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Network Congestion Effect of E-Hailing Transportation Services

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Congestion Effect of E-Hailing Transportation Services

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Acknowledgement

> Collaborators:

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> Graduate Students

– Mr. Jingxing Wang & Ms. Rong Fan, University of Washington

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Advances in Vehicle Technologies

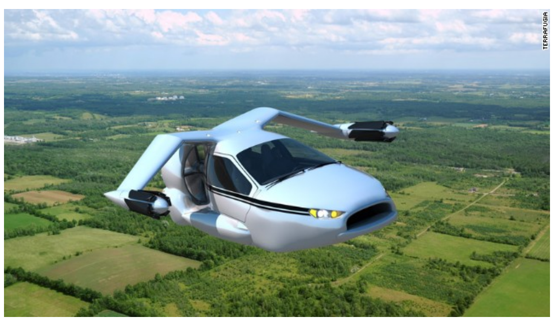
Hybrid Vehicles

Electric vehicles

New Energy Vehicles

Automated vehicles

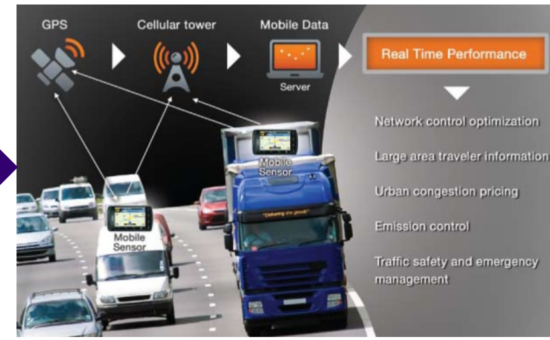
Drones



Flying cars

Uber flying car plan: https://www.wired.com/2016/10/uber-flying-cars-elevate-plan/

Advances in Vehicles/ Transportation (Communications)



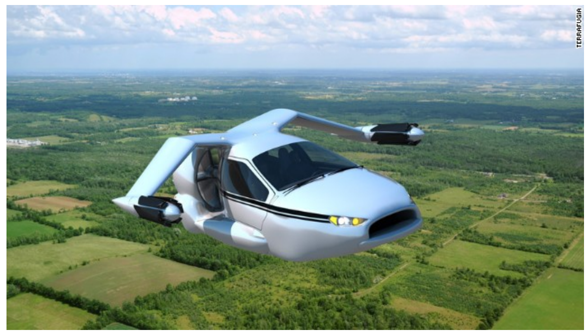
Mobile Sensing

Connected Vehicles

New Social Media

Shared Mobility

Shared Mobility

 +  + UBER

Fifth Element

Modeling and Analyzing E-Hailing Services

Some Basic Concepts

How is traffic distributed in a (urban) traffic network and why?

Some Basic Concepts

- Transportation Network Modeling (Traffic Assignment): predict flow distribution in a traffic network, given the total demand (e.g., during the peak period)
- Traffic Equilibrium (Frank Knight, 1924)
- Wardrop First Principle: User Equilibrium (Wardrop, 1952)

  The journey times on all the routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route

- Wardrop Second Principle: System Optimal (Wardop, 1952)

  At equilibrium, the average journey time is minimum

Some Basic Concepts

- Transportation Network Analysis Paradigm
  - User Equilibrium (UE)
  - System Optimum (SO)
  - Mixed Equilibrium (ME)
  - …
- New developments make them more relevant, not obsolete
  - New systems make it more likely to estimate/predict state/behavior accurately
  - New systems make it easier to communicate / influence users

E-Hailing Services

- > Phone calls
- > **Mobile apps**
- > Other means (e.g., Connected/automated vehicles in the future?)

E-Hailing Service Modes

- E-Hailing Taxi
- TNC (Transportation Network Company)
- Ridesourcing (Uber/Lyft/Didi: drivers are "*for-hire*")
- Ridesharing (both drivers and riders are travelers: carpool)
- Ridesourcing + ridesharing (Uber Pool, Lyft Rideshare, Didi Shunfengche)

Impact of E-Hailing Services: Positive

- Lower costs (compared with traditional taxis)
- More convenient (easier to hail, reduced waiting time, etc.)
- Promoting ridesharing modes (thus more efficient)
- Reduction of the searching-for-parking traffic
- Reduction of the “driving around” vacant taxi traffic
- Others

Impact of E-Hailing Services: Negative

- Safety and comfort concerns (many news items about the safety issues related Uber/Lyft/Didi services)
- Concerns about the experience of the drivers and the reliability of the services
- Deadhead miles (vacant trips)
- Convenience leads to more use of such services (i.e., car trips), which may reduce transit ridership and increase vehicle miles travelled
- Others

Research on the Network Impact

- Empirical Methods (Data)
- Steier (2015): NYC; Chen et al. (2017): Didi data; Nie (2017): taxi data in Shenzhen, China
- Major findings (Nie, 2017):
  - New e-hailing (TNCs) services may mildly increase congestion;
  - Traditional taxis are competitive for specific trips or during specific periods of time (such as peak hours)
  - Certain equilibrium may be reached among different modes

Research on Network Impact

- Systematic Methods (Data + System Modeling)
- Traditional taxis: Yang and Wong (1998); Yang et al. (2002, 2008, 2010, 2011)
- E-hailing services: Xu et al. (2005); **Ban et al**. (2017)
  - Equilibrium may be reached, which depends on the pricing schemes, choices behavior of service providers and customers, and their characteristics (such as value of times, among others); impact depends also on the network/travel characteristics
  - The research did NOT consider ridesharing modes

How to Model E-Hailing Services?

> Multiple key players and their interactions/choices

> "Solo" drivers

> Service Providers

- Taxis drivers
- TNC drivers

> Customers with different Value of Times (VOTs)

- Solo drivers/riders (High)
- Taxi customers (Medium)
- TNC customers (Low)

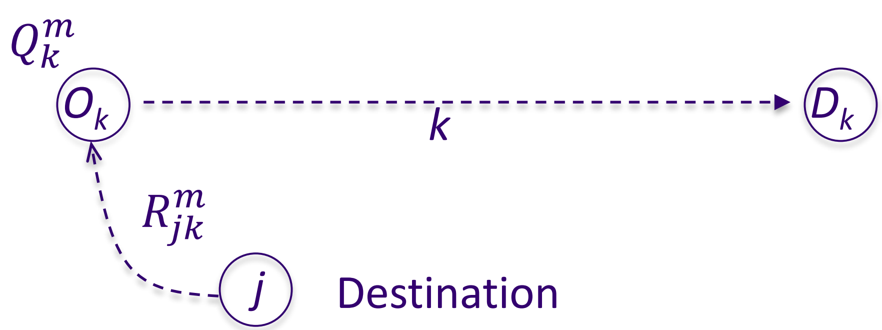
Service Providers Behavior/Choices

- Main consideration: **profit maximization**
- Charging Schemes (basic)
  - Fixed fare + distance-based charge + time-based charge
- Cost: time-based cost and distance-based cost
- Profit:

$$R_{jk}^m = F_{O_k}^m - \underbrace{\beta_1^m (t_{jO_k} + t_{O_kD_k})}_{\text{travel time based cost}} - \underbrace{\beta_2^m (d_{jO_k} + d_{O_kD_k})}_{\text{travel distance based cost}} + \underbrace{\alpha_1^m (t_{O_kD_k} - f_{O_kD_k}^0)}_{\text{time based revenue}} + \underbrace{\alpha_2^m d_{O_kD_k}}_{\text{distance based revenue}}.$$

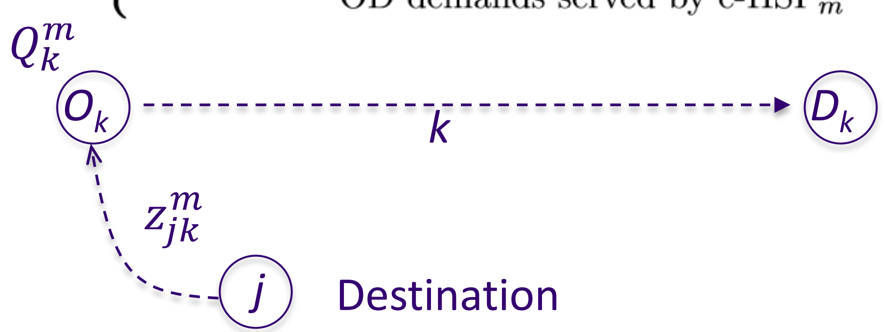
Fixed fare (↑ $F_{O_k}^m$)

For service mode *m*



Service Providers Choice Model

$$
\text{for } m \in \mathcal{M} \left\{
\begin{array}{lll}
\underset{z_{jk}^m \geq 0}{\text{maximize}} & \underbrace{\sum_{k \in \mathcal{K}} \sum_{j \in \mathcal{D}} R_{jk}^m \, z_{jk}^m}_{\text{average trip profit}} & \\
\text{subject to} & \underbrace{\sum_{k \in \mathcal{K}} z_{jk}^m = \sum_{k' : j = \mathrm{D}_{k'}} Q_{k'}^m}_{\text{available e-HSP vehicles for service}} & \text{for all } j \in \mathcal{D} \\
\text{and} & \underbrace{\sum_{j \in \mathcal{D}} z_{jk}^m \geq Q_k^m}_{\text{OD demands served by e-HSP}_m} & \text{for all } k \in \mathcal{K}
\end{array}
\right\}
$$



Customer Behavior/Choices

> Main consideration: utility maximization / disutility minimization

> Disutility

– Solo drivers: time and **distance** related disutility (maybe fixed fare)

$$U_k^0 = \underbrace{\gamma_1^0 t_{\mathrm{O}_k\mathrm{D}_k}}_{\substack{\text{travel time} \\ \text{based disutility}}} + \underbrace{\beta_2^0 d_{\mathrm{O}_k\mathrm{D}_k}}_{\substack{\text{distance} \\ \text{based disutility}}} .$$

– Service riders: fare + time related disutility

$$U_k^m = F_{\mathrm{O}_k}^m + \alpha_1^m \left(t_{\mathrm{O}_k\mathrm{D}_k} - f_{\mathrm{O}_k\mathrm{D}_k}^0 \right) + \alpha_2^m d_{\mathrm{O}_k\mathrm{D}_k} + \underbrace{\gamma_1^m t_{\mathrm{O}_k\mathrm{D}_k}}_{\substack{\text{travel time} \\ \text{based disutility}}} + \underbrace{w_{\mathrm{O}_k}^m}_{\substack{\text{disutility due to} \\ \text{waiting}}} .$$

Customer Choice Model

- Customer waiting time: waiting for service vehicles to travel to the pick up location and extra waiting time if no enough service vehicles

$$w_{O_k}^m = \gamma_2^m \frac{\sum_{j \in \mathcal{D}} z_{jk}^m t_{jO_k}}{\sum_{j \in \mathcal{D}} z_{jk}^m} + \gamma_3^m \lambda_k^m, \quad \text{for all } m = 1, \cdots, M.$$

- Choice Model: disutility of using different models equilibrates, i.e., no one wants to switch modes

$$0 \le Q_k^m \perp U_k^m - u_k \ge 0 \qquad \forall (k, m) \in \mathcal{K} \times \mathcal{M}_+$$

$$u_k \text{ free}, \qquad \sum_{m \in \mathcal{M}_+} Q_k^m = Q_k \quad \forall k \in \mathcal{K},$$

Congestion Model

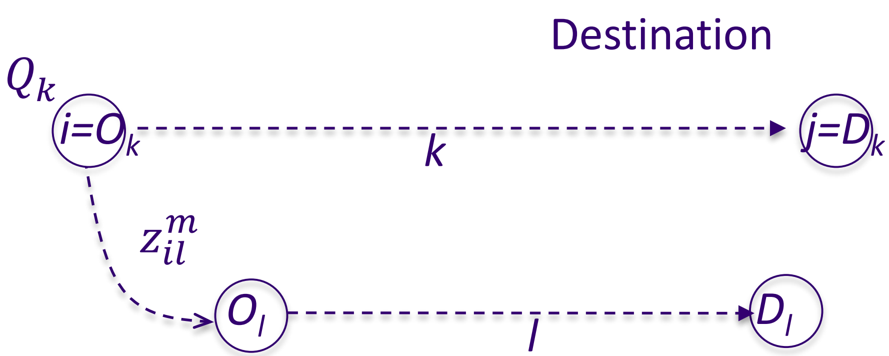
- Choices of customers (which modes to choose) and service drivers (which customers to pick up) generate the flow of traffic (customers from origins to destinations + pick up trips) that interacts on the traffic network, creating network congestion
- **Main Consideration**: during their travels, all drivers choose the routes that minimizes their own travel costs/disutilities
- Similar to the classical UE problem

Congestion Model

> Flow conservation + Route choice

$$0 \leq t_{ij} \perp \sum_{p \in \mathcal{P}_{ij}} h_p - \left[\sum_{k \in \mathcal{K}} \delta_{ijk}^{\mathrm{OD}} Q_k + \sum_{(k,\ell) \in \mathcal{K} \times \mathcal{K}} \delta_{ijk\ell}^{\mathrm{e-HSP}} \sum_{m \in \mathcal{M}} z_{i\ell}^{m} \right] \geq 0$$

$$0 \leq h_p \perp C_p(h) - t_{ij} \geq 0, \quad \text{for all } p \in \mathcal{P}_{ij}.$$

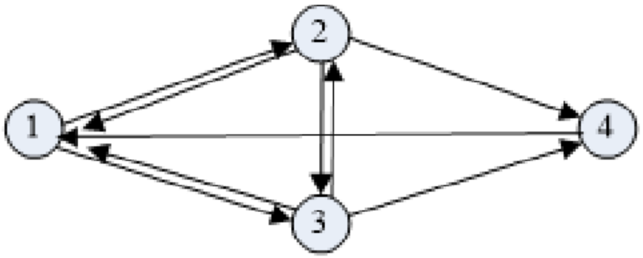


A General Equilibrium Model (GEM)

- A game with multiple players, each aiming to optimizing his/her objective (max. profit, min. disutility, etc.)
- It can be shown that the model has at least one solution and can be obtained by solving a standard mathematical problem.
- The solution can be used to evaluate: % of the deadhead miles, % of travelers choosing each mode, congestion level of the network (e.g., VMTs), and how different charging schemes and other parameters may impact the results

Preliminary Results - I

> A toy network (for illustration)
> Origin 1; destination: 2,3,4
> Demands: 50, 40, 50



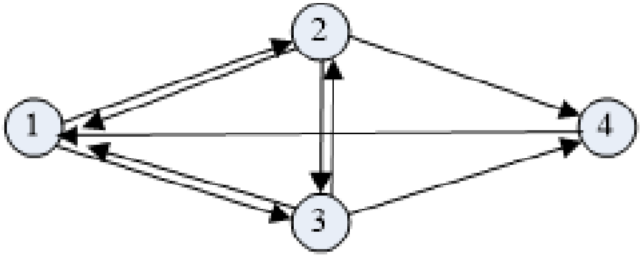
Links	From node	To node	Free flow travel time (h)	Length (mile)	Capacity
1	1	2	0.3	10	40
2	1	3	0.5	20	40
3	2	3	0.4	20	60
4	2	4	0.4	10	40
5	3	4	0.3	20	40
6	4	1	1.0	40	60
7	2	1	0.4	15	50
8	3	1	0.4	20	60
9	3	2	0.5	20	40

Preliminary Results - I

> Demand pattern is extremely *asymmetric*, similar to the AM/PM commute scenario

> Charging Schemes

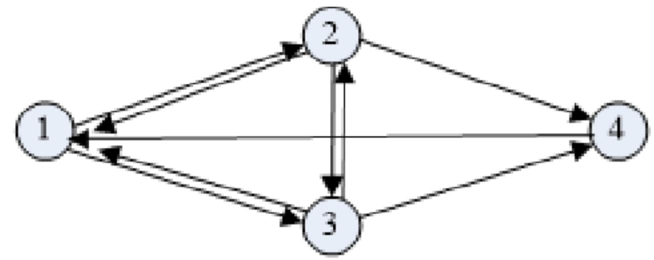
– Seattle Data with modifications



Parameters	Notation	Small network	Sioux-Falls
Fixed fare ($)	$F^m (m = 1, 2)$	3, 1.5	3, 1.5
Time-based fare rate ($/hr)	$\alpha_1^m (m = 1, 2)$	25, 15	30, 20
Distance-based fare rate ($/mile)	$\alpha_2^m (m = 1, 2)$	2.5, 1.5	3, 2
Conversion factor (from travel time to cost, $/hr)	$\beta_1^m (m = 1, 2)$	2, 2	2, 2
Conversion factor (from travel distance to cost, $/mile)	$\beta_2^m (m = 0, 1, 2)$	0.5, 0.2, 0.5	0.5, 0.1, 0.5
Value of time of customer (while traveling, $/hr)	$\gamma_1^m (m = 0, 1, 2)$	55, 2, 20	35, 2.9, 13.5
Value of time of customer (while waiting, $/hr)	$\gamma_2^m (m = 0, 1, 2)$	0, 3, 3	0, 3, 3

Preliminary Results - I

> Total VMT: 5529.94 veh-miles
> Deadhead miles: 2750 veh-miles (~50%)



OD Pair	Mode Choice	Customer Disutility	Num of Used Paths	Min Path TT
1 −> 2	Solo: 0 **Taxi: 49.979** **TNC: 0.021**	Solo: 48.76 **Taxi: 45.817** **TNC: 45.817**	1	0.887
1 −> 3	**Solo: 40** Taxi: 0 TNC: 0	**Solo: 54.528** Taxi: 68.648 TNC: 61.917	1	0.991
1 −> 4	Solo: 0 Taxi: 0 **TNC: 50**	Solo: 71.349 Taxi: 71.906 **TNC: 69.62**	2	1.297

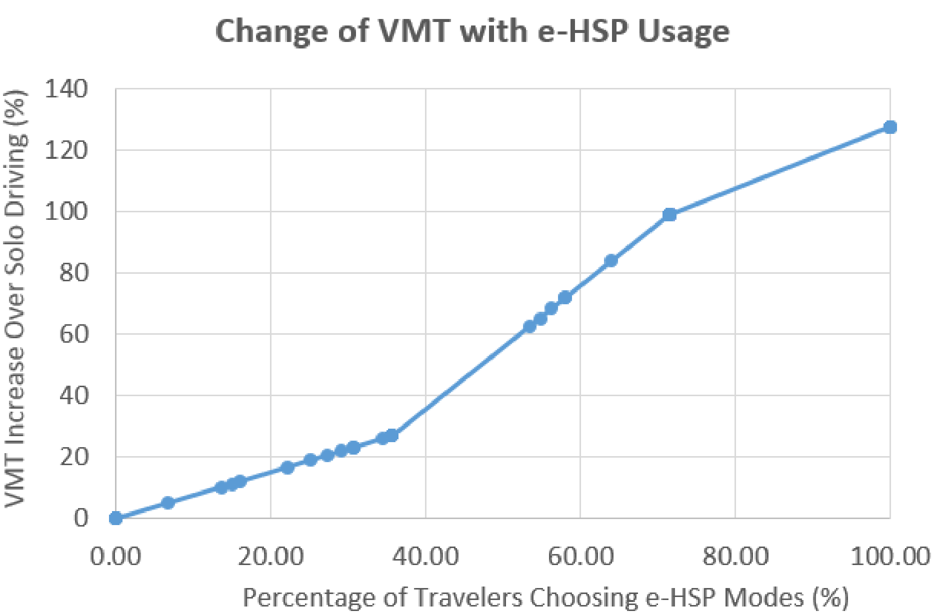
Sensitivity Analysis

> Test how the model results change with the change of a single parameter

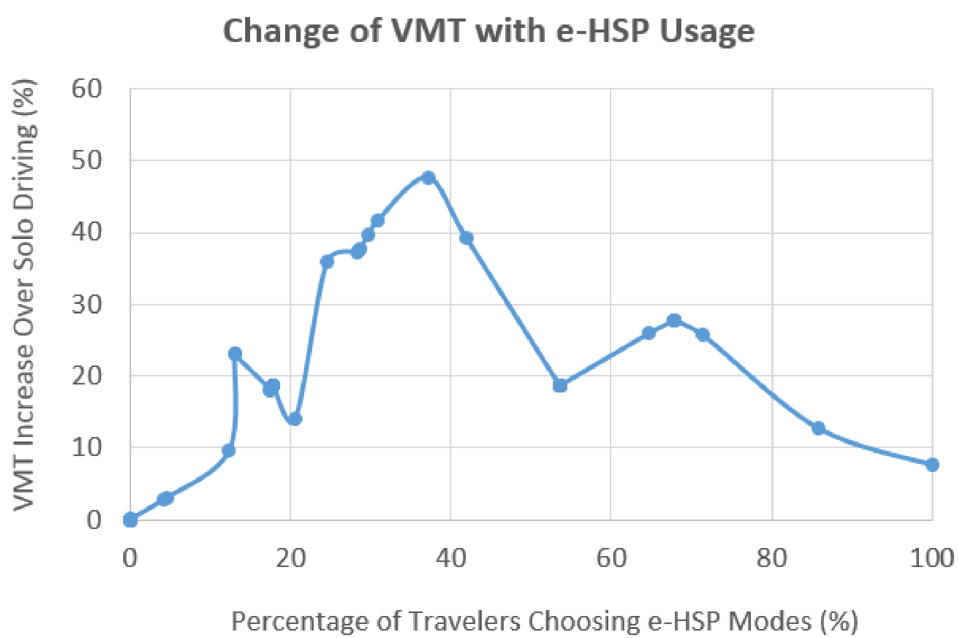
> In general, increasing certain cost factor of a given mode, customers' choice of that mode will decrease.

> The changes are more sensitive to some parameters such as the time- and distance-based charging fee than other parameters (such as the distance-based cost of drivers)

Sensitivity Analysis

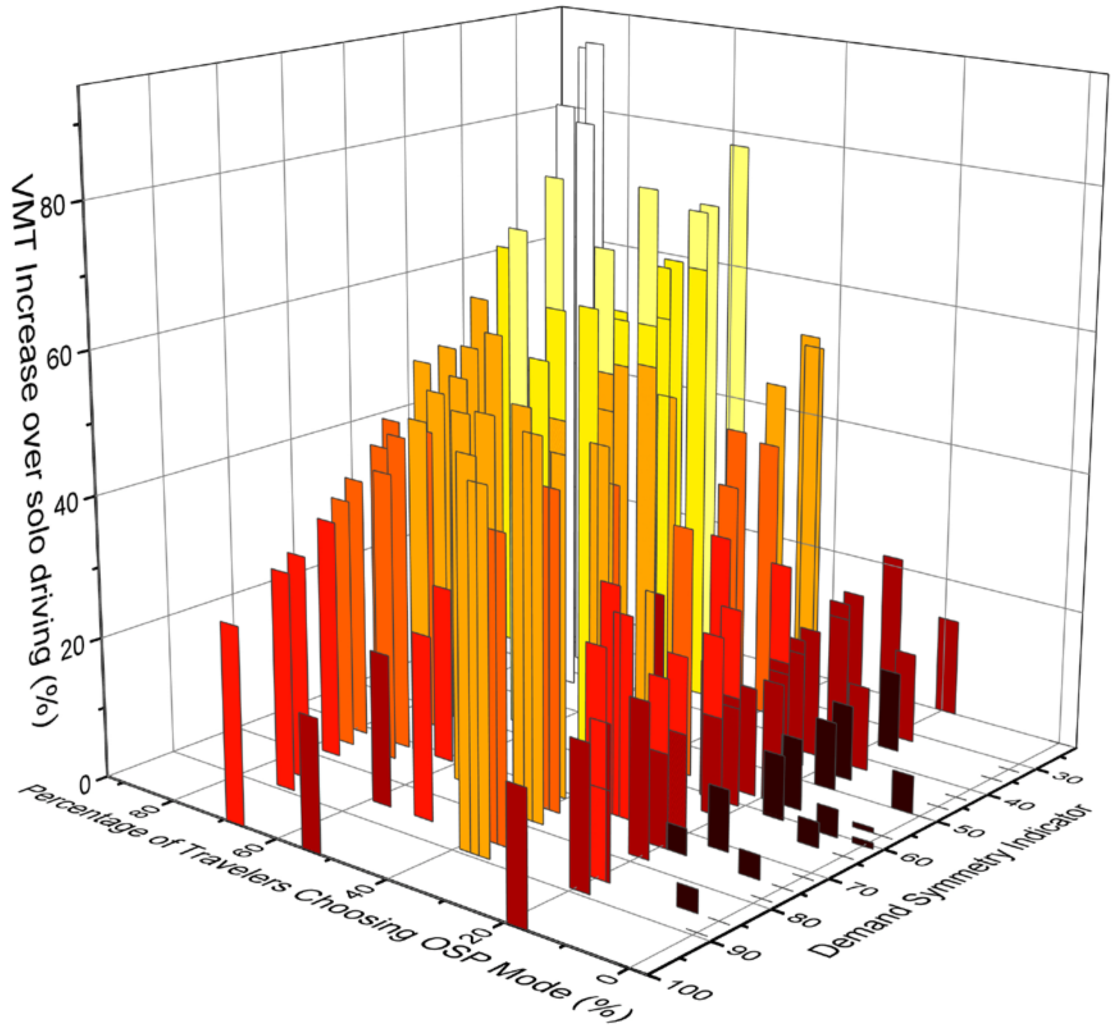


Asymmetric Demand Pattern

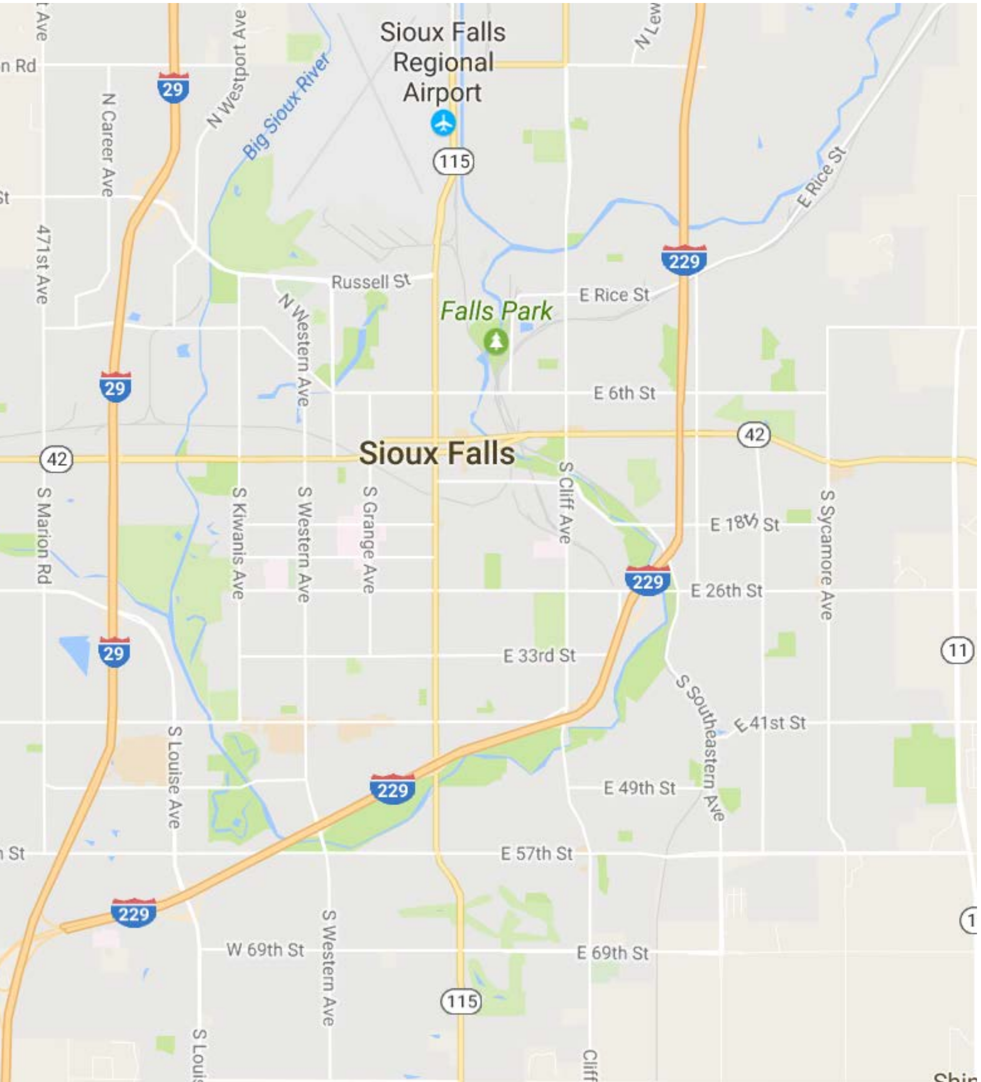


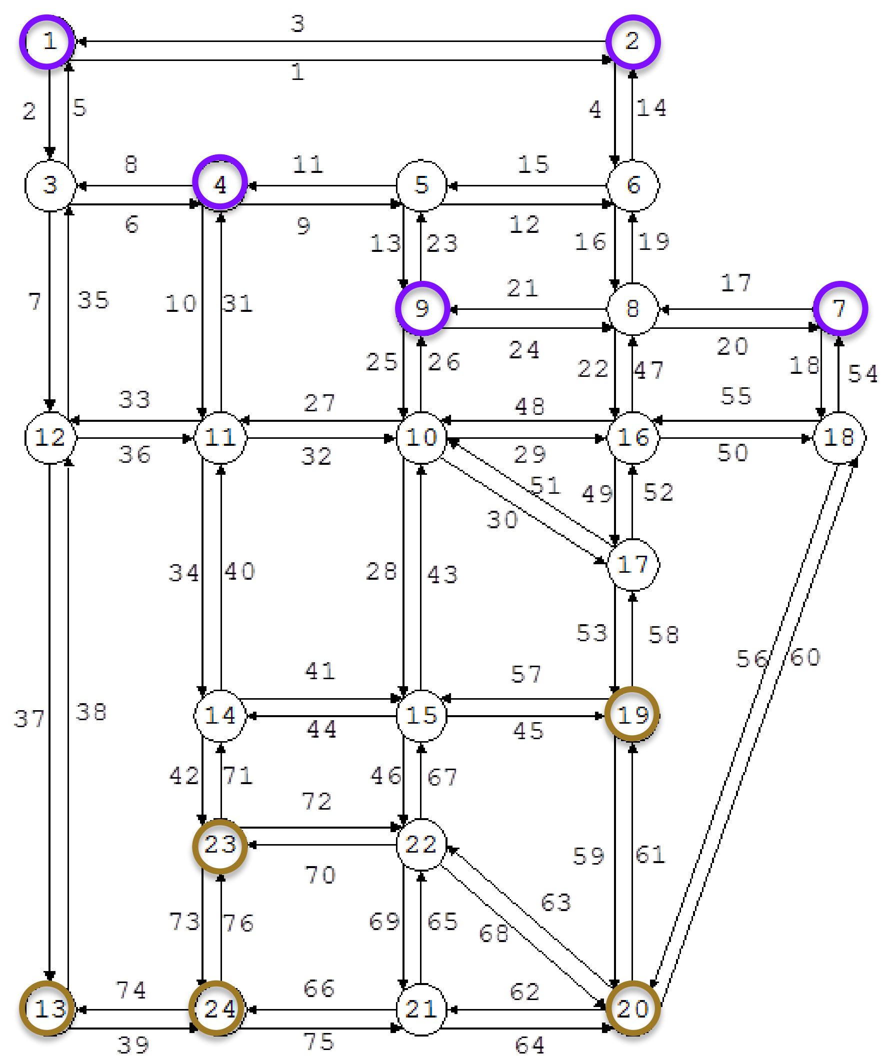
Symmetric Demand Pattern

Sensitivity Analysis

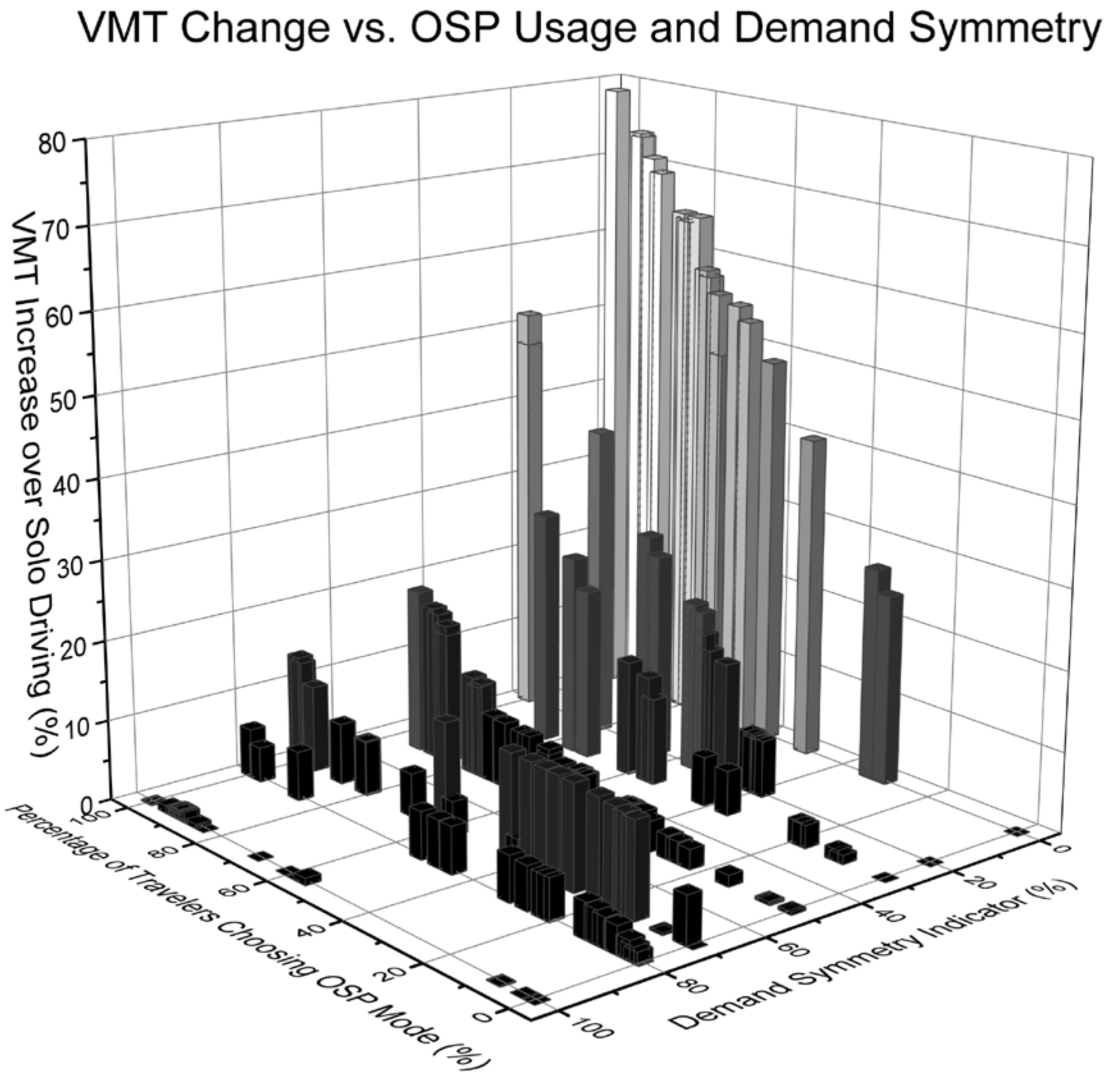


Results - Sioux Falls Network





Results – Sioux Falls Network



Summary of Findings

- The congestion impact of e-hailing services depends on the pricing scheme, the characteristics and choice behavior of providers and customers, the travel demand pattern, and the geometry of the network
- The *larger* the percentage of e-hailing services, the *lower* the demand symmetry, the *larger* the increase of the total VMT
- For certain trips such as AM commute trips, demand pattern may be very asymmetric. In this case, significant use of e-hailing services may noticeably increase VMT and congestion
- E-hailing providers: encourage the use of ridesharing services and reduce deadhead miles

Current / Future Research

- Extensions:
  - Integrate transit or elastic demand
  - Integrate ridesharing modes
  - Consider “dynamics” of the system
  - Optimize system performance (dispatch, congestion, etc.)
- Testing and validation on real-world networks/data

Intelligent Urban Traffic System Lab (iUTS)

- Started at Rensselar Polytechnic Institute (RPI), transferred (almost) to the University of Washington (UW)
- **People and Alumni**:
  - 5 Ph.D. and 3 M.S. students graduated; 2 Post-docs; 30+ undergraduate student researchers;
  - 4 Ph.D. students in progress (2 more in Fall 2017); ~ 5 MS students; a number of undergraduate researchers and visiting scholars / students
- **Funding**: More than $3.0M since 2008, including ~$1.0M from NSF; 25 completed and 3 active projects
- iUTS Homepage: http://faculty.washington.edu/banx/

Intelligent Urban Traffic System Lab (iUTS)

- Research outcomes (since 2008):
  - **Journal publications**: about *50* published or accepted
  - **Conference proceeding papers** (refereed): *about 40*
  - **Invited Talks**: 3*0* (universities, transportation management agencies, transportation research institutes, mobile research institutes, industry)
  - **Research projects**: PI/Co-PI 28 research projects for $3.0 million
  - **Awards**: *NSF CAREER Award* (2011); *CUTC (Council of University Transportation Centers) New Faculty Award* (2012); *Best Paper Award*, University Transportation Research Center (UTRC), Region 2 (2008); Research Excellence Award, School of Engineering, RPI (2014)
- Professional Services (since 2008)
  - **National Committees**: *Elected Vice Chair* (2010-2011) and *Cluster Chair* (2012-2013) of ITS Special Interest Group (SIG) of Transportation Science & Logistics (TSL) Society under INFORMS; *Committee Member* of Transportation Network Modeling (ADB30) and Vehicle Highway Automation (AHB30), Transportation Research Board, National Academies
  - **Editorial Board**: *Associate Editor* of Journal of IEEE Transactions on Intelligent Transportation Systems; Transportation Research, Part C; Intelligent Transportation Systems; *Editorial Board Member* of Transportation Research, Part B; Networks and Spatial Economics; TransporMetrica – B

Thank You!

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