Estimation of Greenhouse Gas Emission Reduction from Shared Micromobility System

シェアードモビリティによる温室ガス削減量の推定

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1. Introduction

Transportation is the second-largest source of global greenhouse gas (GHG). Rapid and deep transportation decarbonization, particularly for road transportation, has been a fundamental challenge in achieving the objective of global warming adaptation and mitigation. As suggested by [1], active travel (e.g., walking and shared micromobility) may be a more feasible decarbonization solution than electric vehicles when the urgency of transportation decarbonization is considered. However, quantitatively assessing the environmental impact of shared micromobility with real-world trip data is an unresolved and challenging subject. In this research, we proposed a system combining machine learning algorithms and the Monte Carlo simulation to address this issue.

2. Methodology

As presented in **Figure1**, our system contains three sections:

(i) Travel mode inference: Firstly, we chose the machine learning algorithms (Random Forest, XGBoost, and LightGBM) for travel mode choice estimation and used real-world travel survey trip data, land use data, and weather data to train the models. Secondly, we input the shared micromobility data into trained model to get the estimated substituted mode of each trip.

The selected features include:

(ii) Monte Carlo (MC) simulation: Trip distance is the most important feature in the substituted modes estimation and is a critical parameter in the GHG emission calculation. To keep its importance in simulation, we aggregated TBI trips into four classes based on trip distance and then calculated the probability distributions of

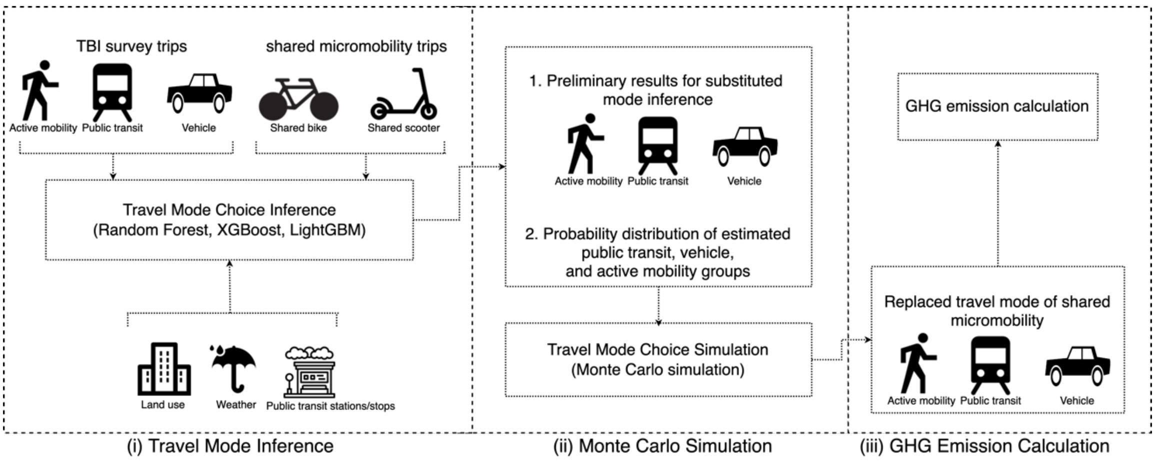


Figure 1. System Overview

true labels in predicted labels for each class. Then, MC simulations were conducted to obtain the replaced travel mode for each shared micromobility trip.

(iii) GHG emission calculation: After determining the substituted mode, we can calculate the GHG emission reduction using the emission factors and trip distances:

$$GHG_m = (\hat{F}_m - F_m) * Distance_m$$

For a shared micromobility trip m, $\hat{F}_m$ means the GHG emission factors of the substituted mode; F_m is the GHG emission factors of the used shared micromobility (i.e., docked bike); $Distance_m$ is the travel distance.

3. Evaluation and result

3.1 Travel mode choice inference model

Using the three algorithms (Random Forest, XGBoost, and LightGBM), we got the preliminary results for substituted mode and probability distribution of each output. The results of the test set are shown in **Table 1**. We can see the performance among the three algorithms has high similarity. However, due to the data imbalance problem of TBI dataset, there is bias in the estimation results, especially for public transit.

Figure 2 describes the proportion of different transportation mode pairs of the predicted label and true label, under 300 trials with the same parameter setting but different train/test set divisions. To mitigate the bias, MC simulation was conducted on the estimation results.

Table 1. Performance of algorithms

Algorithm	Precision	Recall	F1-score
RF	0.8134	0.8152	0.8133
XGBoost	0.8124	0.8145	0.8117
LlightGBM	0.8130	0.8161	0.8140

Figure 2. The proportion of mode pairs between predicted labels and the true labels

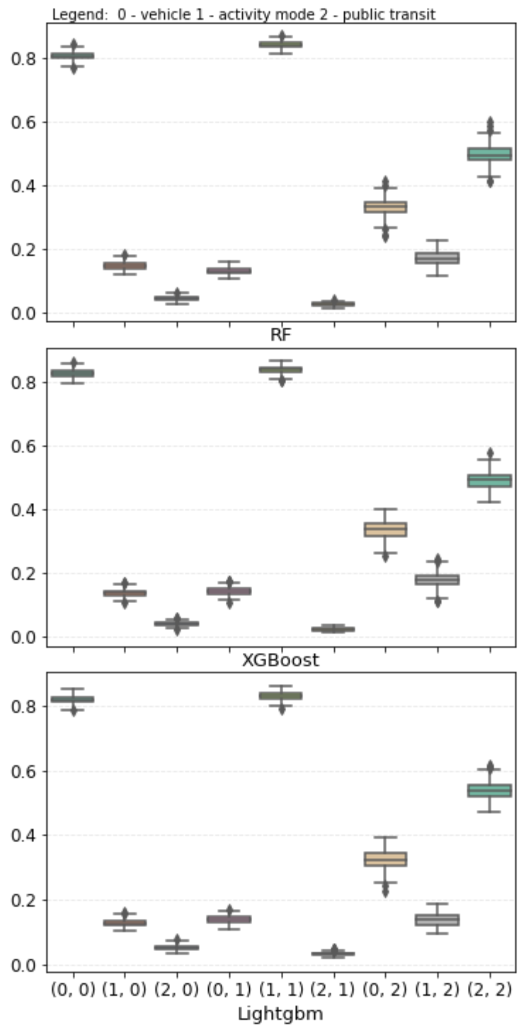


Table 2. The distribution of substituted travel mode (trip number)

Shared Micromobility	Vehicle	Active	Public transit
Docked bikes	48.0%	43.8%	8.2%
Dockless bikes	51.3%	39.3%	9.4%
Dockless scooters	49.7%	40.9%	9.4%

Table 3. The distribution of substituted travel mode (trip distance)

Shared Micromobility	Vehicle	Active	Public transit
Docked bikes	51.1%	40.0%	8.9%
Dockless bikes	53.6%	36.6%	9.8%
Dockless scooters	61.4%	27.9%	10.7%

Table 4. GHG emission reduction by shared micrmomobility

Shared Micromobility	Overall reduction (Unit: metric ton)	Per trip reduction (Unit: g CO_2-eq/trip)
Docked bikes	39.3 – 52.7	187.1 – 250.4
Dockless bikes	7.4 – 11.4	114.9 – 177.6
Dockless scooters	74.1 – 96.6	102.6 – 133.7

3.2 The substituted travel modes by shared micromobility

a) Basic Statistical Analysis

Table 2 and **Table 3** describes the substituted travel mode distributions by shared micromobility based on trip number and trip distance, respectively. It can be observed that 60% of shared micromobility trips replaced vehicle and public transit (for trip number and distance).

Vehicle and public transit are high-emission travel modes compared with shared micrmobility. The high replacement ratio of these travel modes represents that shared micromobility has considerable potential to mitigate carbon emissions.

b) Spatial perspectives

Moreover, there is a noticeable relationship between the distribution of substitution travel modes and the traveled distance by shared micromobility trips. As travel distance rises, the replacement ratio of vehicles and public transit grows, while the active mobility replacement ratio reduces.

These findings suggest that shared micromobility trips with longer distance are more likely to have positive environmental impacts. Increasing competition of shared micromobility in mid-distance and long-distance trips may be a strategy to enhance SMSs' positive environmental impacts.

3.3 Environmental influences of shared micromobility

a) Basic Statistical Analysis

Figure 3 depicts the GHG emission reduction of shared micromobility before and after MC simulation. It shows that MC simulation mitigated the estimation bias caused by data imbalance problem and reduced the dispersions of GHG emission reduction volumes.

Table 3 represents the overall and per trip GHG emission reduction of shared micrnomobility. We can see shared micromobility positively impacts GHG emission reduction. However, their contribution to transportation decarbonization is limited. The total GHG emission reduction from shared micromobility is between 120.8 metric tons to 160.6 metric tons, which accounts of 0.012% to 0.016% of total on-road emissions in Minneapolis.

Moreover, there is a significant variance in the average and total emission reductions between shared micromobility modes. Shared micromobility's emission factors account for a substantial part of this discrepancy. Among shared micromobility, docked bikes have a minor emission factor; therefore, their per-trip emission reduction level is the most prominent. Station-based systems have lower carbon emissions from daily collection and allocation than dockless mobility, which is one possible explanation for the minor emission factor. Even though the dockless shared scooters have the lowest per-trip emiss--ion reduction level, the much more trip numbers than the other two modes make it contribute the greatest volume of emission reduction.

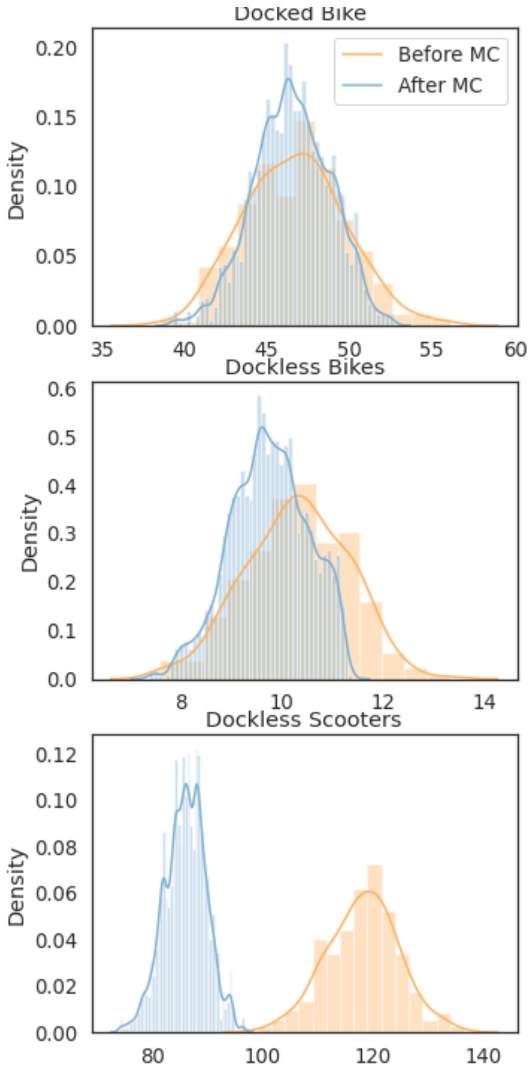
b) Spatial perspectives

For total emission reduction, the TAZs near the city center contribute more than other places. Because TAZs in the city center have significantly higher density of shared micromobility users. For per-trip emission reduction perspective, TAZs away from the city center have higher value than TAZs near the city center. Because trips originate away from city center tend to have longer trip distance and more likely to substitute vehicle trips. Therefore, increasing per-trip emission reduction near city center and increasing micromobility usage away from city center could be two directions to improve emission reduction of micromobility system.

4. Conclusion

This study aims to construct an estimation model to evaluate the environmental effects of shared micromobility services. According to our analysis, over 70% of the replaced trip distance by

Figure 3. GHG emission before and after simulation



shared micromobility trips is from the higher-emission transportation alternatives. This high replacement ratio indicates that shard micromobility has positive environmental impacts and has significant potential in transportation decarbonization.

References

[1] BRAND, Christian, et al. The climate change mitigation effects of daily active travel in cities. Transportation Research Part D: Transport and Environment, 2021, 93: 102764.