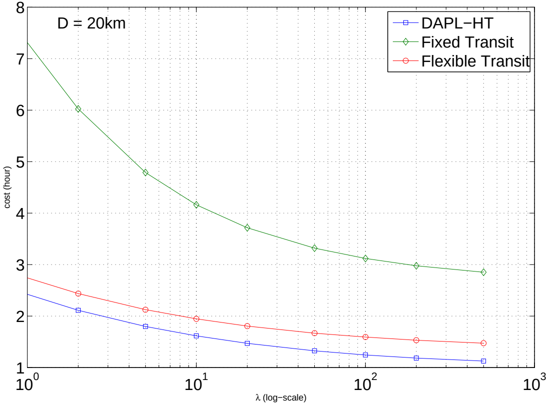
Notation	Value	Description
$s(km)$	0.15	the distance between two adjacent streets (street spacing)
$\mu(\$/h)$	20	value of time
$\tau_1(s)$	12	time lost per stop due to deceleration and acceleration
$\tau_1'(s)$	1	time added per boarding passenger for fixed-route vehicles
$\tau_2(s)$	13	additional pick-up and drop-off time required per passenger
$v(km/h)$	25	vehicles' cruising speed
$v_w(km/h)$	2	walking speed
$\delta(km)$	0.03	transfer penalty expressed in terms of equivalent distance walked
$\$_Q(\$/veh \cdot km)$	2	operation cost per vehicle distance
$\$_M(\$/veh \cdot h)$	40	operation cost per vehicle hour

Grid paired-line system vs. non-hybrid systems



Cost versus demand levels for $D = 20km$

Sensitivity analysis: inconvenient walking



$$v_w = 0.1 km/h$$

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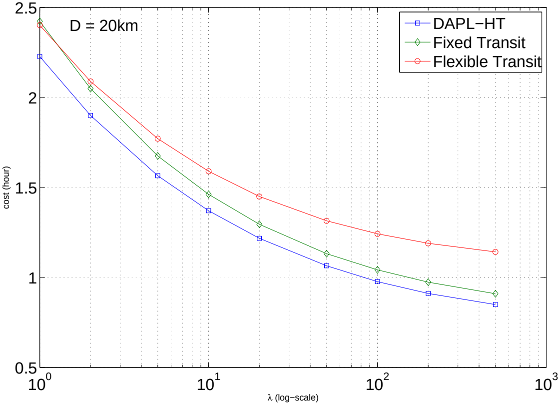
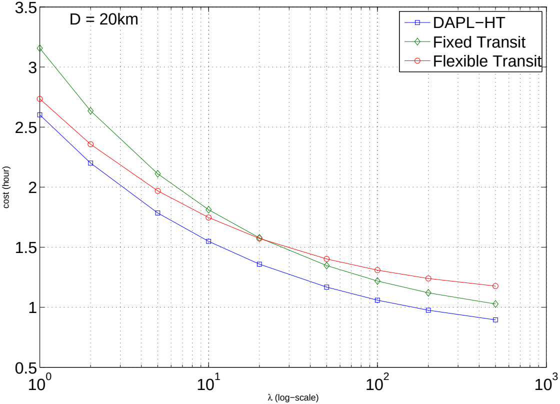
Sensitivity analysis: fast walking



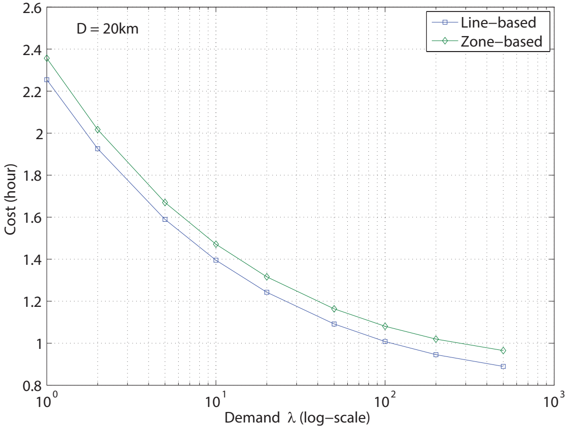
$$v_w = 3km/h$$

Sensitivity analysis: high weight of waiting

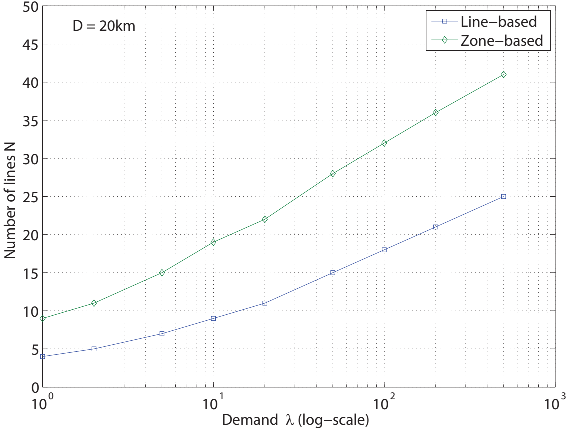


1 unit of waiting time = 1.8 unit of in-vehicle time

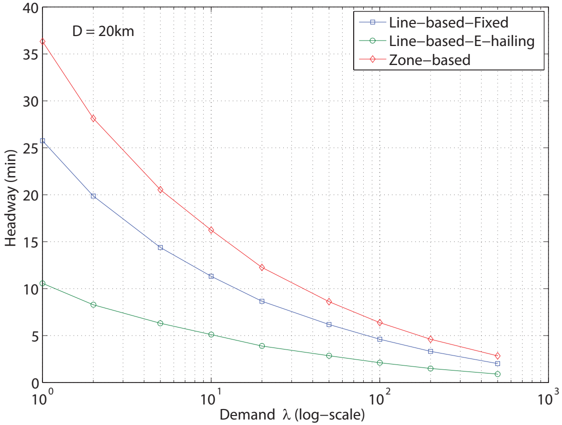
Zone-based vs. line-based: total cost



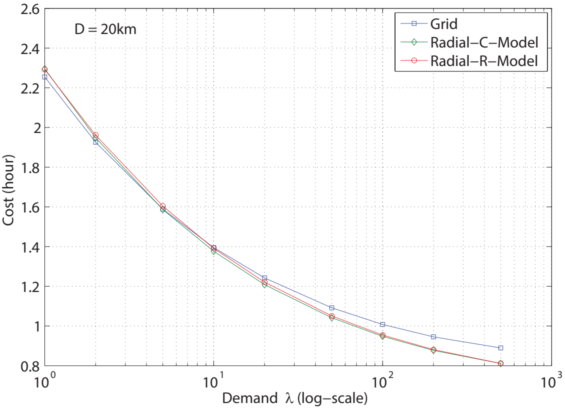
Zone-based vs. line-based: number of lines



Zone-based vs. line-based: headway



Grid vs. radial: total cost



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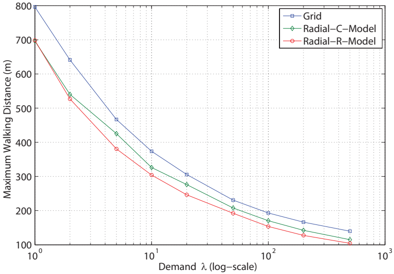
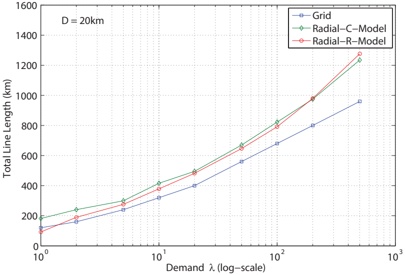
Grid vs. radial



Maximum walking distance



Total line length

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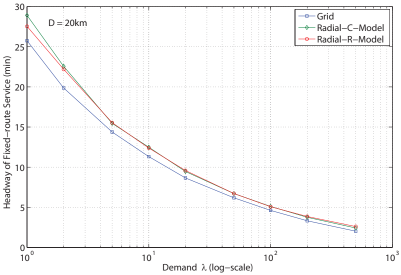
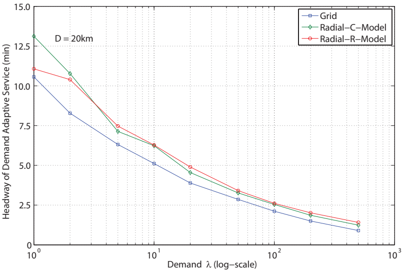
Grid vs. radial



Headway of structured routes



Headway of flexible routes

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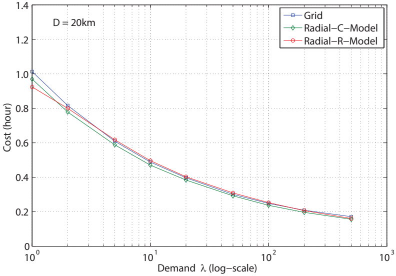
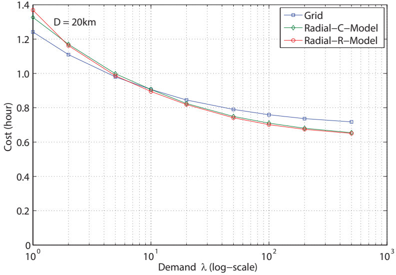
Grid vs. radial



Agency cost



User cost

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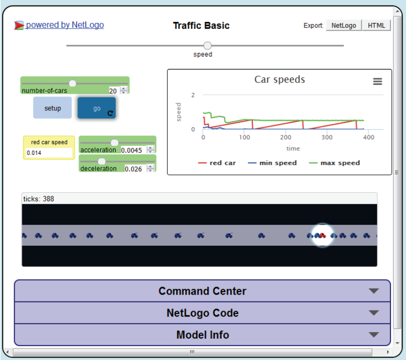
Simulation platform: NetLogo



NetLogo is a multi-agent programmable modeling environment

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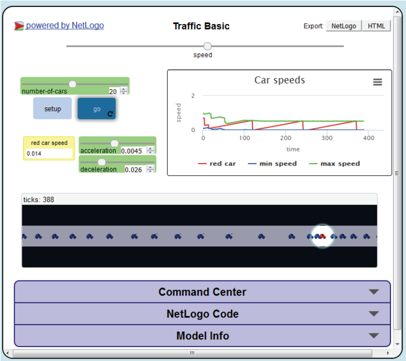

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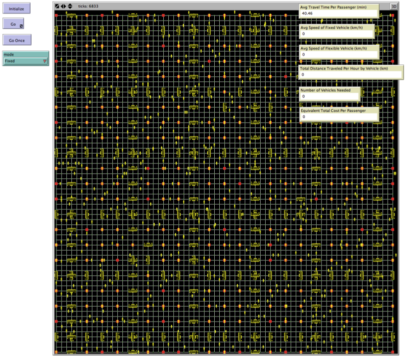
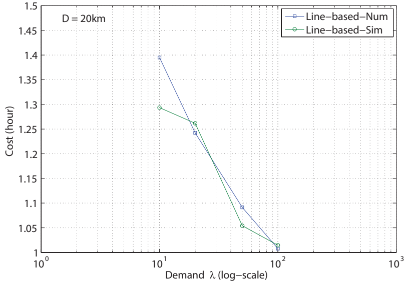
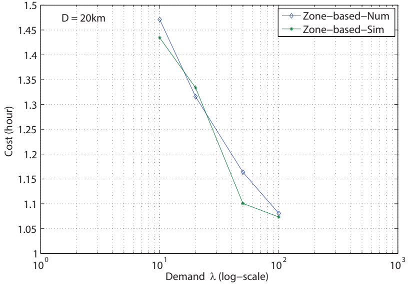


Transit System Simulation Interface developed using NetLogo

Simulation vs. analysis results



Paired-line system



Zone-based system

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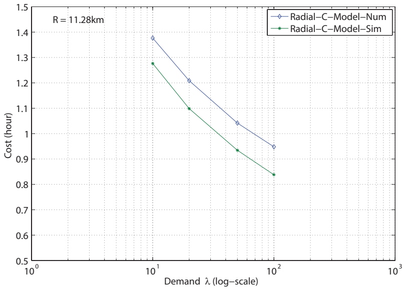
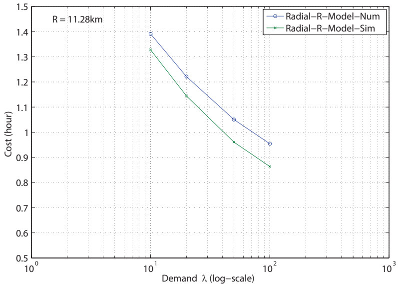
Simulation vs. analysis results



Radial paired-line system with circular flexible routes



Radial paired-line system with radial flexible routes

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Summary of findings

- Hybrid systems clearly outperform traditional transit systems, especially in terms of user costs.

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Summary of findings

- Hybrid systems clearly outperform traditional transit systems, especially in terms of user costs.
- The line-based systems outperform the zone-based systems in both agency and user costs;
- The line-based design features a sparser structured routes but a higher dispatching frequency;
- Radial paired-line systems save about 10% system cost for larger networks with relatively high demand; and
- Analytical results match simulation results well in grid systems, but tend to overestimate the system cost in radial systems.

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What did we learn?

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- Electrification and automation will make novel transit systems like CREDIT much more competitive.

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What did we learn?

- Hybrid transit holds promise to improve user experience while operating the system efficiently.
- It personalizes transit services and is well equipped to balance cost and level of service.
- Electrification and automation will make novel transit systems like CREDIT much more competitive.
- Transportation systems analysts have the unique skill set to contribute to the intelligence of such systems.

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Where do we go from there?

Future research can further develop:

- Efficient real-time vehicle routing;

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Future research can further develop:

- Efficient real-time vehicle routing;
- Coordination and control strategies;
- Personalized service and pricing;
- A high-fidelity, high-performance simulation platform

Thank you for listening!

Acknowledgement

ormick
Northwestern Engineering
CCITT Center for the Commercialization of Innovative Transportation Technology

1. Nie (2016). How can the Taxi Industry Survive the Tide of Ridesourcing? Evidence from China. Transportation Research Part C, under review.
2. Chen, P. and Y. M. Nie (2016). Demand adaptive paired-line hybrid transit system. Transportation Research Part B, under review.
3. Chen, P. and Y. Nie. (2016). Optimal Design of Demand Adaptive Paired-Line Hybrid Transit: the Case of Radial Route Structure. European Journal of Operational Research, under review.
4. Chen, P. and Y. Nie. (2016). Connecting E-Hailing to Mass Transit Platform: Analysis of Relative Spatial Position, Transportation Research Part C, under review.
5. Li, Q., Chen, P., Nie, Y., (2015). Finding optimal hyper-paths in large transit networks with realistic headway distributions. European Journal of Operational Research 240 98 - 108.
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