Which links should we apply a policy to?

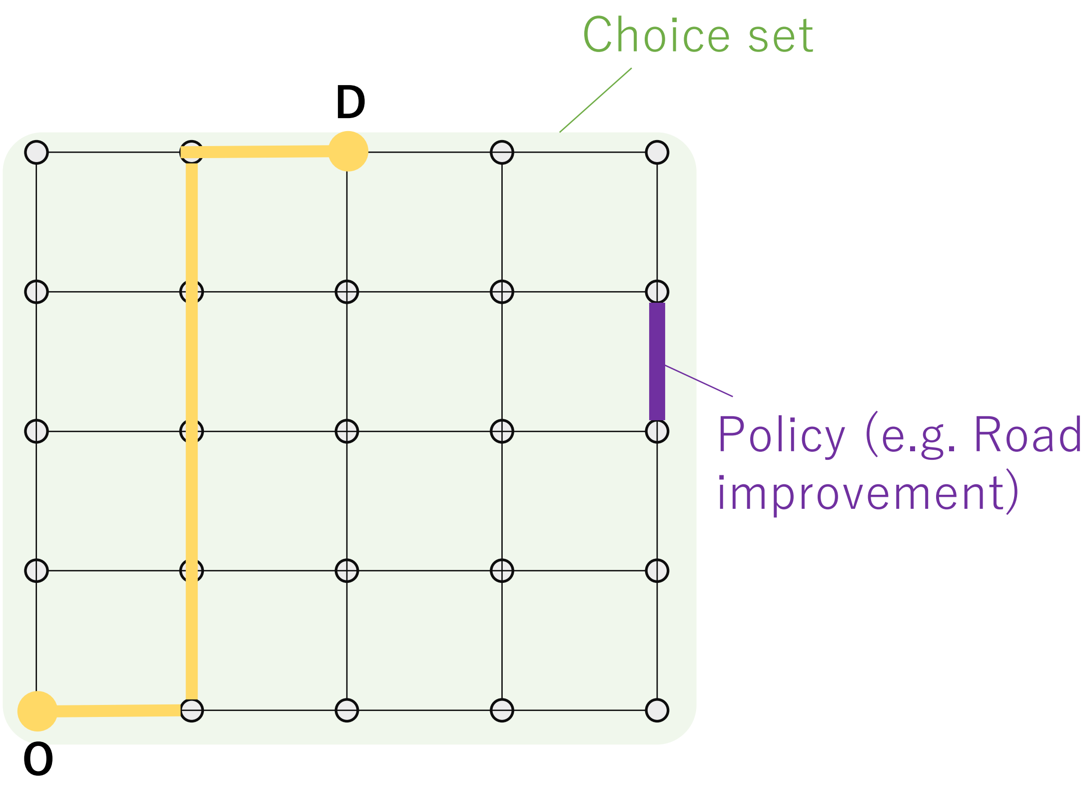
- Perspective from estimating the size of route choice set -

Aoi Watanabe, Hiroyuki Yamada, Mari Wakao, Ken Hidaka

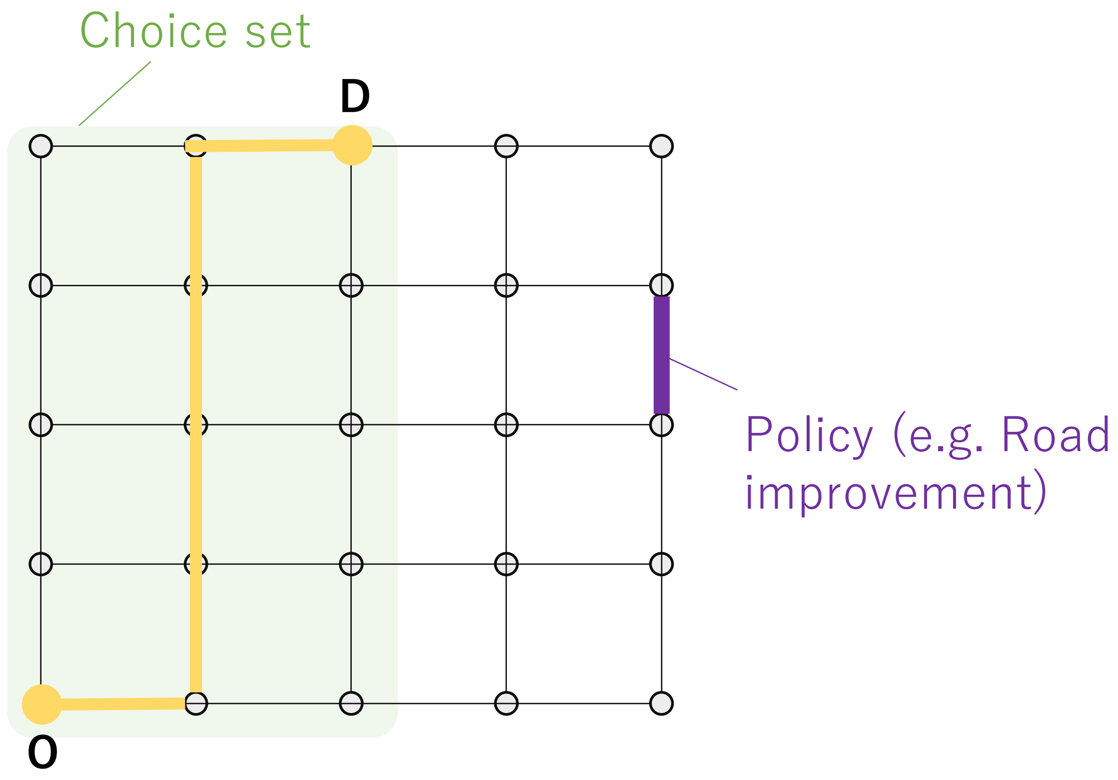
Toyota Central R&D Labs., Inc.

Introduction

In an MNL-based model (e.g. RL model) which does not explicitly deal with choice sets, all travelers benefit, even if a policy is applied to links far from the OD.



a)MNL-based models



b)actual

■ **Some people may not benefit from the policies.**

Introduction

To make the policy fairer and more personalized, we need to consider choice set.

However, traveler's choice set is not observable.

estimate the size of the choice set using a route choice model that can express zero probability

(Watanabe&Hidaka, 2023)

Methodology

Route choice model: α PURCM（Perturbed Utility Route Choice Model）

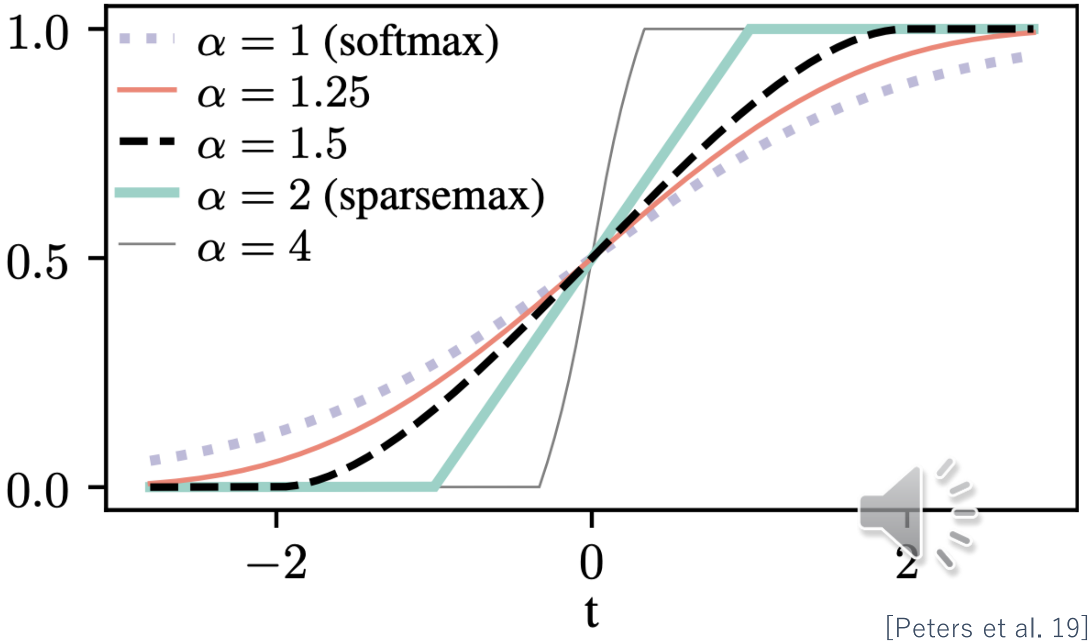
[Watanabe & Hidaka 23]

$$\boldsymbol{P}_n = \underset{\boldsymbol{q}_n \in \Delta^{|\mathcal{C}_n|}}{\mathrm{argmax}} \{ \underbrace{\boldsymbol{V}_n(X_n;\boldsymbol{\beta})^T \boldsymbol{q}_n}_{\text{Expected utility}} + \underbrace{H^\alpha(\boldsymbol{q}_n)}_{\text{Perturbation term}} \}$$

α -Tsallis entropy

$$; H^\alpha(\boldsymbol{q}_n) \equiv \begin{cases} \frac{1}{\alpha(\alpha-1)} \sum_{j\in\mathcal{C}_n} (q_{nj} - q_{nj}^\alpha) & ; \alpha \neq 1 \\ -\sum_{j\in\mathcal{C}_n} q_{nj} \log q_{nj} & ; \alpha = 1 \end{cases}$$

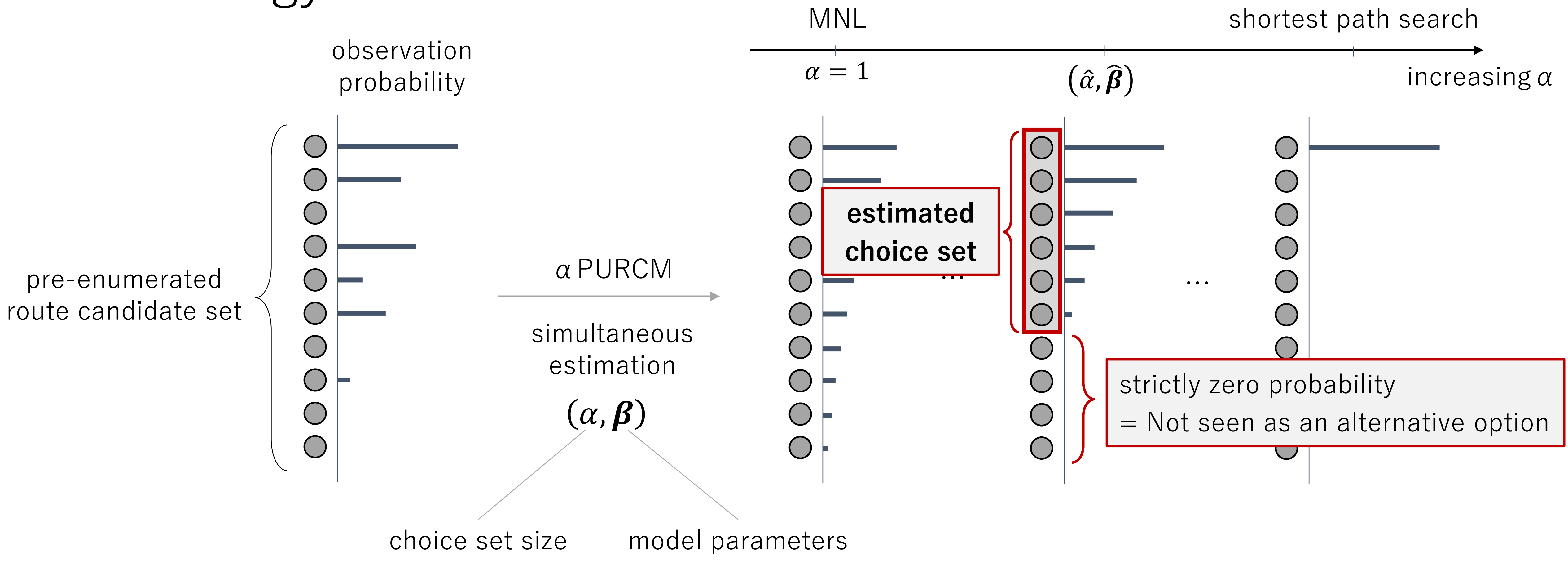
- Based on Perturbed Utility Maximization incorporating Additive Random Utility Maximization
- Equivalence to MNL at $\alpha = 1$
- Representation of zero probability within the route candidate set at $\alpha > 1$



[Peters et al. 19]

$\boldsymbol{P}_n$: choice probability vector for person $n \in \mathcal{N}$
$\boldsymbol{V}_n(X_n;\boldsymbol{\beta})$: strict utility for person $n \in \mathcal{N}$
X_n : explanatory variables matrix for person $n \in \mathcal{N}$
$\boldsymbol{\beta}$: route choice model parameters vector
$\mathcal{C}_n$: route candidate set for person $n \in \mathcal{N}$
$\Delta^{|\mathcal{C}_n|}$: $|\mathcal{C}_n|$-dimension probability simplex

Methodology



- **By using a behavior model that can represent strictly zero probability, model parameters and choice set can be estimated simultaneously.**

α PURCM : $\boldsymbol{P}_n = \underset{\boldsymbol{q}_n \in \Delta^{|\mathcal{C}_n|}}{\operatorname{argmax}} \{ \underbrace{\boldsymbol{V}_n(X_n; \boldsymbol{\beta})^T \boldsymbol{q}_n}_{\text{expected utility}} + \underbrace{H^\alpha(\boldsymbol{q}_n)}_{\alpha\text{-Tsallis entropy}} \}$; $H^\alpha(\boldsymbol{q}_n) \equiv \begin{cases} \frac{1}{\alpha(\alpha-1)} \sum_{j \in \mathcal{C}_n} (q_{nj} - q_{nj}^\alpha) & ; \alpha \neq 1 \\ -\sum_{j \in \mathcal{C}_n} q_{nj} \log q_{nj} & ; \alpha = 1 \end{cases}$

Data

- Toyosu PP 2019 – 2021

- Network

530 nodes, 1592links

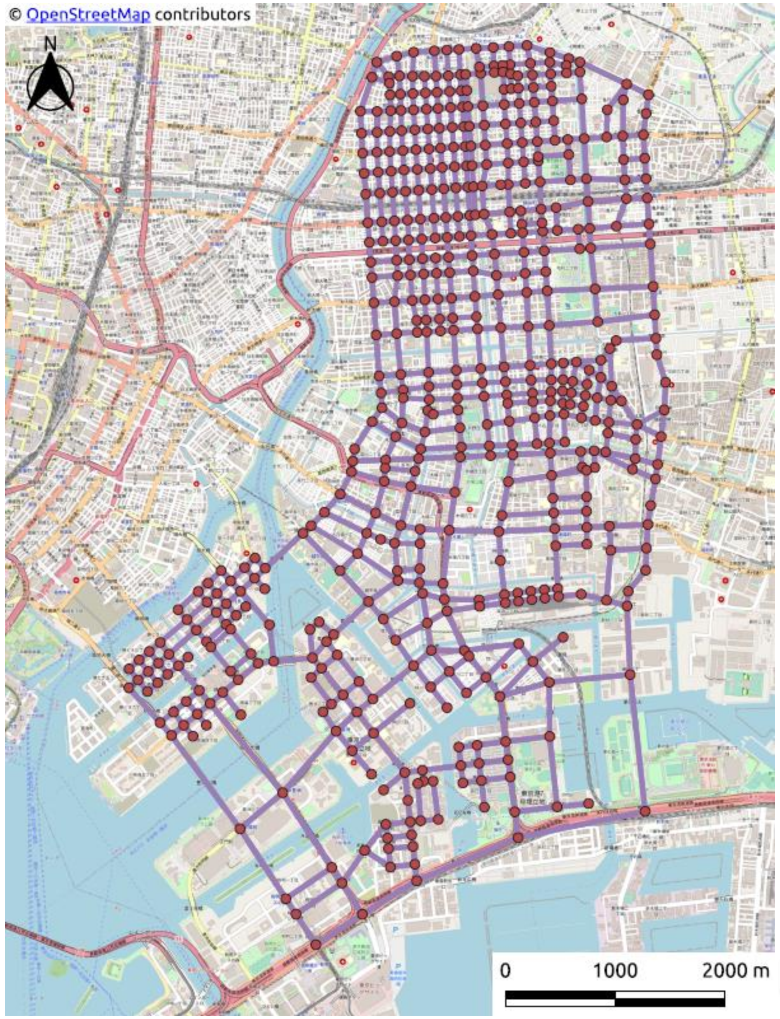
- Car trips within the network

Drive to work or school: 100trips (19 unique users)

Drive to home: 512trips (91 unique users)

- Utility function

$V_{ni} = \beta_{dist} \cdot length_{ni}$ for person $n \in \mathcal{N}$, route $i \in \mathcal{C}_n$



road network

Estimation result

purpose # of samples # of unique monitors	drive to work or school 100 19						drive to home 512 91					
	α PURCM			**MNL**			**α PURCM**			**MNL**		
	EST.	S.E.	t-val*1	EST.	S.E.	t-val*1	EST.	S.E.	t-val*1	EST.	S.E.	t-val*1
α	1.372	0.060	6.17	-	-	-	0.991	0.123	-0.08	-	-	-
β_{dist}	-2.261	0.386	-5.86	-7.133	0.019	-3660	-8.818	0.609	-14.48	-8.476	0.002	-363667
adjusted-ρ^2	0.571			0.527			0.576			0.576		
Loss in cross validation	21.746			53.311			246.6779			239.1857		

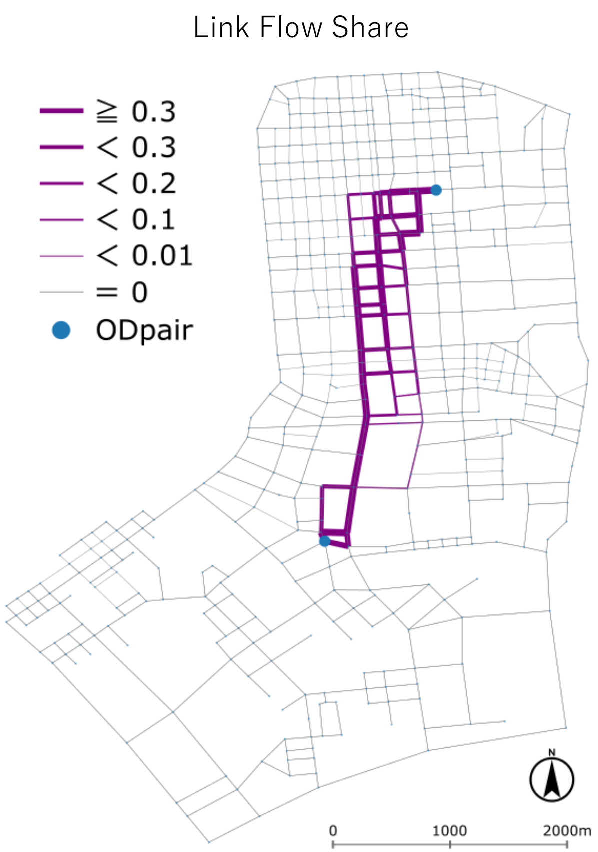
(No-limited choice set)

*1 We report t-value for α w.r.t. 1 and that for β_{dist} w.r.t. 0. α PURCM is equivalent to MNL when $\alpha = 1$.

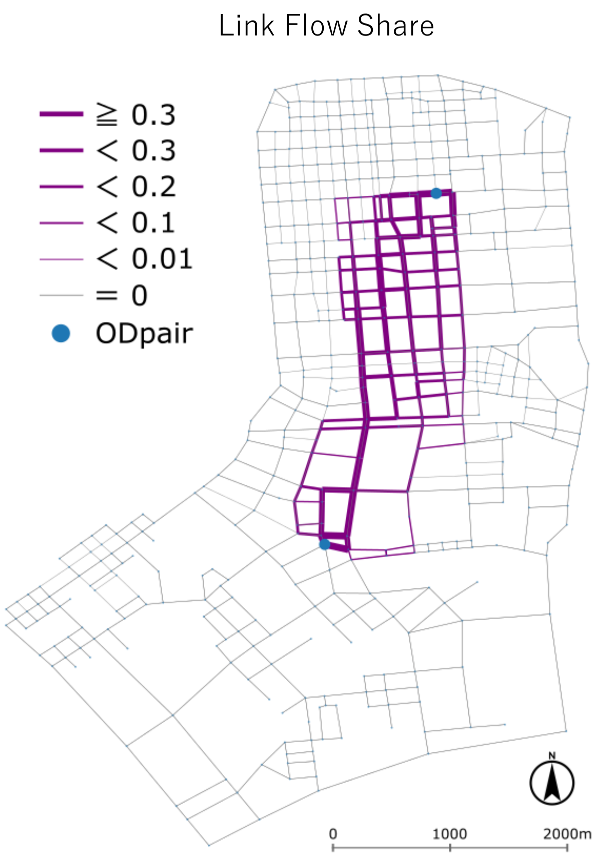
- **The proposed model shows higher fitness and predictive performance than MNL.**
- **For commuting purposes, the choice set size is limited with strict arrival time constraints.**

Estimation result

Examples of Estimated Route Choice Set



Drive to work or school

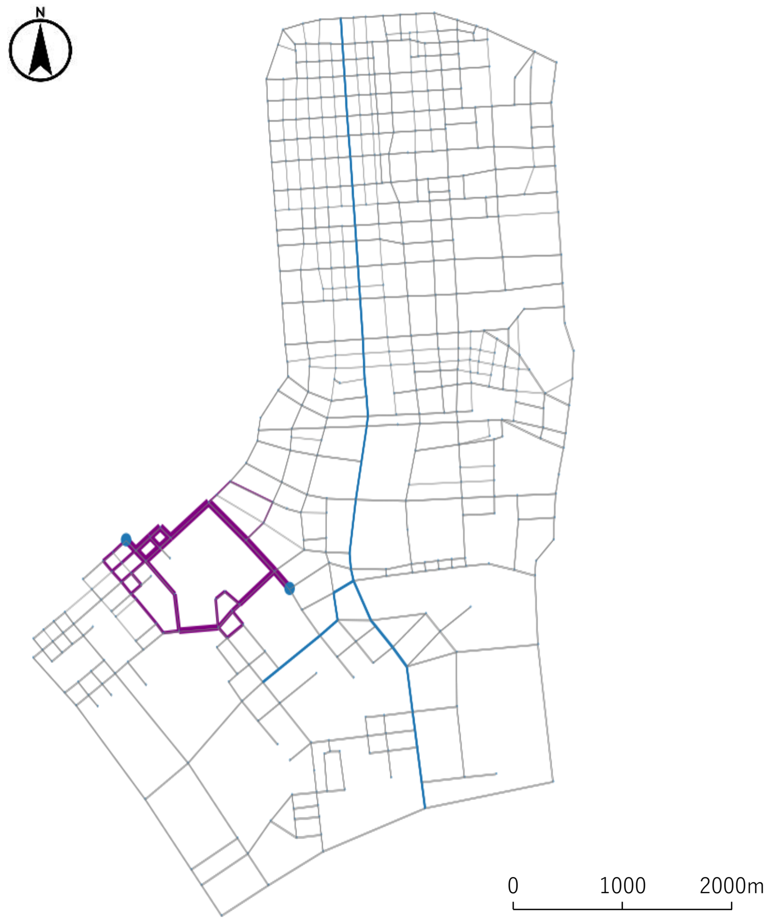


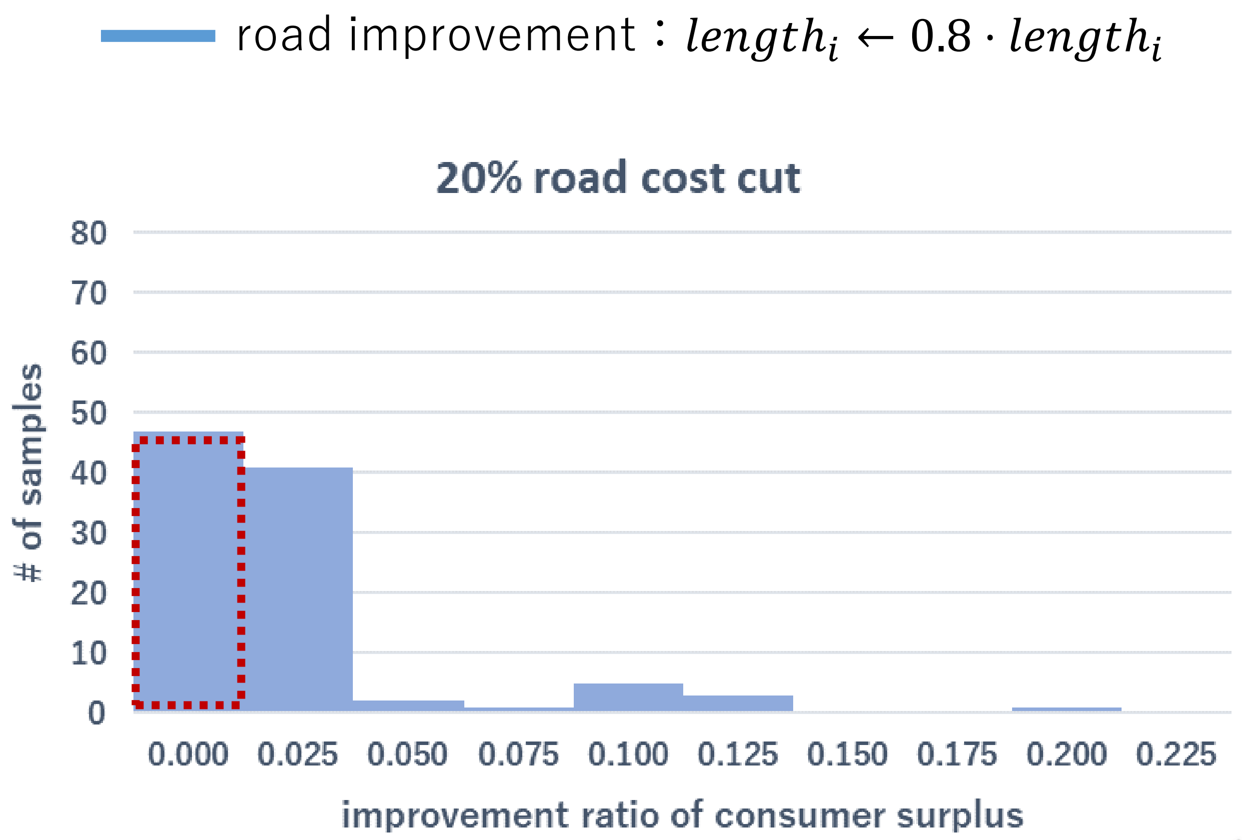
Drive to home

- **For commuting purposes with strict arrival time constraints, the choice set size is limited.**

Policy analysis

Road improvements

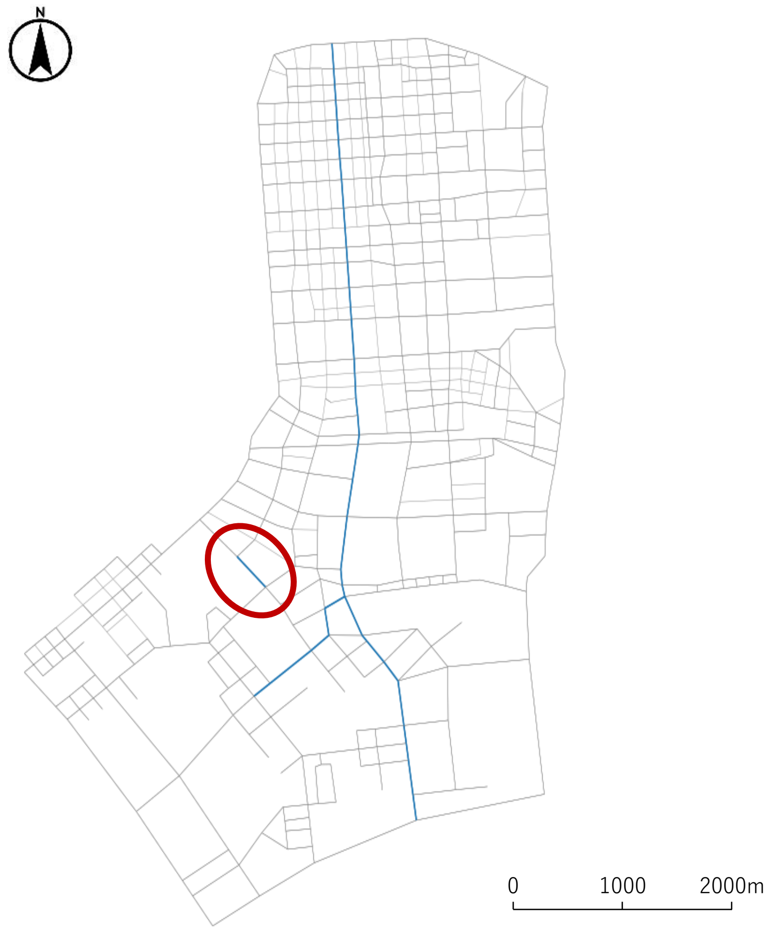


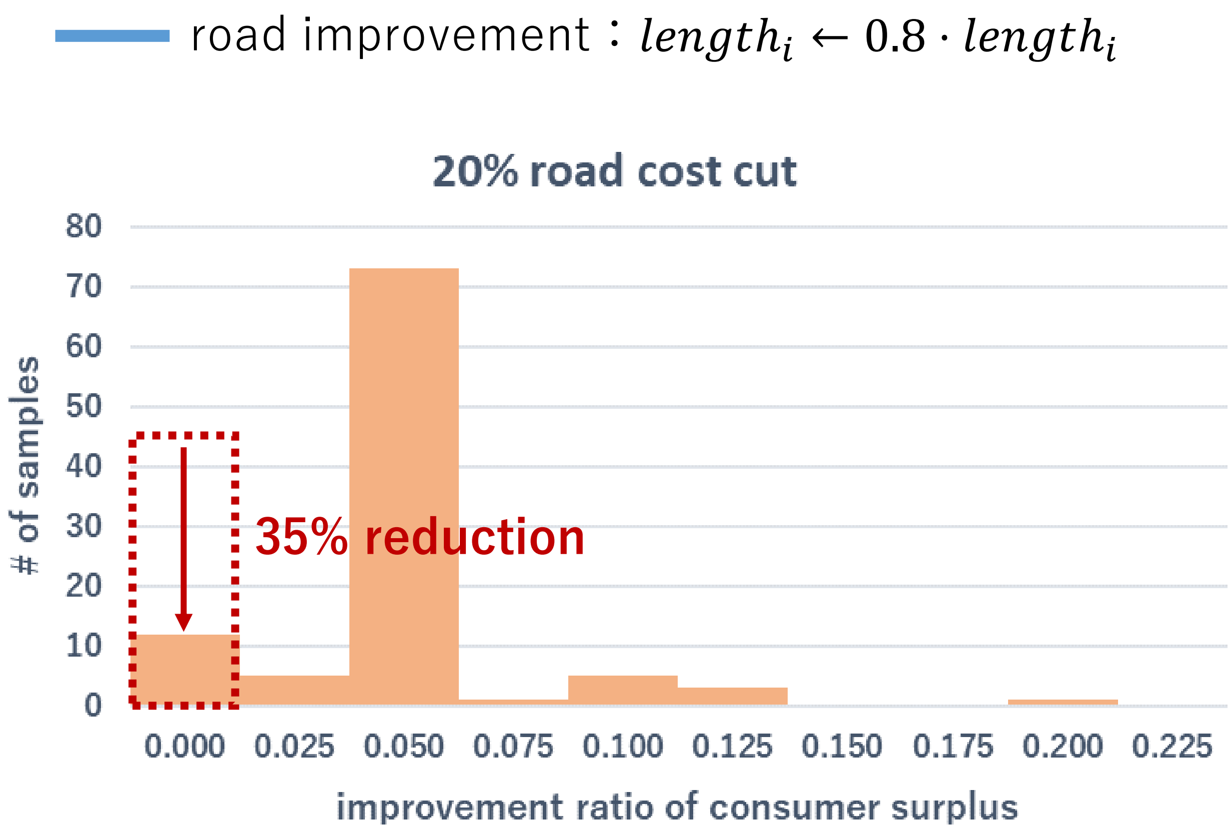


- **Even if the overall social welfare improves, half of users have no surplus change because the improved links are not included in the choice set.**

Policy analysis

Add only 1 link





- By deciding where to take a policy based on a choice set, it is possible to make the policy fairer and more personalized.

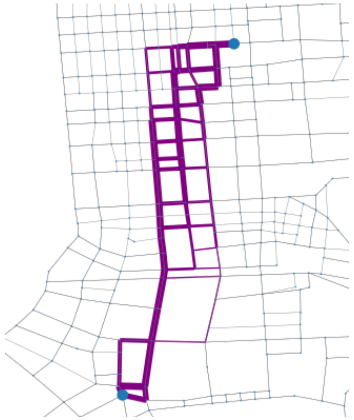
Summary

- **Estimating the choice set size with a route choice model that can represent zero choice probability**

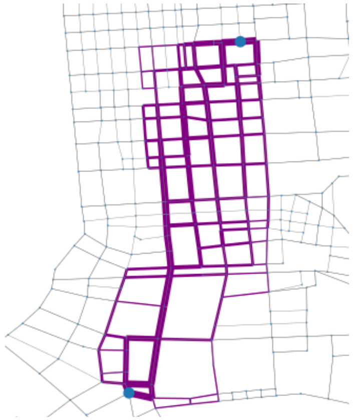
α PURCM： $$\boldsymbol{P}_n = \underset{\boldsymbol{q}_n \in \Delta^{|\mathcal{C}_n|}}{\operatorname{argmax}} \{\boldsymbol{V}_n(X_n;\boldsymbol{\beta})^T \boldsymbol{q}_n + H^\alpha(\boldsymbol{q}_n)\} \quad ; H^\alpha(\boldsymbol{q}_n) \equiv \begin{cases} \frac{1}{\alpha(\alpha-1)} \sum_{j\in\mathcal{C}_n}(q_{nj} - q_{nj}^\alpha) & ; \alpha \neq 1 \\ -\sum_{j\in\mathcal{C}_n} q_{nj}\log q_{nj} & ; \alpha = 1 \end{cases}$$

expected utility　α -Tsallis entropy

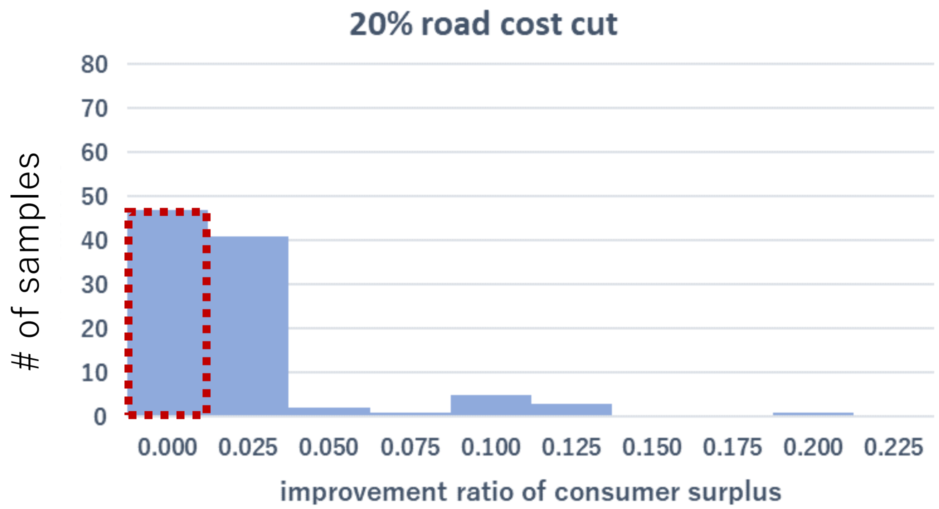
- **The choice set is limited for commuting with time-constraint.**
- **By considering the choice set, we can evaluate those who does not benefit from the policy.**



Drive to work or school



Drive to home



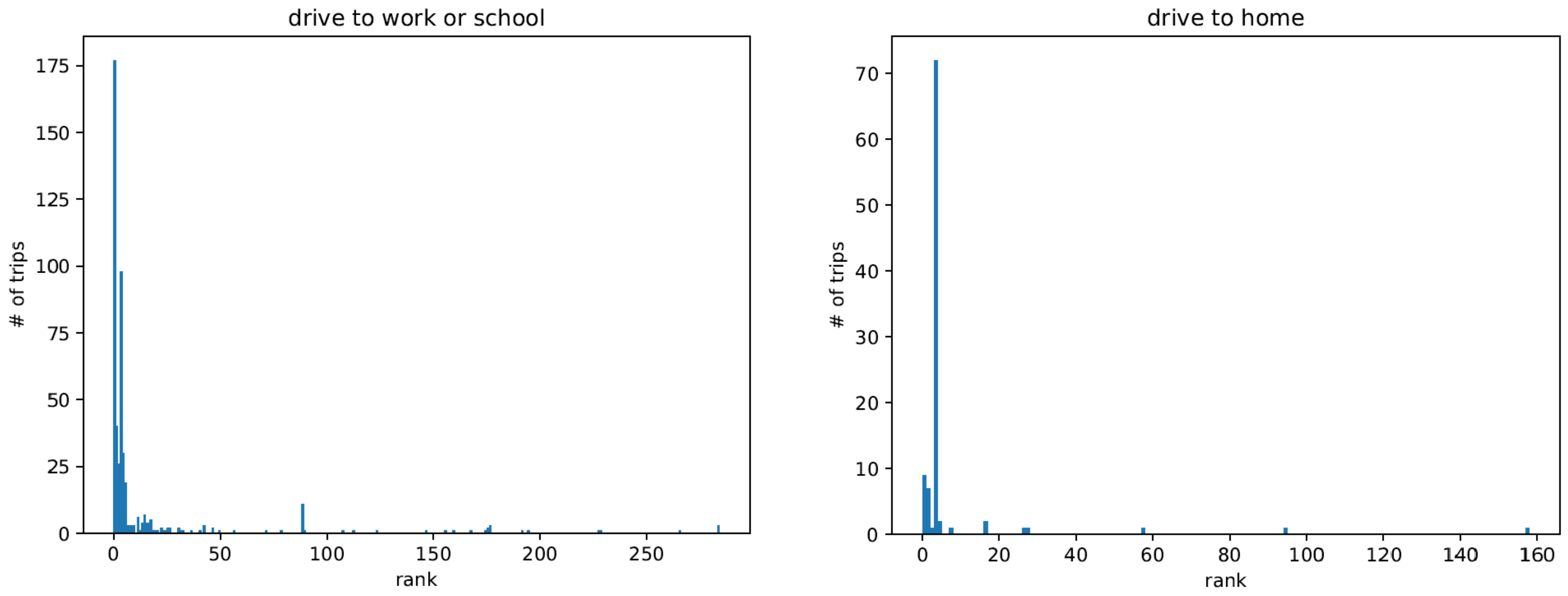
References

1. Watanabe, Aoi and Hidaka, Ken, Representing Zero-Flow: Perturbed Utility Based Stochastic User Equilibrium Assignment Model. Available at SSRN: http://dx.doi.org/10.2139/ssrn.4493779
2. Peters, B., Niculae, V., and Martins, A. F. T.: Sparse Sequence-to-Sequence Models, in *Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics*, pp. 1504-1519, Florence, Italy (2019), Association for Computational Linguistics

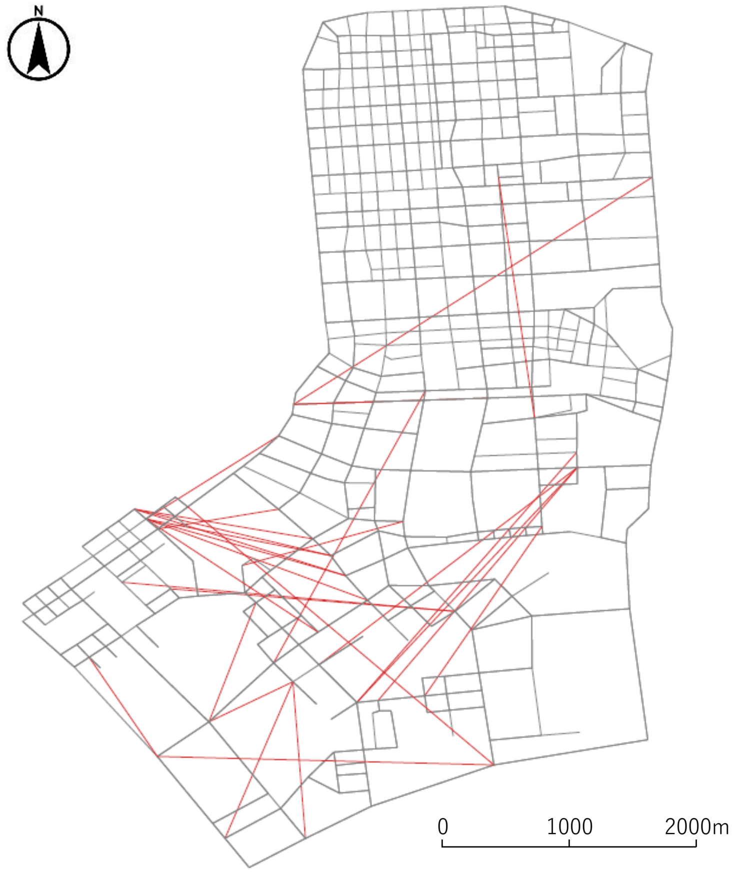
Appendix

Observation probability

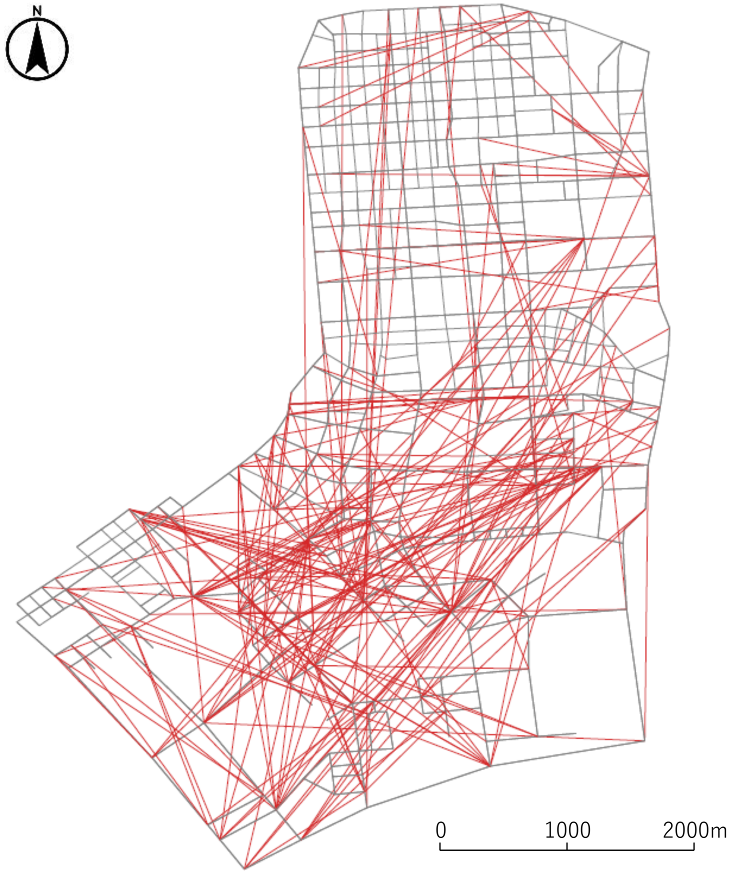
For each trip, how many paths are shorter than the selected path?



OD distribution



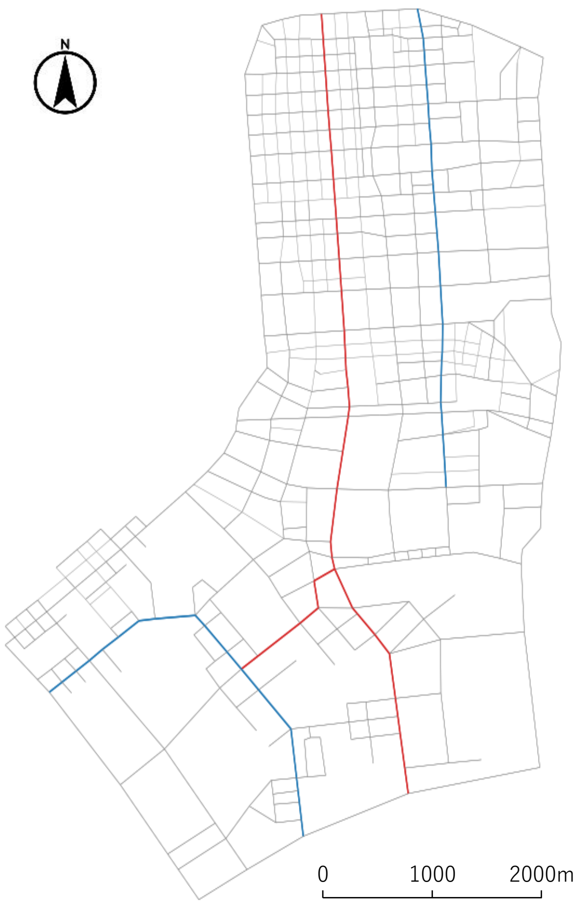
Drive to work or school



Drive to home

Policy analysis (2)

Road closures and improvements



road closure

road improvement

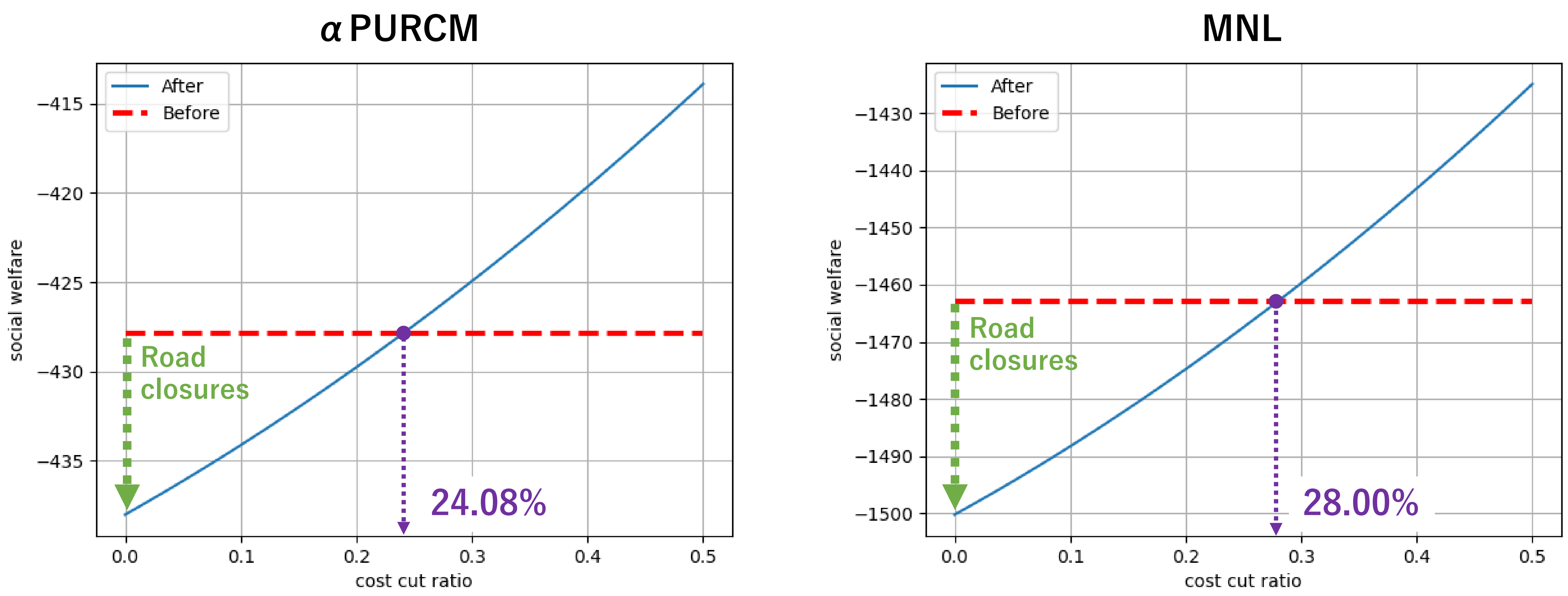
$length_i \leftarrow (1 - CostCutRatio) \cdot length_i$

- Trying to compensate for decrease in social welfare due to road closures by improving other roads

Policy analysis (2)

$length_i \leftarrow (1 - CostCutRatio) \cdot length_i$

Changes in social welfare due to road closures and improvements



- **In this instance, MNL overestimates the scale of policies needed to compensate.**