COMMUTING SERVICE PLATFORM: CONCEPT, METHOD AND ANALYSIS

Final Exam Defense

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Content

1. Introduction

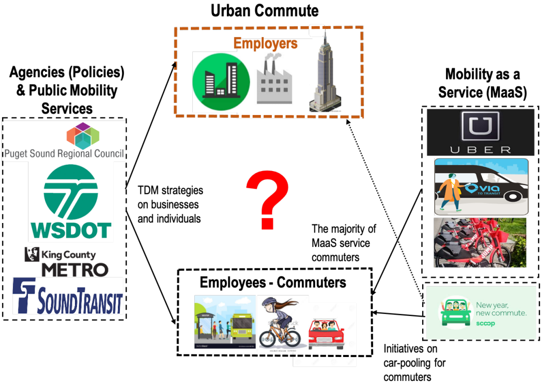
Business is a major attractor of commuting trips:

- Employer-sponsored transportation programs (ESTP)
- Companies such as Microsoft, Apple volunteer to provide ESTP

Transportation demand management (TDM) strategies:

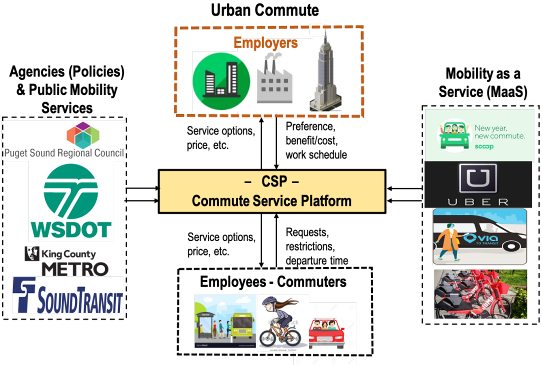
- **Worksites related TDM strategies:** employer-based transit passes, vanpooling, telecommuting, parking management

However, the impact of business sites in the commuting problem is still underrepresented



1. Introduction - Commuting Service Platform (CSP)

- We invision a new type of MaaS: **Commuting Service Platform (CSP)**
- A multi-modal on-demand mobility service platform that connects commuters and worksites direclty to relieve peak hour congestion
- Enhances the collaboration among CSPs (MaaS), employers, and commuters
- Helps to build the next generation TDM strategies, where there are systematic schemes to encourage commuters to choose shared rides/transit



1. Introduction - Commuting Service Platform (CSP)

- The planning- and operational-level challenges of building a CSP

Planning level
Short / long term management for market expansion
The optimal pricing strategy towards the two groups
… …

Operational level
The matching of passengers and vehicles
Dispatching strategy (route choices)
Dynamic pricing, pricing for surge demand, holidays, etc
The integration with transit … …

- This dissertation focuses on some key aspects of the planning/operational level analyses of CSP:
  - Planning level: **optimal pricing strategies** (for the two sides: commuters and worksites)
  - Operational level: **optimal mode** & **route choices** of integrated ridesourcing and transit system

2. Literature Review - Two-sided market

A platform is said to be two-sided if the **price allocation** but not only the aggregated price of the two sides affects the profit (or participation) (Rochet & Tirole, 2006).

Examples of two-sided market:

- CSP: employers and employees (commuters) are the two sides

sellers and buyers are the two sides

drivers and passengers are the two sides

hosts and guests are the two sides

What are the benefits of a two-sided market?

2. Literature Review - Two-sided market

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Examples of two-sided market:

- CSP: employers and employees (commuters) are the two sides

sellers and buyers are the two sides

drivers and passengers are the two sides

hosts and guests are the two sides

Benefits of two-sided market for CSP:

- Employers can outsource the employer-sponsored transportation program (ESTP) to a third party to save related cost and raise employee satisfaction
- CSP has more room for price optimization (will show later in the numerical experiments)
- Employees can choose more efficient commuting services with lower cost

2. Literature Review - Two-sided market

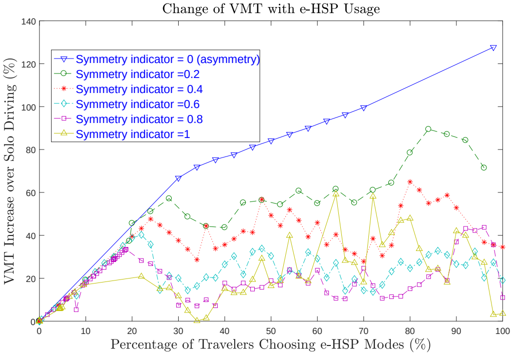
- Most of the existing two-sided market analysis in transportation field treat the drivers (vehicles) and the passengers as the two sides (groups)
- In our study, businesses (employers) and the commuters (employees) are the two sides

Table 1: Applications of Two-sided Market

Field	Platform(s)	Two sides	Findings	Authors
Academic Journals	Academic journals	authors ; readers	Open access policy makes publications free to readers and charges high publication fees to authors. This policy is good when considering maximizing social welfare, but may harm readers utility, the impact or profit of the journal.	Jeon & Rochet (2010)
Payment card	credit card, debit card	merchants ;customers	Benchmark model shows that HAC rule not only benefits the multi-card platform but also raises social welfare. However, in the extended model HAC rule may no longer raise social welfare under all parameter settings.	Rochet & Tirole (2008)
Magazine	Magazine companies	readers; advertisers	Higher demand on the reader side increases advertising rates. Higher demand on the advertiser side reduces the price of magazine to readers.	Kaiser & Wright (2006)
Internet	Internet Service Provider (ISP)	content / application providers; broadband users	Network neutrality regulation increases the total surplus under certain parameter ranges for both monopoly and Competitive platforms.	Economides & Tåg (2012)
Flexible mobility services	The built environment	operators ; travelers	The differences between one-sided and two-sided market. The threshold when the network externalities lead to two-sidedness.	Djavadian & Chow (2017)
Ride-sourcing	Ride-sourcing services	drivers; passengers	The matching condition/ regulation policy when the first / second best solution holds in monopoly case is found. The study of competing platforms suggests merging of platforms as competition won't lower the price level or improve social welfare	Zha *et al.* (2016)

2. Literature Review - general equilibrium model

- The operational level anlysis in this dissertation significantly extends the model in Ban *et al.* (2019) to encompass **shared rides** and **transit services** under the **CAV** environment.
- Mode split is more complex when the ridesourcing platform has more than 2 types of modes
- Ban *et al.* (2019) proposed a general equilibrium model that consists of the optimization of three main players: **service providers**, **passengers** and the **network congestion**

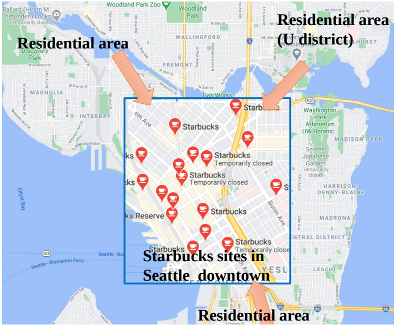


(Ban *et al.*, 2019)

3. Planning level analysis - Problem Statement

Starbucks case study:

- Platform: CSP; Two sides: commuters and starbucks worskites



The distribution of Starbucks in downtown Seattle and the commuting trends

3. Planning level analysis - Monopoly Case

Monopoly model

Utility function

$$\underbrace{U^C}_{\text{utility of commuters}} = \underbrace{U_0^C}_{\text{fixed utility for commuters to join the CSP}} + \underbrace{b^C q^B}_{\text{cross-side benefits}} - \underbrace{t^C q^C}_{\text{same-side negative effects}} - \underbrace{p^C}_{\text{price charged to commuters}}$$

$$\underbrace{U^B}_{\text{utility of worksites}} = \underbrace{U_0^B}_{\text{fixed utility for worksites to join the CSP}} + \underbrace{b^B q^C}_{\text{cross-side benefits}} - \underbrace{t^B q^B}_{\text{same-side negative effects}} - \underbrace{p^B}_{\text{price charged to worksites}} \tag{1}$$

- Cross-side benefits: commuters are more willing to join the CSP if there are lots of worksites joining the CSP; the reverse is also true
- Same-side negative effects: commuters have lower utility if additional commuters join the same CSP

3. Planning level analysis - Monopoly Case

Monopoly model

Utility function

$$U^C = U_0^C + b^C q^B - t^C q^C - p^C \qquad U^B = U_0^B + b^B q^C - t^B q^B - p^B \tag{1}$$

CSP profit

$$R = (\underbrace{p^B}_{\substack{\text{price charged}\\ \text{to worksites}}} - \underbrace{f^B}_{\substack{\text{fixed cost of}\\ \text{serving worksites}}}) \underbrace{q^B}_{\substack{\text{the quantity of}\\ \text{worksites joining the CSP}}} + \underbrace{(p^C - f^C)q^C}_{\substack{\text{profit gained}\\ \text{from the commuters}}} \tag{2}$$

3. Planning level analysis - Monopoly Case

Monopoly model

Utility function

$$U^C = U_0^C + b^C q^B - t^C q^C - p^C \qquad U^B = U_0^B + b^B q^C - t^B q^B - p^B \tag{1}$$

CSP profit

$$R = (\underbrace{p^B}_{\text{price charged to worksites}} - \underbrace{f^B}_{\text{fixed cost of serving worksites}}) \underbrace{q^B}_{\text{the quantity of worksites joining the CSP}} + \underbrace{(p^C - f^C)q^C}_{\text{profit gained from the commuters}} \tag{2}$$

Equilibrium exists when worksites or commuters are indifferent between choosing and not choosing the CSP. We can solve $p^B, p^C = \arg\max_{p^B, p^C} R$ as a ***Constrained Nonlinear Problem***.

3. Planning level analysis - Monopoly Case

Monopoly model

Utility function

$$U^C = U_0^C + b^C q^B - t^C q^C - p^C \qquad U^B = U_0^B + b^B q^C - t^B q^B - p^B \tag{1}$$

CSP profit

$$R = (p^B - f^B)q^B + (p^C - f^C)q^C \tag{2}$$

Equilibrium exists when worksites or commuters are indifferent between choosing and not choosing the CSP. We can solve $p^B, p^C = \arg\max_{p^B, p^C} R$ as a ***Constrained Nonlinear Problem***. Equilibrium prices are

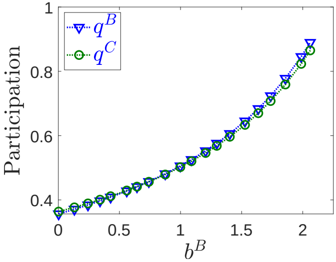
$$p^B = \frac{-b^{B\,2} f^B - b^{C\,2} U_0^B + (2t^B t^C - b^B b^C)(f^B + U_0^B) + t^B(b^B - b^C)(U_0^C - f^C)}{4t^B t^C - (b^B + b^C)^2} \tag{3}$$

$$p^C = \frac{-b^{C\,2} f^C - b^{B\,2} v^C + (2t^B t^C - b^B b^C)(f^C + U_0^C) + t^C(b^B - b^C)(f^B - U_0^B)}{4t^B t^C - (b^B + b^C)^2} \tag{4}$$

3. Planning level analysis

Monopoly Case: numerical experiments

The baseline parameters for this case study are $U_0^B = 1.9$, $U_0^C = 2.1$, $b^B = 0.5$, $b^C = 0.7$, $t^B = 2$, $t^C = 2.2$, $f^B = 0.73$, $f^C = 0.75$.



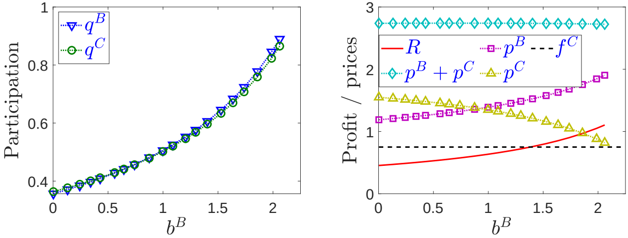
Sensitivity analysis of b^B

$$U^C = U_0^C + b^C q^B - t^C q^C - p^C \qquad U^B = U_0^B + b^B q^C - t^B q^B - p^B \tag{1}$$

- $b^B \uparrow \longrightarrow q^B \uparrow$ (more worksites join the CSP); $q^C \uparrow$ (more commuters join the CSP)

3. Planning level analysis

Monopoly Case: numerical experiments



Sensitivity analysis of b^B

- The CSP sets low prices to commuters (p^C ↓) to attract more commuters to join the platform
- The CSP recoups profit from the worksites side by setting high prices for worksites (p^B ↑)
- The CSP gain more profit by allocating prices between the two sides (commuters and worksites)

3. Planning level analysis - Duopoly model

The agents from either side can choose to join the work-flexible (WF) CSP or the none-work-flexible (NWF) CSP

$$U_W^B = \underbrace{U_0^B}_{\text{fixed benefit}} - \underbrace{p_W^B}_{\text{subscription price}} - \underbrace{t^B(q_W^B + Q^B)}_{\text{same-side/inconvenience costs}} + \underbrace{\alpha_W(q_W^C + Q^C)}_{\text{cross-side benefits}} \quad (5)$$

$$U_N^B = \underbrace{U_0^B}_{\text{fixed benefit}} - \underbrace{p_N^B}_{\text{subscription price}} - \underbrace{t^B(q_N^B + Q^B)}_{\text{same-side/inconvenience costs}} + \underbrace{\alpha_N(q_N^C + Q^C)}_{\text{cross-side benefits}} \quad (6)$$

(8)

- α_i: the cross-side benefit on CSP i
- When $Q^k = 0$, group k single home, i.e., choose one from WF CSP and NWF CSP

3. Planning level analysis - Duopoly model

The agents from either side can choose to join the work-flexible (WF) CSP or the none-work-flexible (NWF) CSP

$$U_W^B = \underbrace{U_0^B}_{\text{fixed benefit}} - \underbrace{p_W^B}_{\text{subscription price}} - \underbrace{t^B(q_W^B + Q^B)}_{\text{same-side/inconvenience costs}} + \underbrace{\alpha_W(q_W^C + Q^C)}_{\text{cross-side benefits}} \quad (5)$$

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$$U_{NW}^B = \underbrace{U_0^B}_{\text{fixed benefit}} - \underbrace{(p_W^B + p_N^B)}_{\text{subscription price}} - \underbrace{t^B(q_W^B + q_N^B + Q^B)}_{\text{same-side/inconvenience costs}} + \underbrace{[\alpha_W(q_W^C + Q^C) + \alpha_N(q_N^C + Q^C)]}_{\text{cross-side benefits}}$$

(7)

(8)

- α_i: the cross-side benefit on CSP i
- When $Q^k = 0$, group k single home, i.e., choose one from WF CSP and NWF CSP

3. Planning level analysis - Duopoly model

The agents from either side can choose to join the work-flexible (WF) CSP or the none-work-flexible (NWF) CSP

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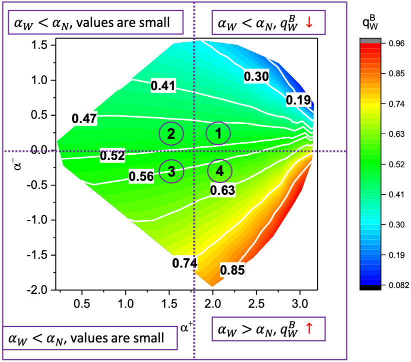
$$R_i = \underbrace{(q_i^B + Q^B)(p_i^B - f_i^B)}_{\text{profit collected from worksites}} + \underbrace{(q_i^C + Q^C)(p_i^C - f_i^C)}_{\text{profit collected from commuters}} \quad \forall i \in \{W, N\} \tag{8}$$

- α_i: the cross-side benefit on CSP i
- When $Q^k = 0$, group k single home, i.e., choose one from WF CSP and NWF CSP

3. Planning level analysis - Duopoly model

α_N and α_W are the cross-side benefit rates of worksites on the two CSPs
$\alpha^+ = \alpha_N + \alpha_W$
$\alpha^- = \alpha_N - \alpha_W$: relative cross-side benefit from the two CSPs

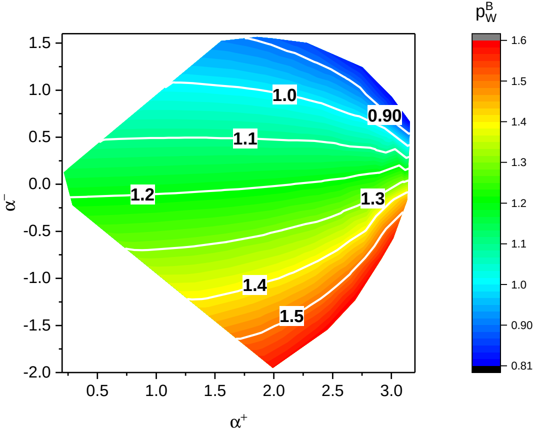


q_W^B

The change of participation w.r.t. α^+, α^-

3. Planning level analysis - Duopoly model

The change of price can be understood in similar ways



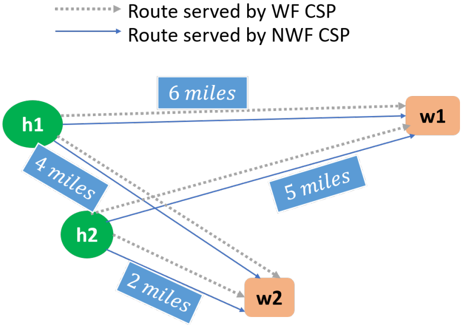
p_W^B

The change of price w.r.t. α^+, α^-

3. Planning level analysis - General model

Network for the general model:

- The general model can be applied to scenario with **multiple home locations, worksites, and CSPs**
- Here, we show a simple example with 2 home locations, 2 worksites, and 2 CSPs



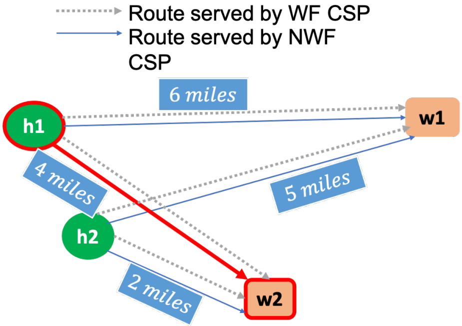
The general case: network and baseline parameters

3. Planning level analysis - Notations

To **differentiate the locations of commuters and worksites**, we adjust the notations as:

U, U_0, B, T, P, Q, F	variables/parameters for the commuters' side
u, u_0, b, t, p, q, f	variables/parameters for the worksites' side

- We set $i = 1$ as WF CSP, set $i = 2$ as NWF CSP
- $U_i^{m,n}$: $U_1^{1,2}$ (similar for $F_1^{1,2}, P_1^{1,2}$, etc.)



3. Planning level analysis - General model

Model (multiple home locations multiple worksites)

Treat commuters, worksites and CSPs as three players, and maximize each of their utility/profit

(I) Commuters' utility maximization problem

$$U_i^{m,n} = \begin{cases} U_{0,i}^{m,n} + B_i^{m,n} q_i^n - T_i^{m,n} Q_i^{m,n} - P_i^{m,n} & \text{joining CSP i} \\ 0 & \text{not joining CSP i} \end{cases} \quad (9)$$

$$0 \leq U_i^{*,m} - U_i^{m,n} \perp Q_i^{m,n} \geq 0 \quad (10)$$

$$0 \leq (1 - \sum_{i,n} Q_i^{m,n}) \perp U_i^{*m} \geq 0 \quad (11)$$

(II) Worksites' utility maximization problem

$$u_i^n = \begin{cases} u_{0,i}^n + b_i^n \sum_m Q_i^{m,n} - t_i^n q_i^n - p_i^n & \text{joining CSP i} \\ 0 & \text{not joining CSP i} \end{cases} \quad (12)$$

$$0 \leq u_i^{*,n} - u_i^n \perp q_i^n \geq 0 \quad (13)$$

$$0 \leq 1 - q_i^n \perp u_i^{*,n} \geq 0 \quad (14)$$

3. Planning level analysis - General model

Model (multiple home locations multiple worksites)

(III) CSP's utility maximization problem

$$\max_{P_i^{m,n}, p_i^n} R = \sum_{i,m,n} (P_i^{m,n} - F_i^{m,n} Q_i^{m,n}) + \sum_{i,n} (p_i^n - f_i^n) q_i^n \tag{15}$$

$$s.t. \qquad P_i^{m,n} \geq 0, p_i^n \geq 0 \tag{16}$$

Then the above maximization problem can be reformulated using its KKT conditions as:

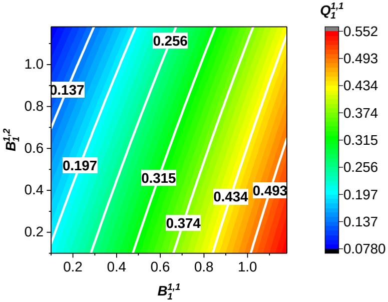
$$0 \leq 2P_i^{m,n} + U_i^{m,n} - F_i^{m,n} - U_{0,i}^{m,n} - B_i^{m,n} q_i^n \perp P_i^{m,n} \geq 0 \tag{17}$$

$$0 \leq 2p_i^n + u_i^n - u_{0,i}^n - f_i^n - b_i^n (\sum_m Q_i^{m,n}) \perp p_i^n \geq 0 \tag{18}$$

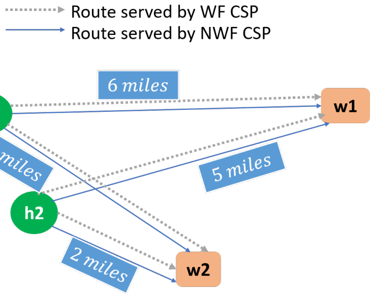
- The general model can be formulated as a ***Mixed Complementarity Problem***
- The utility/profit of the three players are optimized simultaneously

3. Planning level analysis

General model: numerical results



$Q_1^{1,1}$



network

Participation on WF CSP vs. $B_1^{1,1}, B_1^{1,2}$

3. Planning level analysis

General model: numerical results

Results of sensitivity analysis for the general model

	Change pattern with respect to B_1^{11}, B_1^{12}		Change pattern with respect to T_1^{11}, T_1^{12}	
	commuter side	worksite side	commuter side	worksite side
Same CSP, same home loc.	$Q_1^{11} \Uparrow \downarrow$ $Q_1^{12} \downarrow \Uparrow$	$q_1^1 \Uparrow \blacksquare$ $q_1^2 \blacksquare \Uparrow$	$Q_1^{11} \Downarrow \uparrow$ $Q_1^{12} \uparrow \Downarrow$	$q_1^1 \Downarrow \blacksquare$ $q_1^2 \blacksquare \Downarrow$
Same CSP, diff. home loc.	$Q_1^{21} \uparrow \blacksquare$ $Q_1^{22} \blacksquare \uparrow$		$Q_1^{21} \downarrow \blacksquare$ $Q_1^{22} \blacksquare \downarrow$	
Diff. CSP, same home loc.	$Q_2^{11} \Downarrow \Downarrow$ $Q_2^{12} \Downarrow \Downarrow$	$q_2^1 \downarrow \blacksquare$ $q_2^2 \blacksquare \downarrow$	$Q_2^{11} \Uparrow \Uparrow$ $Q_2^{12} \Uparrow \Uparrow$	$q_2^1 \uparrow \blacksquare$ $q_2^2 \blacksquare \uparrow$
Diff. CSP, diff. home loc.	$Q_2^{21} \downarrow \blacksquare$ $Q_2^{22} \blacksquare \downarrow$		$Q_2^{21} \uparrow \blacksquare$ $Q_2^{22} \blacksquare \uparrow$	

Remark: (1) $\Uparrow$ indicates increasing as the parameter increases; $\Downarrow$ indicates decreasing as the parameter increases; bold arrows indicate major impacts, while thin arrows indicate minor impacts; $\blacksquare$ indicates no obvious changes
(2) Arrows and boxes to only represent the direction and extend of the sensitivity effect (minor, major, still), they do not indicate the real "slop", many results show obvious nonlinear trend;
(3) The first arrow (or solid box) is for B_1^{11} (or T_1^{11}), and the second arrow (or solid box) is for B_1^{12} (or T_1^{12})

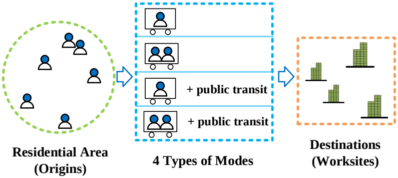
What's next?

- The planning level analysis covers the ***pricing strategy*** for the CSP
- In the next step, I will introduce the operational-level analysis
- The operational level analysis covers the ***matching*** between customers/passengers with vehicles and the ***route choices*** of vehicles for the CSP

4. Operational Level Analysis - Problem statement

The operational model considers 4 types of modes:

- Taxi: single ride for whole trip (m=1)
- Ridesharing: shared ride for whole trip (m=2)
- Ttransit: single ride as first mile, then transfer to transit (m=3)
- RStransit: shared ride as first mile, then transfer to transit (m=4)



Morning commute scenario

	Single ride	Shared ride
Ridesourcing mode	Taxi, m= 1	Ridesharing, m=2
Integrated mode	Ttransit, m=3	RStransit, m=4

Four types of modes

Integrated multimodal network

4. Operational Level Analysis - Problem statement

The model can be formulated into a ***Mixed Complimentarity Problem (MCP)***

- Each *Module* has its own decision variables and exogenous variables
- We can solve the three *Modules* simultaneously

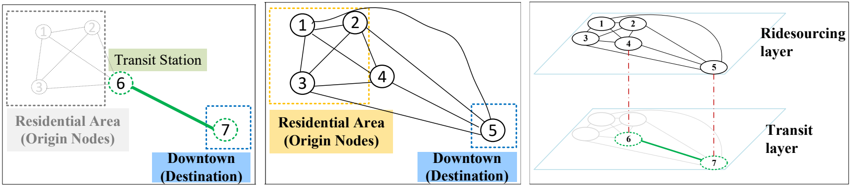
Module I		**Module II**		**Module III**	
Ridesourcing Choice		**Customer Choice**		**Network Congestion**	
max *Revenue* (Satisfy constraints)		max *Utility* (Satisfy constraints)		min *Travel Times* (Satisfy constraints)	
Decision variable	Exogenous variable	Decision variable	Exogenous variable	Decision variable	Exogenous variable
vehicle supply	route choice demand	demand	route choice vehicle supply	route choice	demand vehicle supply

A summary of the general equilibrium model

4. Operational Level Analysis - Problem Statement

Vehicular flow and passenger flow are calculated differently for the integrated system of ridesourcing and transit

- Vehicular flow: ridesourcing layer only
- Passenger flow: ridesourcing layer and transit layer

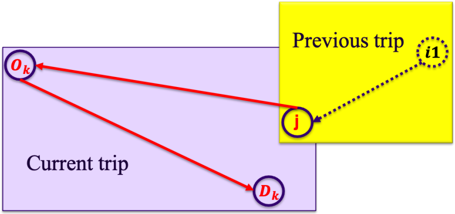


Transit layer | Ridesourcing layer | Two-layer network

Extended network structure of the small network

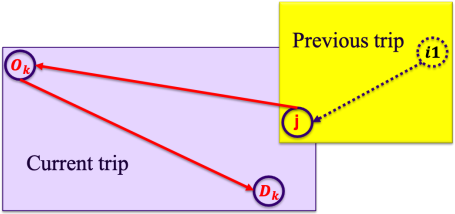
4. Operational Level Analysis - Notations

single ride trip z_{jk}^{m}

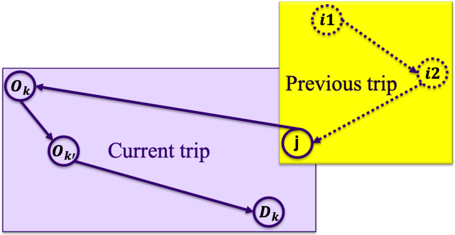


4. Operational Level Analysis - Notations

single ride trip z^m_{jk}



shared ride trip $z^m_{jkk'}$



4. Operational Level Analysis - Model Formulation

Ridesourcing choice module (*Module I*)

Profit maximization:

$$\max_{z^m_{jk}\geq 0, z^m_{jkk'}\geq 0, q^m_{kk'}, b^m_{kk'}} \underbrace{\sum_{m\in\{1,3\}}(R^m_{jk}\cdot z^m_{jk}) + \sum_{m\in\{2,4\}}(R^m_{jkk'}\cdot z^m_{j\tilde{k}\tilde{k}'} - w^m\cdot|q^m_{\tilde{k}\tilde{k}'}| - w^m\cdot|b^m_{\tilde{k}\tilde{k}'}|)}_{\text{average trip profit}} \tag{19}$$

- Profit $R^m_{jkk'} = Revenue - Cost$
- Revenue = fixed revenue + time based revenue + distance based revenue
- Cost = time based cost + distance based cost

4. Operational Level Analysis - Model Formulation

Ridesourcing choice module (*Module I*)

Profit maximization:

$$\max_{z^m_{jk}\geq 0, z^m_{jkk'}\geq 0, q^m_{kk'}, b^m_{kk'}} \underbrace{\sum_{m\in\{1,3\}} (R^m_{jk}\cdot z^m_{jk}) + \sum_{m\in\{2,4\}} (R^m_{jkk'}\cdot z^m_{j\tilde{k}\tilde{k}'} - w^m\cdot|q^m_{\tilde{k}\tilde{k}'}| - w^m\cdot|b^m_{\tilde{k}\tilde{k}'}|)}_{\text{average trip profit}} \quad (19)$$

Four types of constraints:

- vehicle supply satisfies customer demands;
- vacant CAVs are available to serve the next trip;
- the total number of vehicles is no larger than the fleet limit;
- shared vehicles pick up 2 customers in each trip

- Profit $R^m_{jkk'} = Revenue - Cost$
- Revenue = fixed revenue + time based revenue + distance based revenue
- Cost = time based cost + distance based cost

4. Operational Level Analysis - Model Formulation

Customer choice module (*Module II*)

Cost minimization for commuters:

$$\min_{Q^m_{k'k}, Q^m_{kk'}, Q^m_k} \sum_{m=1,3} V^m_k Q^m_k + \sum_{m=2,4} V^m_{kk'} Q^m_{kk'} + \sum_{m=2,4} V^m_{k'k} Q^m_{k'k} \tag{20}$$

$$\text{s. t.} \sum_{m=1}^{4} Q^m_k = Q_k \quad \forall k \in K \tag{21}$$

$$\sum_{k' \in K} (Q^m_{k'k} + Q^m_{kk'}) = Q^m_k \quad \forall m \in \{2, 4\}, k \in K \tag{22}$$

4. Operational Level Analysis - Model Formulation

Customer choice module (*Module II*)

Cost minimization for commuters:

$$\min_{Q^m_{k'k}, Q^m_{kk'}, Q^m_k} \sum_{m=1,3} V^m_k Q^m_k + \sum_{m=2,4} V^m_{kk'} Q^m_{kk'} + \sum_{m=2,4} V^m_{k'k} Q^m_{k'k} \tag{20}$$

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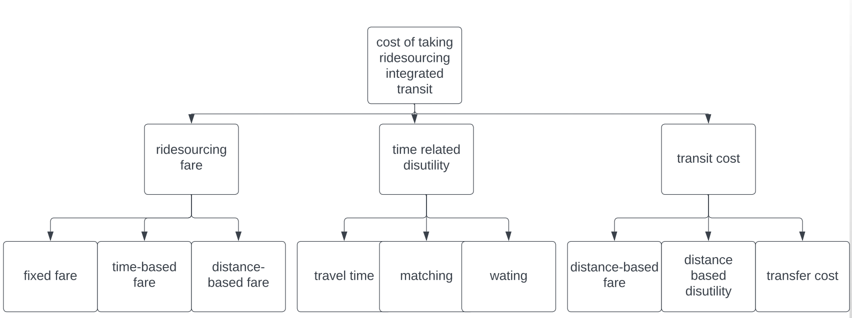
$$\sum_{k' \in K} (Q^m_{k'k} + Q^m_{kk'}) = Q^m_k \quad \forall m \in \{2, 4\}, k \in K \tag{22}$$

The commuter disutility function V^m_k or $V^m_{kk'}$ consists of ridesourcing fare, time related disutility and transit cost

4. Operational Level Analysis - Model Formulation

Customer choice module (*Module II*)

Commuter disutility function V_k^m or $V_{kk'}^m$ consists of:



4. Operational Level Analysis - Model Formulation

Network congestion module (*Module III*)

Vehicle miles traveled:

(i) Deadhead miles: $\sum_{m=1,3} z^m_{jk} t_{jO_k} + \sum_{m=2,4} \sum_{k' \in K} z^m_{jkk'} t_{jO_k}$

(ii) Detours: $\sum_{m=2,4} \sum_{k' \in K} Q^m_{kk'} t_{O_k O_{k'}}$

(iii) Ocuppied trips: $\sum_{m=1,3} Q^m_k t_{O_k D_k} + \sum_{m=2,4} \sum_{k' \in K} Q^m_{k'k} t_{O_k D_k}$

4. Operational Level Analysis - Model Formulation

Network congestion module (*Module III*)

Vehicle miles traveled:

(i) Deadhead miles: $\sum_{m=1,3} z_{jk}^{m} t_{jO_k} + \sum_{m=2,4} \sum_{k' \in K} z_{jkk'}^{m} t_{jO_k}$

(ii) Detours: $\sum_{m=2,4} \sum_{k' \in K} Q_{kk'}^{m} t_{O_k O_{k'}}$

(iii) Ocuppied trips: $\sum_{m=1,3} Q_{k}^{m} t_{O_k D_k} + \sum_{m=2,4} \sum_{k' \in K} Q_{k'k}^{m} t_{O_k D_k}$

- Each type of flow can be formulated as complimentary conditions to ensure that the route choice follows **Wardrop's principle**

4. Operational Level Analysis - Numerical Experiments

Small network

Sensitivity analysis of changing γ_2^1 ($\gamma_2^1 = \gamma_2^3$):

- **No one takes ridesharing**
- γ_2^1: waiting time cost parameter for single rides (\$/h)
- $\gamma_2^1 \uparrow \longrightarrow$ the cost of taxi, Ttransit $\uparrow \longrightarrow$ less commuters choose taxi/Ttransit, more commuters choose RStransit $\longrightarrow$ VMT $\downarrow$ since commuters switch from taxi & Transit to RStransit

Unilaterally change γ_2^1

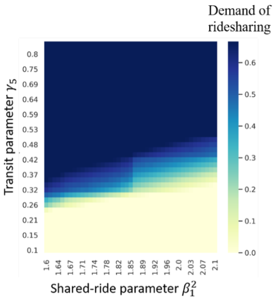
$\gamma_2^1 = \gamma_2^3$	**Taxi, m=1**	**Ridesharing, m=2**	**Ttransit, m=3**	**RStransit, m=4**	**VMT (miles)**
1.75	33%	0%	67%	0%	1149.57
1.79	24%	0%	58%	18%	927.45
1.81	18%	0%	51%	31%	763.75
1.83	8%	0%	42%	50%	521.50
1.85	2%	0%	35%	63%	359.27

4. Operational Level Analysis - Numerical Experiments

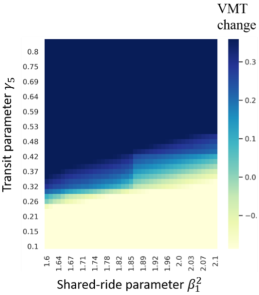
Small network

Sensitivity analysis of changing $\beta_1^2 (\beta_1^2 = \beta_1^4)$ and γ_5:

- **The demand of single ride is zero, no one takes taxi or Ttransit**
- β_1^2, β_1^4 : conversion factor from time to cost for *shared rides* (\$/h)
- $\beta_1^2 (\beta_1^4) \uparrow \longrightarrow$ the cost of ridesharing $\uparrow \longrightarrow$ less commuters choose ridesharing, more commuters choose RStransit $\longrightarrow$ VMT $\downarrow$ since commuters switch from ridesharing to RStransit



Percentage of Demand of ridesharing (m=2)



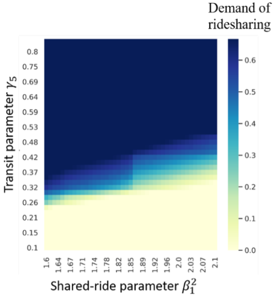
VMT change

4. Operational Level Analysis - Numerical Experiments

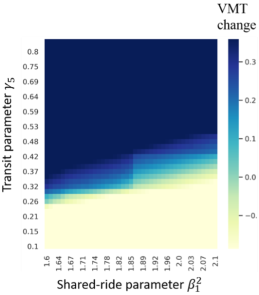
Small network

Sensitivity analysis of changing $\beta_1^2(\beta_1^2 = \beta_1^4)$ and γ_5:

- **The demand of single ride is zero, no one takes taxi or Ttransit**
- γ_5: transfer cost of transit (\$/transfer)
- γ_5 $\uparrow$ $\longrightarrow$ the cost of transit $\uparrow$ $\longrightarrow$ demand of RStransit $\downarrow$ $\longrightarrow$ VMT $\uparrow$



Percentage of Demand of ridesharing (m=2)



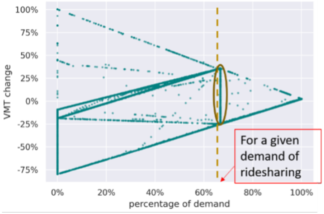
VMT change

4. Operational Level Analysis - Numerical Experiments

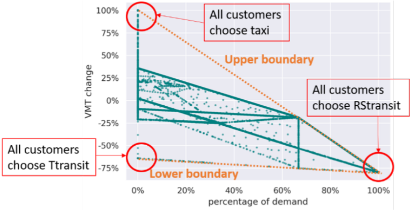
Small network

Model choices versus VMT change for the small network

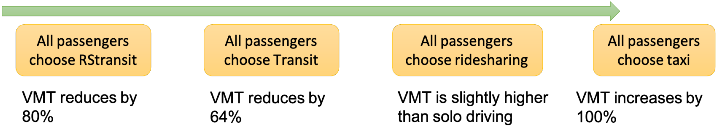
- For a giving demand value of ridesharing, each passenger can choose from the other three modes, so that the VMT is a region instead of a fixed value
- The 3 vertices of the triangular area indicate the cases when all passengers choose one mode



Demand of ridesharing (m=2)



Demand of RStransit (m=4)



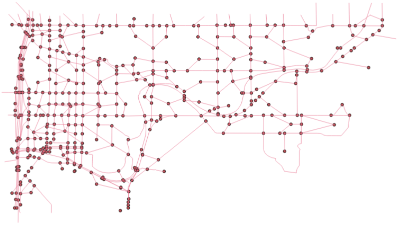
Summary of corner cases

4. Operational Level Analysis - Data preparation

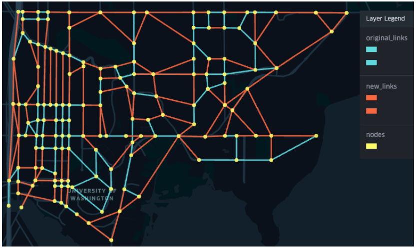
Seattle network

To apply the operational level model to Seattle network, I first simplify the Seattle U-district network

- The original links: blue links
- New links: red links.
- Link properties, such as length, free flow time, capacity are modified for the new links.



U-district: the original network (439 nodes, 1241 links)

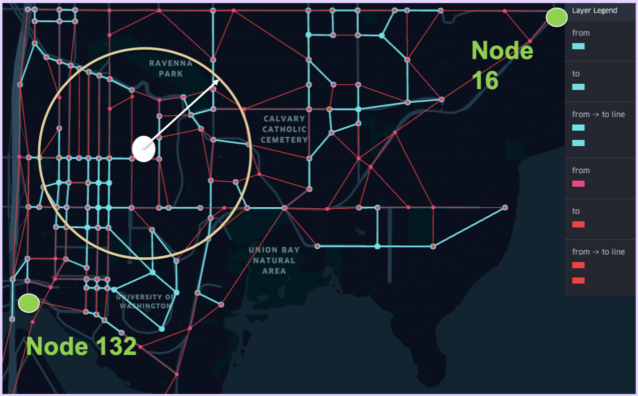


U-district: simplified network (151 nodes, 491 links)

4. Operational Level Analysis - Data preparation

Seattle network

Select two nodes within 1 mile distance to be a ridesharing (RS) pair

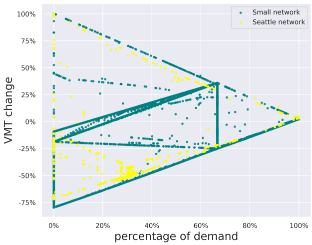


RS pairs

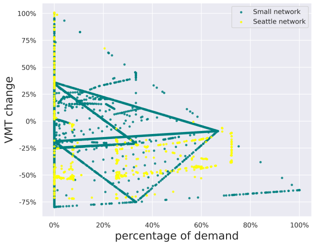
4. Operational Level Analysis - Numerical Experiment

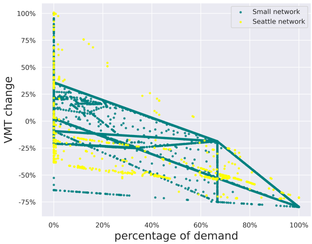
Seattle network

Demand of taxi (m=1)



Demand of ridesharing (m=2)





5. Conclusion

- Considered multiple players in the morning commute scenario and provide a systematic way to minimize the cost of each player
  - Planning: employer side and the employee side
  - Operational: revenue of the fleet, the utility of passengers (commuters), and the network congestion

5. Conclusion

- Considered multiple players in the morning commute scenario and provide a systematic way to minimize the cost of each player
  - Planning: employer side and the employee side
  - Operational: revenue of the fleet, the utility of passengers (commuters), and the network congestion
- Provided a platform for TDM strategies to be applied to multiple players at the same time
  - Planning: use pricing incentives to promote flexible hour commutes (WF CSP), which can be expanded to consider hybrid work, public transit, and other TDM strategies.
  - Operational: onboard TDM strategies related to congestion reduction, such as ridesourcing integrated with transit

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- Provided a platform for TDM strategies to be applied to multiple players at the same time
  - Planning: use pricing incentives to promote flexible hour commutes (WF CSP), which can be expanded to consider hybrid work, public transit, and other TDM strategies.
  - Operational: onboard TDM strategies related to congestion reduction, such as ridesourcing integrated with transit
- Proposed a two-sided market where commuters and their employers are the two sides on a CSP (expanded to network level)
  - The CSP can have more room for price optimization
  - Employers can outsource the ESTP to a third party to reduce cost and raise employee satisfaction
  - Employees have the option to choose more efficient commuting services with lower cost

Related publications

- **Fan, R.**, Ban, X., 2022. Commuting Service Platform: Concept and Analysis. *Transportation Research Part B: Methodological, 158*, pp.18-51
- **Fan, R.**, McCabe, D.,Ban, X., 2021. A General Equilibrium Model for Integrated CAV Ridesourcing and Transit Services for the Morning Commute. *Transportation Research Board Annual Meeting 2021*, TRBAM-21-03593.
- Ban, X.J., Dessouky, M., Pang, J.S. and **Fan, R.**, 2019. A general equilibrium model for transportation systems with e-hailing services and flow congestion. *Transportation Research Part B: Methodological, 129*, pp.273-304.

End

Thank you!

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