GREEN CITIES
GREEN LOGISTICS FOR GREENER CITIES

7th International Conference Green Cities 2026 – Green Logistics for Greener Cities, 15-17 April 2026, Szczecin, Poland

An empirical study of last-mile delivery modes and mode choice modeling

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Abstract

The rapid growth of e-commerce has significantly increased parcel volumes, placing mounting pressure on last-mile delivery systems, particularly in dense urban areas. In metropolitan cores, curbside loading and unloading often reduce road capacity and create traffic safety concerns. In response, governments have introduced various urban freight policies, such as dedicated loading spaces, protection of logistics land, and the promotion of alternative delivery modes—including handcarts and cargo bicycles—as well as parcel lockers and pickup points. However, systematic data on last-mile delivery mode use and its spatial variation remain limited. This study provides empirical evidence on last-mile delivery mode choice in the Tokyo Metropolitan Area. Field observations were conducted in Tokyo's 23 special wards and surrounding areas on weekdays between 9:00 a.m. and 5:00 p.m. To reduce temporal and spatial bias, bicycle-based patrol surveys were carried out across different days, times, and locations. Using these data, a multinomial logit model was estimated to examine how logistics operators select delivery modes in response to urban characteristics. The analysis focuses on major parcel carriers—Yamato Transport, Sagawa Express, and Amazon subcontractors. Explanatory variables include population density, proximity to MRT stations, land-use type, and road width. Results show that handcarts are more likely to be used in high-density areas, commercial districts, and near MRT stations, while vans are more frequently selected on narrow single-lane roads. These findings provide rare empirical evidence on last-mile delivery mode choice and offer practical implications for curbside management and sustainable urban logistics planning.

Keywords: last-mile delivery; urban freight; delivery mode choice; e-commerce; Tokyo

1 Introduction

In recent years, with the rapid expansion of the e-commerce (EC) market, the volume of parcel deliveries has been increasing year by year. In Japan, the number of parcels handled has continued to rise annually, with a particularly notable surge in 2020 during the outbreak of COVID-19. By 2023, the annual number of parcels handled had reached approximately 5 billion (MLITT, 2025a). As a result, last-mile delivery operations—especially in urban areas—have come under significant strain. In central urban districts, curbside parking for loading and unloading frequently reduces road capacity and compromises traffic safety. However, to the best of our knowledge, there is no comprehensive dataset in major cities around the world that systematically captures the choice of last-mile delivery modes, such as trucks, vans, handcarts, and cargo bicycles, which play a crucial role in urban logistics. Statistical data on the actual use of these last-mile delivery modes remain limited. As a result, essential knowledge of last-mile logistics has not been sufficiently systematized for policy making. For example, questions such as "In which areas are bicycles used more frequently?" and "To what extent do traffic congestion, road width, and land-use zoning influence the choice of delivery mode?" remain largely unanswered. If such information were available, it could inform policies such as the development of bicycle lanes, the redesign of pedestrian spaces, and the revision of curbside parking regulations. Furthermore, although existing urban freight simulation models account for freight vehicle travel demand, they often do not explicitly represent the choice of delivery modes at the last mile deliveries (i.e. trucks, vans, handcarts, and cargo bikes). For instance, even in integrated urban simulation models such as SimMobility (Sakai et al., 2020), differences in traffic impacts and spatial usage arising from variations in last-mile delivery modes have not been fully examined. By constructing models that incorporate actual, area-specific delivery mode choices, it becomes possible to more precisely evaluate the impacts of urban freight transport on urban traffic and pedestrian spaces.

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This study focuses on the central area of the Tokyo Metropolitan Area, one of the largest metropolitan areas in the world, specifically the 23 special wards of Tokyo and their surrounding areas. Targeting parcel deliveries, the study collected data on last-mile delivery modes with the objective of identifying in which areas logistics operators choose particular delivery modes and what factors influence their choices. Using the collected data, a last-mile delivery mode choice model was estimated to analyze how logistics operators select delivery modes in response to location-specific characteristics. Furthermore, the choice probabilities of each delivery mode were calculated based on the model for the entire study area.

2 Literature review

As noted above, with the growth of the EC market, parcel delivery volumes in urban areas have continued to increase in cities around the world. Allen et al. (2018) conducted a case study in London using GPS tracking data from 83 delivery vehicles and drivers. Their study demonstrated that the growth of the EC market has significantly increased both the vehicle kilometers traveled and the number of trips made by light goods vehicles (LGVs) used for last-mile deliveries. In particular, in central urban areas, the increase in delivery frequency was found to reduce the overall efficiency of the transport network through heightened road congestion and increased curbside parking activity.

In response to these challenges, the public sector has promoted policies such as securing loading and unloading spaces, guiding land use for logistics purposes, and encouraging the adoption of non-automobile-dependent delivery modes. Sheth et al. (2019) developed a comparative cost function model based on actual delivery data for downtown Seattle in the United States, examining whether truck-based or bicycle-based delivery is more efficient. Narayanan and Antoniou (2022) categorized previous studies on electric cargo bicycles according to model types and methodologies. These studies indicate that cargo bikes and handcarts can serve as effective delivery modes in short-distance, high-density urban areas.

Overall, the existing literature has accumulated insights into the impacts of increasing last-mile deliveries on urban traffic and the potential effectiveness of alternative delivery modes. However, there remains a lack of research that links actual delivery mode choices to intra-urban spatial characteristics. This study addresses this gap by focusing on the TMA by collecting field-observed data on last-mile delivery modes. Using a discrete choice model, we analyse delivery mode choice based on empirical data.

3 Survey of last-mile delivery modes

3.1 Survey method

In this study, a field survey based on street-level observations was conducted to capture the actual conditions of last-mile delivery in the 23 special wards of Tokyo and their surrounding areas. The survey was carried out over multiple days between March and August 2025. Observations were conducted mainly on weekdays from 9:00 a.m. to 5:00 p.m., when delivery activities are particularly concentrated, while ensuring that no systematic bias arose from specific days of the week or time periods.

The survey area covered the 23 wards of Tokyo, where delivery volumes are presumed to be high, as well as adjacent municipalities: Kawaguchi, Toda, and Soka in Saitama Prefecture; Urayasu, Funabashi, and Ichikawa in Chiba Prefecture; and Yokohama in Kanagawa Prefecture. The survey areas included locations with diverse characteristics, such as residential neighborhoods, central business districts, and shopping streets, and encompassed deliveries conducted by multiple logistics operators. By patrolling the areas by bicycle, the survey was designed to enable seamless observation of multiple locations within a single day. An overview of the collected last-mile delivery data is presented in Table 1.

During the observations, several stations and landmark buildings were designated in advance, and routes were planned to pass by these points, primarily along major arterial roads. To minimize spatial bias in observation points, GPS was used to record travel routes, and care was taken to avoid repeatedly traversing the same roads. Observation results were recorded in real time using a smartphone application, including photographs documenting delivery modes and surrounding conditions.

Table 1. Overview of last-mile delivery data.

No.	Data Item	Categories
1	Observation Area	Kitasenju, Funabashi, Sumiyoshi, Tsukishima, Shinjuku, etc.
2	Logistics Operator	Seino Transportation / Coop Deli / Sagawa Express / Yamato Transport / Amazon, etc.
3	Delivery Destination Type	Apartment building / Office / Detached house / Restaurant, etc.
4	Delivery Vehicle	LGV: Truck / Van: Van / Handcart or Cargo Bicycle
5	Parking Location	On-street parking / Coin-operated parking / Parking meter
6	Delivery Status	Delivering / In transit / Loading
7	Latitude of Observation Point	—
8	Longitude of Observation Point	—

3.2 Characteristics of last-mile delivery modes in the survey area

All last-mile delivery-related activities that were visually observable on the street were included in the survey. Specifically, the observation covered not only scenes in which goods were being loaded, unloaded, or delivered, but also delivery vehicles and personnel traveling to their next destination. By doing so, the study aimed to capture a more comprehensive picture of last-mile delivery activities in urban space, rather than focusing solely on parked vehicles. Most frequently observed delivery modes were LGVs, vans, cargo bikes, and handcarts. Figure 1 presents photographs of each of these delivery modes.

Fig. 1. Photos of each delivery mode (LGV, van, handcart, cargo bike).

In collecting the data, these delivery modes were classified into three categories: LGV, Van, and Handcart/Bike. In actual delivery operations, it is common for parcels to be transferred from trucks or vans to handcarts for final distribution. However, at the stage of departure from the depot where parcels are stored, logistics operators are considered to primarily choose among trucks, vans, or handcarts/cargo bikes as their main delivery mode. This study adopted the above three-category classification.

A total of 788 observations were collected. Figure 2 illustrates the spatial distribution of the observed last-mile delivery modes at the survey locations. During the data collection process, on-street parking was frequently observed during delivery operations. In relatively narrow residential streets, van-based deliveries were commonly observed, whereas truck-based deliveries were more prevalent along arterial roads and roads with multiple lanes. In areas around shopping streets, human-powered delivery modes, such as cargo bikes and handcarts, were frequently identified.

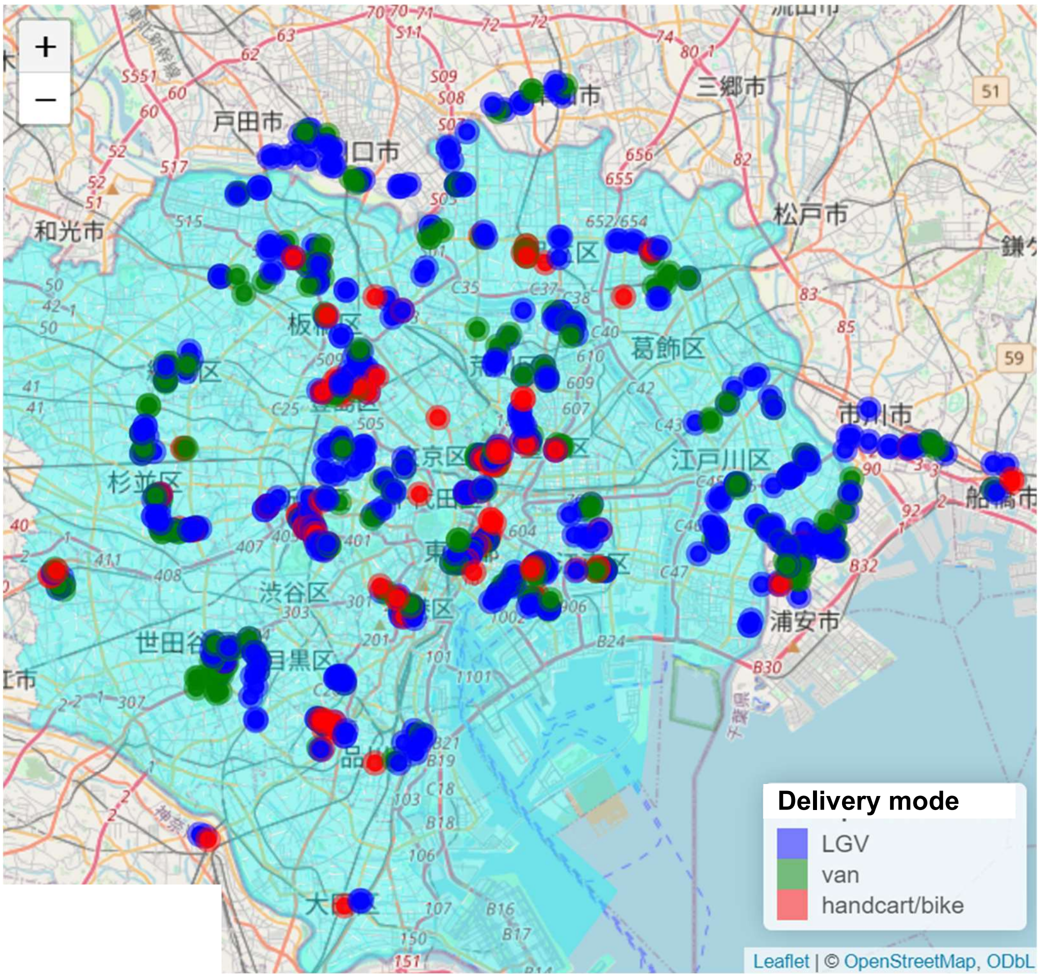

Fig. 2. Delivery modes by observation location

4 Delivery mode choice modeling

4.1 Model specification

By estimating a delivery mode choice model based on a multinomial logit framework, this study aims to identify the factors that influence last-mile delivery mode selection. For the model estimation, 485 observations were used from the 788 records obtained through the field survey. These 485 observations correspond to deliveries conducted by major parcel carriers, namely Yamato Transport, Sagawa Express, and subcontractors of Amazon. Sagawa Express, Yamato Transport, and Japan Post together account for more than 90% of the parcel delivery market share (excluding Amazon subcontractors). However, Japan Post was excluded from the analysis because it is difficult to distinguish between postal services and parcel deliveries in the observational data, resulting in concerns about data reliability. Although Amazon's subcontractors are not included in official market share statistics, they were incorporated into the analysis because delivery volumes comparable to those of Sagawa Express and Yamato Transport were observed in the field. Furthermore, this study separately estimated last-mile delivery mode choice models for the two major parcel carriers, Sagawa Express and Yamato Transport, using only their respective delivery observation data. The objective was to capture differences in delivery behavior between operators and to clarify how operator-specific delivery strategies and spatial characteristics influence delivery mode choice.

An analysis was conducted on delivery mode data using a multinomial logit model. The choice set consists of three alternatives: LGV, van, and handcart/bike. The unit of analysis was defined at the *chōme* (town-block) level. Boundary data for each *chōme* were obtained from the Statistical GIS dataset provided by the government statistics portal site e-Stat (Statistics Bureau of Japan, 2025). For each town-block, the proportion of delivery modes (LGV, van, and handcart/bike) was calculated, and the mode with the highest share was designated as the representative delivery mode of that area. Among the explanatory variables described later, continuous variables were represented by their mean values within each town-block, while categorical variables were represented by their modal (most frequent) values, thereby assigning representative characteristics to each town-block.

The basic explanatory variables include population density, distance to the nearest MRT station, dummy variables for land-use zoning type, and dummy variables for road width (MLITT, 2025b). Furthermore, for the models estimated for Sagawa Express and Yamato Transport, another explanatory variable, “distance from the nearest delivery station”, was introduced, using the location data of each operator’s delivery stations.

In this study, the utility U_{ni} obtained at location n from choosing delivery mode alternative i is defined as follows.

$$U_{ni} = V_{ni} + \varepsilon_{ni} \qquad (1)$$

3 companies combined:

$$V_{ni} = \beta_i + \beta_{iO} \log O_n + \beta_{iP} \log P_n + \sum_j \beta_{iZ_j} Z_{nj} + \sum_m \beta_{iR_m} R_{nm} \qquad (2)$$

Sagawa Express or Yamato Transport:

$$V_{ni} = \beta_i + \beta_{iO} \log O_n + \beta_{iP} \log P_n + \sum_j \beta_{iZ_j} Z_{nj} + \sum_m \beta_{iR_m} R_{nm} + \beta_{iD} \cdot D_n \qquad (3)$$

Where:
O_n: Population density within the 500 m × 500 m polygon at location n.
P_n: Distance from location n to the nearest railway station.
Z_{nj}: Dummy variables. 1 if zoning type at location n is j; 0 otherwise.
R_{nm}: Dummy variables. 1 if road width category at location n is m; 0 otherwise.
D_n: Distance from location n to the nearest delivery station.

V_{ni} denotes the deterministic component of utility, ε_{ni} is the error term assumed to follow a Gumbel distribution (location = 0, scale = 1), and β represents the parameters to be estimated.

LGV is set as the reference category. The probability that delivery mode i is chosen at location n, denoted by P_{ni}, is given as follows:

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_{j \in C} e^{V_{nj}}}$$

where C denotes the set of available delivery mode alternatives.

4.2 Results

Table 4 presents the estimation results of the last-mile delivery mode choice model (3 companies combined). Since the coefficients of the alternative-specific constants for both Handcart/bike and Van are negative, it can be inferred that LGV tends to be chosen more frequently as the baseline alternative. For Handcart/bike, the parameters associated with population density and commercial areas are positive, while the parameter for distance to the nearest station is negative. This indicates that deliveries by handcart or bicycle are more likely to be chosen in densely populated areas, in areas close to MRT stations, and in commercial districts. In contrast, the parameter for urban residential areas—where apartment buildings are commonly observed—is negative, suggesting that handcart or bicycle deliveries are less likely to be selected there compared to low-rise residential areas.

For Van, the parameters for distance to the nearest MRT station and wider road width categories are negative. This implies that vans are more likely to be chosen, relatively to LGV, in locations closer to MRT stations and on narrower roads, such as single-lane streets. Furthermore, the negative coefficients for urban residential areas and commercial areas suggest that vans are more likely to be selected in low-rise residential areas than in these other zoning types.

Table 2. Estimation results (3 companies combined)

Explanatory Variable	Handcart/bike Coef.	S.E.	Van Coef.	S.E.
Constant	-1.00	0.953	-0.333	0.819
Population density	0.170***	0.162	-0.012	0.181
Distance to nearest MRT station	-0.357**	0.165	-0.174	0.196
Zoning type				
Low-rise residential area	0	-	0	-
Urban residential area	-0.306	0.874	-0.353	0.790
Commercial area	0.522	0.843	-0.467	0.778
Industrial area	-13.2***	2.01e-06	-15.5***	2.59e-07
Road width type				
Road width < 5.5 m	0	-	0	-
5.5 m ≤ Road width < 13 m	-0.274	0.677	-0.691	0.690
Road width ≥ 13 m	-0.061	0.723	-0.923	0.784
Rho-squared: 0.162				
Number of samples: 282				

Note: Significance levels: *** ($p < 0.01$), ** ($p < 0.05$), * ($p < 0.1$); Base category: LGV.

Table 4 presents the estimation results of the multinomial logit models separately estimated using the data of Sagawa Express and Yamato Transport. The results confirm that both common factors and operator-specific characteristics influence last-mile delivery mode choice. Focusing on the alternative-specific constants, the results indicate that, for Sagawa Express, handcart/bike deliveries are less likely to be selected, while vehicle-based modes such as vans and LGVs are more likely to be chosen. For Yamato Transport, LGV tends to be selected as the baseline alternative. In areas with high population density, vans are more likely to be selected by Sagawa Express, suggesting a vehicle-centered delivery strategy. In contrast, Yamato Transport is more likely to use handcart/bike in such dense areas. In commercial districts, both Sagawa Express and Yamato Transport tend to select handcart or bicycle deliveries. Regarding road width, the results show that Sagawa Express is more likely to select handcart or bicycle deliveries in locations with wider roads. Examining the distance from the delivery station, all coefficients are negative for both operators, indicating that when the delivery location is closer to the delivery station, smaller modes such as vans or handcart/bike are more likely to be used instead of LGVs.

Overall, these estimation results suggest that Sagawa Express adopts a relatively vehicle-centered delivery strategy, using human-powered delivery as a complementary measure. In contrast, Yamato Transport appears to employ a more diversified strategy, combining multiple delivery modes to adapt to high-density urban environments with narrower roads.

Table 3. Estimation results (Sagawa Express and Yamato Transport)

Explanatory Variable	Sagawa Express Handcart/bike (Coef.)	Van (Coef.)	Yamato Transport Handcart/bike (Coef.)	Van (Coef.)
Constant	-32.5***	1.45	-1.00	-15.0
Population density	-0.0399	0.605*	0.260***	0.276
Distance to nearest MRT station	0.223	0.0332	-0.449**	0.343
Zoning type				
Low-rise residential area	0	0	0	0
Urban residential area	10.7***	-1.33	-2.68e-04	-1.42
Commercial area	11.2***	-1.64	0.815	-0.243
Industrial area	-20.5***	-8.93	-8.65***	0.970
Road with type				
Road width < 5.5 m	0	0	0	0
5.5 m ≤ Road width < 13 m	19.8***	-0.986	-0.456	13.3
Road width ≥ 13 m	19.8***	-2.12**	-0.476	13.5
Distance from delivery station	-0.931***	-0.0276	-0.454	-0.769
Rho-squared	0.247		0.323	
Number of samples	196		237	

4.3 Prediction of last-mile delivery modes using the model

Using the estimated model, delivery modes were predicted for the entire study area, and the choice probability for each delivery mode were calculated. Figure 4 presents a map showing the delivery mode with the highest predicted probability in each town block. While LGV is widely selected across the area, Handcart/bike appears sporadically in the city center and in areas close to MRT stations. The fact that Handcart/bike does not spread continuously over large areas but instead appears locally suggests that cargo bike and handcart deliveries function as complementary modes to motor vehicles, operating only under specific spatial conditions. Van is observed to appear sporadically in the western part of the study area, where residential neighborhoods are more prevalent.

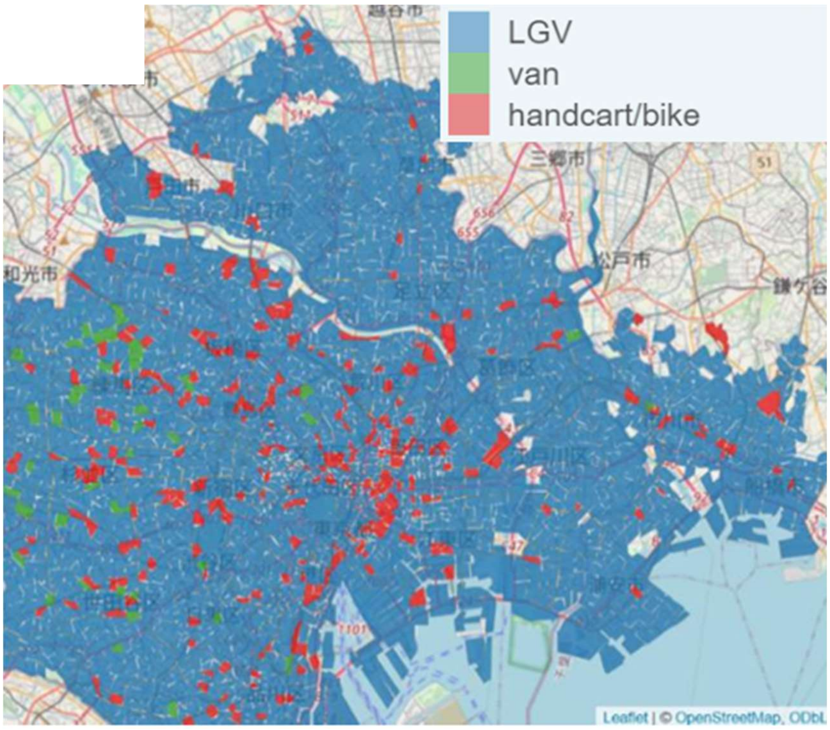

Fig. 3. Delivery mode with the highest predicted choice probability by town block

Next, Fig. 4 presents the predicted probabilities of each delivery mode at the town-block level. The predicted probability of LGV is high mainly in suburban and coastal areas, and is widely distributed in areas characterized by relatively low population density and sufficient road width. In contrast, the predicted probability of Handcart/bike is high only in dense urban areas such as the city center and around MRT stations, suggesting that this mode is used for short-distance and high-frequency last-mile deliveries. Van shows relatively high predicted probabilities in wards of Tokyo that are predominantly residential. This suggests that vans may represent a delivery mode adapted to the specific street structure and delivery conditions typical of residential neighborhoods.

5 Conclusion

This study collected data on last-mile delivery modes in the central area of the Tokyo Metropolitan Area—one of the largest metropolitan regions in the world—focusing on the 23 wards of Tokyo and their surrounding areas. Using these data, a multinomial logit model was used to estimate a last-mile delivery mode choice model, and the analysis examined how logistics operators select delivery modes according to location-specific characteristics. The estimation results reveal that non-motorized delivery modes, such as handcarts and cargo bike, are more likely to be selected in areas with high population density, in locations close to MRT stations, and in commercial districts. In contrast, vans are more likely to be chosen along narrow single-lane roads and in low-rise residential areas. Furthermore, to capture differences in delivery behavior across operators, separate delivery mode choice models were estimated for the two major parcel carriers, Sagawa Express and Yamato Transport. The results suggest that Sagawa Express adopts a relatively vehicle-centered delivery strategy, using human-powered delivery as a complementary approach, whereas Yamato Transport appears to implement a more flexible strategy that combines multiple delivery modes in response to urban characteristics.

This study provides insights that can contribute to the formulation of urban freight policies, such as the development of bicycle lanes and the appropriate allocation of loading and unloading spaces. Furthermore, the findings have potential applications in the development of urban freight simulation models that explicitly incorporate last-mile delivery modes. As a direction for future research, it is necessary to collect and analyze data that account for external factors—such as weather conditions—that may influence delivery mode choice. Furthermore, developing models that reflect operators' delivery strategies, including vehicle ownership conditions and the location of delivery depots, is also required. By incorporating these elements, it is expected that a more realistic and explanatory delivery mode choice model can be developed.

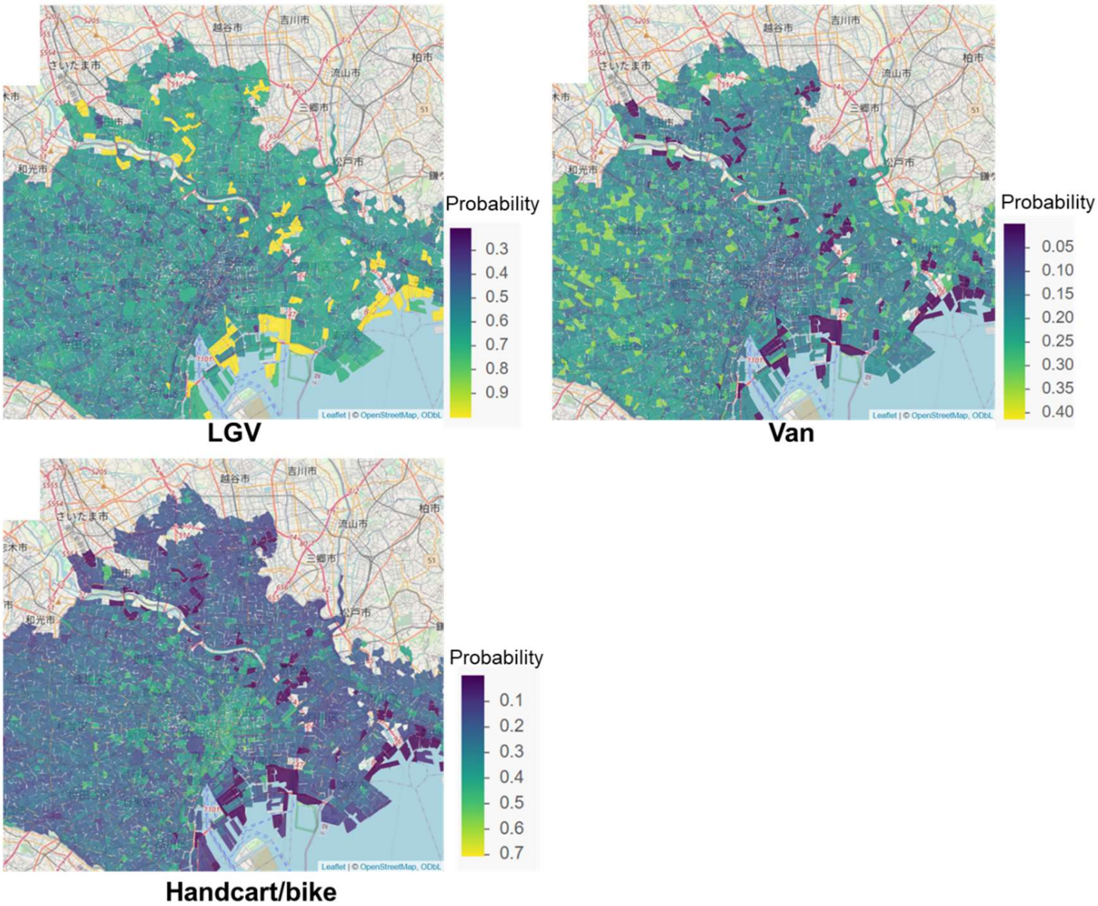

Fig. 4. Predicted choice probability by delivery mode

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