研究ノート

Issues in Last-Mile Delivery for e-Commerce: Discussion around Unattended Home Delivery

MATSUI Yoshiki

1. Introduction

This article aims to note key issues in the last-mile of e-commerce logistics and look into potential benefits and concerns of unattended home delivery (UHD), Okihai in Japanese, as an option for resolving or mitigating some of those key issues. The note should be regarded as a preliminary milestone towards analytical framework and hypotheses for empirical studies on UHD.

The diffusion of the Internet and information technology in business and society has promoted e-commerce between businesses and consumers. According to a series of surveys by METI (Ministry of Economy, Trade and Industry), market size of B2C e-commerce in Japan reached 6.8 trillion yen in 2014 fiscal year and then grew steadily up to 15.2 trillion yen in 2024. Figure 1 presents the trend of the e-commerce market size between 2014 and 2024. The line graph shows a surge in sales from 2019 to 2020, which would be caused by the COVID-19 pandemic.

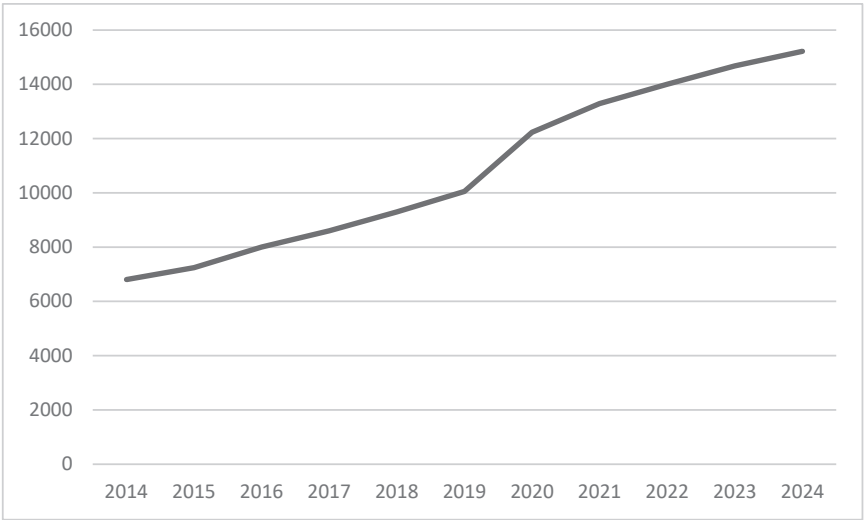

Figure 1: B2C e-Commerce Market Size (billion yen)
Source: Ministry of Economy, Trade and Industry

It is natural to expect that the number of home delivery packages is growing steadily in Japan, which could be suggested by the trend of the e-commerce market size. According to surveys conducted by MLIT (Ministry of Land, Infrastructure, Transport and Tourism) and formerly Ministry of Transport, the number of home delivery packages was 498 million in 1985 and became almost tenfold up to 4,953 million in 2021 as shown in Figure 2. From 2019 to 2020, it grew by 11.9% from 4,323 million to 4,836 million. However, the growth rate has reduced significantly since 2021 subject to a limitation in transport capacity, particularly due to a shortage of truck drivers. The number of home delivery packages has been stable, 5,006 million in 2022, 5,007 million in 2023, and 5,031 million in 2024, when intensified regulations on working hours and conditions targeted at the logistics sector would further squeeze the transport capacity and trigger the industrywide crisis.

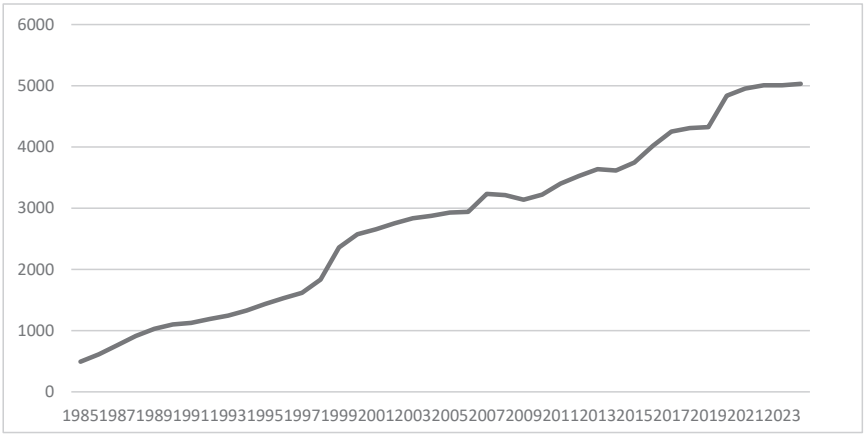

Figure 2: Number of Home Delivery Packages in Japan (million)
Source: Ministry of Land, Infrastructure, Transport and Tourism

These trends in e-commerce market size and the number of home delivery packages imply that the recent growth of e-commerce market could be realized by the increase of logistics fees rather than physical growth. Physical growth is constrained by the transport capacity and the availability of truck drivers. The recent increase in logistics fees reflects the rise of wage level to attract more truck drivers. However, it is not easy for logistics companies to employ more truck drivers by offering higher wages, even though they tried to migrate drivers from other countries. They are forced to find other solutions.

2. Key Issues in Last-Mile Delivery

Most of the products ordered through an e-commerce platform are shipped from a distribution center of the platform, PDC, to a logistics company's sales office or distribution center in the same or nearby region, LSD1, where those products are sorted by receiver's region and shipped to another distribution center or sales office of logistics company nearest to the receiver, LSD2, and then finally delivered to the receiver's home or designated residential address, RH. Inefficiency arises with failed deliveries, redeliveries and higher costs in the final leg between LSD2 and RH, which is called the last-mile of logistics. This note

focuses on the last-mile, where several key issues and concerns are pointed out, leading to inefficiency. Considering these issues and concerns is vital for customer satisfaction and loyalty from the perspective of e-commerce platform, because the last-mile of the product's journey is the customer's only physical contact via logistics service providers. Main issues are:

1) Customer expectations: Current e-commerce customers expect fast, often on the same day, flexible, convenient, and free delivery with real-time tracking. This puts immense pressure on logistics service providers to offer tight delivery time windows and superior communication, which is difficult and expensive to achieve.
2) High operational costs: The final leg of delivery is often the most expensive part of the entire product's journey. Delivering individual packages to different residential addresses is far less efficient than transporting truckload batches to a single distribution center. Factors like fuel, labor, vehicle maintenance, stop-and-go deliveries and re-attempting failed deliveries add up expenses. Even though being the shortest part of the delivery process, the last-mile may account for more than 50% of total delivery costs, up to 53% of total delivery costs in 2023 suggested by some logistics experts in Maersk and Statistica.
3) Failed deliveries: Failed deliveries occur due to no one being home, inaccurate addresses, or poor communication. A failed delivery results in wasted time and incur substantial costs for redelivery attempts and harms customer satisfaction. When a delivery fails because the receiver is not available, the dispatcher usually leaves a short message and waits for a response from the receiver or simply re-attempts the delivery until the receiver becomes available at home.
4) Inefficient route planning: Poorly optimized routes are a major source of inefficiency, leading to increased delivery times, higher fuel consumption, and lower driver productivity. Planning routes manually is time-consuming and prone to human error. Without software that can adapt to real-time conditions of traffic and weather, drivers may choose inefficient paths, increasing fuel consumption, costs, and delays.
5) Urban congestion: Navigating congested urban areas is a significant challenge, causing delivery delays and raising operational costs. Limited parking and restricted access zones in big cities further complicate the last-mile deliveries.
6) Rural distances: Rural areas present challenges due to long travel distances between fewer delivery stops, which increases time and fuel costs.
7) Reverse logistics for product returns: Managing the complexity of handling product returns adds another layer of logistical challenge and headache to the last-mile. An unoptimized returns process can disrupt outbound deliveries and harm the customer experience (Lorenzo-Espejo *et al.,* 2024).
8) Lack of visibility: Without real-time tracking, it is difficult for both businesses and customers to know the exact location of a package, which can lead to delayed deliveries, frustration and customers' support calls and erode customer trust.
9) Environmental pressure: The rise in last-mile deliveries contributes to traffic congestion and carbon emissions, pressuring companies to adopt more sustainable and eco-friendly delivery methods such as using electric vehicles. However, this can be costly and challenging, especially in rural areas.
10) Driver shortages: A lack of available drivers can cause delivery delays and put a strain on existing

staff.

To resolve or mitigate these issues, various solutions and technological development have been explored, including an unattended delivery option besides attended delivery mode to reduce failed deliveries, redelivery attempts, operating costs, and carbon emissions. Smart parcel lockers and local partner businesses such as convenience stores and local supermarkets or grocery stores act as central locations for customers to pick up and drop off (PUDO) parcels, increasing delivery density and reducing failed deliveries. Electronic proof of delivery (ePOD) technology allows dispatchers to collect digital signatures, photos, or barcode scans, which provides a verifiable record of a successful delivery.

For route planning, AI-powered optimization software creates the most efficient multi-stop routes by analyzing factors such as traffic, delivery time windows, and fuel consumption. Also, the software can dynamically re-route drivers in response to real-time disruptions. For more visibility, GPS-enabled real-time tracking systems give dispatchers and customers live updates on delivery status and estimated time of arrival. Data analytics can provide insights into driver performance and bottlenecks. Automated communication via SMS or mobile app alerts can keep customers informed of delivery status, managing expectations and reducing support calls. For environmental sustainability, electric vehicles and bikes have been introduced instead of heavy trucks to reduce carbon emissions and navigate congested urban areas more efficiently. Autonomous delivery robots and aerial drones are being tested to automate delivery, especially for lightweight parcels in urban and remote areas. For the shortage of drivers, crowdsourced delivery is explored in some regions. This delivery model uses a network of local drivers to handle last-mile or high-demand deliveries, providing flexibility and scalability during peak time windows and seasons.

3. Unattended Home Delivery as a Solution to Last-Mile Issues

(1) Delivery modes for last-mile logistics

Olsson, Hellstrom and Vakulenko (2023) showed the classification scheme of delivery modes for the last-mile logistics, which is based on two dimensions; attended vs. unattended deliveries and home vs. alternative locations. It leads to four basic delivery modes: attended home delivery (AHD), unattended home delivery (UHD), stationary delivery location, and roaming delivery. Stationary delivery location includes PUDO points and parcel lockers outside of home, convenience stores, gas stations, gyms or workplaces.

Roaming delivery is an innovative last-mile delivery mode that allows products to be delivered to a customer's designated roaming or mobile location, rather than a stationary home or work address. It is a system built to adapt to customers' mobile lifestyles, minimizing failed deliveries and operating costs for logistics service providers. In a roaming delivery system, products customers ordered are delivered to a designated mobile location such as the trunk of their car at a specific time and place. To achieve this, the system must offer sophisticated coordination between customers, logistics service providers, and technology.

The customer specifies a flexible time window and a specific roaming delivery point such as a known parking garage, their vehicle's location, or another public access point. If the customer's itinerary changes,

the delivery system can dynamically adapt the route and delivery location. For in-car or trunk delivery, the dispatcher is given temporary, secure access to the vehicle to place the package inside. Some car manufacturers and logistics companies have started partnerships to experiment with car trunk delivery. In the case of Audi, DHL and Amazon, "if the Audi owner agrees to the tracking of their automobile for the specific delivery time frame, the DHL driver handling the parcel receives a digital access code for the trunk of the customers vehicle. It can be used one time only for a specific period of time and expires as soon as the luggage compartment has been closed again. Similarly, Audi connect easy delivery customers will also be able to send letters and parcels from their own car in the future" (Reyes, Savelsbergh and Toriello; 2017). Then, the delivery service providers use algorithms to optimize vehicle routes. These processes aim to reduce the total distance traveled and improve efficiency by bundling deliveries for customers in similar roaming locations.

(2) Merits and demerits of UHD to logistics service providers and receivers

In the unattended home delivery (UHD) mode, dispatchers leave parcels in out-of-home environments such as doorstep, entrance, some secret spot, mailbox, etc., whether receivers are present or absent. In special occasions, they can leave them indoor. This is not a sophisticated solution but rather a simple solution to the last-mile issues. However, it may work well in certain settings. Particularly logistics service providers can get direct benefits from UHD. They are a series of reductions in failed deliveries, redelivery attempts, operating costs, carbon emissions, and inefficiency. Basically, dispatchers do not need to bring back and redeliver parcels even if receivers are absent.

To receivers, UHD has certain merits. They can receive parcels in absence. They do not need to dare to stay at home to wait for dispatchers carrying the parcels. Even if they are present at home, they do not need to open doors to contact dispatchers, which makes receivers feel safe in certain situations. Also, to e-commerce platforms, UHD may be a source of differentiation and customer satisfaction.

On the other hand, UHD cannot go without any concerns. Some products must be directly delivered to receivers in person. One of the most serious concerns about UHD is security issues suggested by Mckinnon and Tallam (2003). From the perspective of receivers, UHD entails risks of false delivery, loss and deterioration. They may not receive the right parcels. Parcels may be stolen. Products they ordered may be damaged by leaving parcels outside door without good protection. Higher these risks, lower service quality receivers perceive. This means higher transaction costs to deal with these risks for logistics service providers. They need to send certificates for the parcel delivery to receivers. Otherwise, they would be subject to risk of false claims from receivers. They may consider buying insurance for parcel losses and damages. Both Logistics companies and parcel receivers contemplate the tradeoff among cost, convenience and security carefully.

(3) Redelivery rate of home packages

Surveys by MLIT suggest that delivery success and failure rate at the first attempt would be around 85% and 15% respectively. The recent trend of redelivery rate in Japan is shown in Figure 3. It was around 15% before the COVID-19 pandemic. In April 2025, the redelivery rate became below 10%, reflecting the diffusion of UHD.

Allen (2018) found a consistent delivery failure rate was 15%. Albeit Song (2009) suggested it would be more than 20% in Sussex. Seghezzi, Siragusa and Mangiaracina (2022) assumed that the failure rate would be 15% for the first attempt and 20% for the second and subsequent attempts.

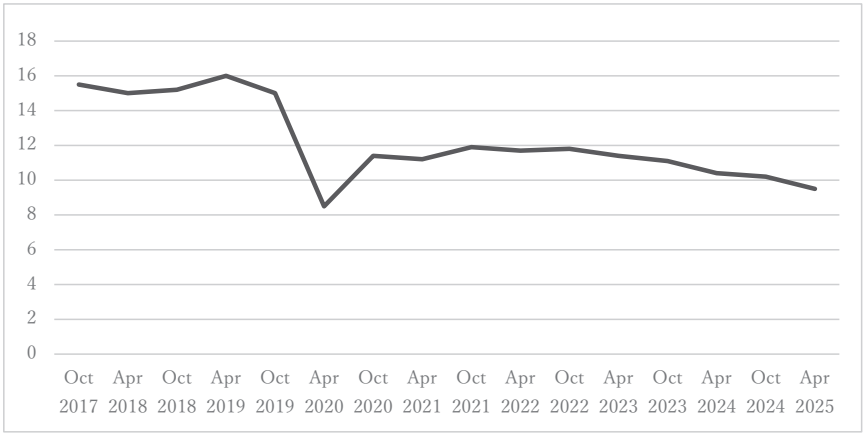

Figure 3: Redelivery Rate of Home Packages (%)
Source: Ministry of Land, Infrastructure, Transport and Tourism

4. Discounting Logistics Fee for UHD as an Incentive

UHD could reduce the last-mile delivery workload and cost by eliminating the possibility of redeliveries. It is expected to raise the probability of delivery success at the first attempt towards 1. However, it is difficult to achieve 100% success. Wrong addresses on waybills may cause the chance of delivery failure even in the case of UHD. Cash-on-delivery parcels need a direct handover to the receiver in exchange for cash. Valuable items and pharmaceutical/medical products need to be delivered to the receiver in person. Frozen and chilled products couldn't be left outside of door usually. Items designated for specific delivery points or attended delivery should not be dropped off in front of door.

Logistics companies have an option to discount their logistics fee to the receivers who choose UHD. The question is how much delivery fee could be discounted by logistics companies when a receiver selected UHD for a parcel. The following three cases will be analyzed.

(1) Case 1: Probability of delivery success is stable

Let us start with the case of attended home delivery (AHD). In case the parcel receiver is absent from home, the delivery fails, and the parcel must be brought back by the dispatcher. It is important to consider the probability of delivery success and failure. Let p and n denote as follows:

p = probability of successful delivery at the first attempt

n = number of redeliveries until successful delivery (0, 1, 2, 3, …)

Then, the probability of failed delivery at the first attempt = 1 - p. If the same probability of delivery success can apply for the second and the subsequent attempts, the probability of the number of redeliveries until a package could be successfully received is shown as follows:

Prob $\{n = 0\} = p$,
Prob $\{n = 1\} = p\,(1 - p)$,
Prob $\{n = 2\} = p\,(1 - p)^2$,
……
Prob $\{n = k\} = p\,(1 - p)^k$,
……

Hence, the expected value of redeliveries, E(n), can be calculated as follows:

$$E(n) = \sum_{k=0}^{\infty} k\,p\,(1 - p)\,k = (1 - p)/p$$

If the unit cost of redelivery is D, the expected cost of redeliveries per parcel can be estimated as D E(n), which could be the maximum discount offered for the receivers who chose UHD. When p = 0.85, E(n) = 0.15/0.85 = 0.17647. When D is estimated to be 1000, the maximum discount = 176.47.

(2) Case 2: Probability of delivery success becomes lower for the second and subsequent attempts

However, the probability of delivery success for the second and subsequent attempts may be different from the probability for the first attempt. Usually, it may be lower. Let q denote the probability of delivery success for the second and subsequent attempts. Then, the probability of the number of redeliveries until a package could be successfully received is shown as follows:

Prob $\{n = 0\} = p$,
Prob $\{n = 1\} = q\,(1 - p)$,
Prob $\{n = 2\} = q\,(1 - p)\,(1 - q)$,
Prob $\{n = 3\} = q\,(1 - p)\,(1 - q)^2$,
……
Prob $\{n = k\} = q\,(1 - p)\,(1 - q)^{k-1}$,
……

Hence, the expected value of redeliveries can be calculated as follows:

$$E(n) = \sum_{k=1}^{\infty} k\,q\,(1 - p)\,(1 - q)^{k-1} = (1 - p)/q$$

When p = 0.85 and q = 0.8, E(n) = 0.15/0.8 = 0.1875. With D = 1000, the maximum discount = 187.5.

(3) Case 3: Probability of delivery success becomes further lower for the third and subsequent attempts

Along this line, the probability of delivery success for the third and subsequent attempts might be further lower than the probability for the second attempt. Let r denote the probability for the third and subsequent attempts. Then, the probability of redeliveries until a package could be successfully received is shown as follows:

Prob $\{n = 0\} = p$,
Prob $\{n = 1\} = q\,(1 - p)$,
Prob $\{n = 2\} = r\,(1 - p)\,(1 - q)$,

Prob $\{n = 3\} = r\,(1 - p)\,(1 - q)\,(1 - r)$,

Prob $\{n = 4\} = r\,(1 - p)\,(1 - q)\,(1 - r)^{2}$,

……

Prob $\{n = k\} = r\,(1 - p)\,(1 - q)\,(1 - r)^{k-2}$,

……

Hence, the expected value of redeliveries can be calculated as follows:

$$\mathrm{E}(n) = q\,(1 - p) + \sum_{k=2}^{\infty} k\,r\,(1 - p)\,(1 - q)\,(1 - r)^{k-2} = (1 - p)\,\{\,q + (1 - q)\,(1 + 1/r)\,\}$$

When $p = 0.85$ and $q = 0.8$, $r = 0.75$, $\mathrm{E}(n) = 0.15\times\{0.8+0.2\times(1+1/0.75)\,\} = 0.19$. With $D = 1000$, the maximum discount = 190.

(4) Rationale for redelivery cost

The actual value of D depends on the size and weight of the parcel, travel distance, delivery speed, and other optional services. For light and small parcels, D might be close to 1000 yen. The last-mile delivery occupied 53% of the total logistics cost. The total logistics cost, T, consists of three elements: cost before the last-mile, B, cost of successful last-mile delivery at the first attempt, C, and cost of redeliveries including return trips $D\,\mathrm{E}(n)$. That is,

$T = B + C + D\,\mathrm{E}(n)$

The 53% statement means $C + D\,\mathrm{E}(n) = 0.53T$, then $B = 0.47T$.

If we can assume $D = 2C$ approximately, taking account of return trip with the same distance, and $\mathrm{E}(n) = 0.1875$ in Case 2, $C = 0.53T\,/\{1 + 2\mathrm{E}(n)\} = 0.3855T$, and $D\,\mathrm{E}(n)=0.1445T$. Then, $D = 0.1445T\,/\mathrm{E}(n) = 0.7707T$.

When $T = 1298$, $B = 610$, $C = 500$, and $D = 1000$. The maximum discount for UHD would be 187, if the probability of delivery failure is 85% for the first attempt and 80% for the second and subsequent attempts.

5. Discussion

Based on previous empirical studies, we may assume that the probability of delivery success would be around 85% for the first attempt and around 80% for the second attempt. For the third and subsequent attempts, it may be further lower, When the unit cost of last-mile delivery is 10US$, the maximum discount for UHD would be between 1.76US$ and 1.9US$. Small discount may not be effective.

Japanese logistics companies did not offer any discounts to receivers who selected the UHD option. One of reasons is that UHD was not a formal delivery option approved by the central government, MLIT. Rather, they would like to keep the undiscounted fees and invest them to increase the security level of UHD such as promoting and implementing parcel lockers at PUDO points and developing autonomous delivery robots that can unlock automatic locking system at the entrance to large-scale condominiums/ apartments and operate elevators to access the receiver’s condominium.

After MLIT formally approves UHD as a delivery option, logistics companies may consider offering discounted fees to UHD receivers/customers, as well as more secure delivery options.

6. Conclusions

This note outlines the main issues regarding the last-mile delivery and possible solutions to those issues, including the UHD option. It also analyzes the economic benefit of UHD to logistics service providers and the possibility to offer discounted fees to the receivers who choose the UHD option.

At this point, both logistics companies and e-commerce platforms have not offered any discount even if parcel receivers choose the UHD option. They have kept the rent generated by the introduction of UHD. Logistics companies and e-commerce platforms might share the rent by negotiation. The rent could be invested in technology development to enhance the security level of UHD or simply used to buy insurance for protecting against stollen or missed parcels. This suggests that subcontract logistics service providers face discounted fees when receivers select the UHD option, which may accelerate the shortage of drivers. In future research, technological solutions should be considered to make UHD safer and more convenient and promote the UHD option widely. Autonomous delivery robotics, aerial drones, and smart parcel lockers are among them.

Formal analysis of pricing and negotiation among e-commerce platforms, logistics service providers and customers may be required. Kurata (2023) picked up the relationship between logistics companies and customers and showed the possibility that two prices can exist for attended and unattended deliveries in a game-theoretic setting.

Finally, empirical study should be explored for customers' choice of UHD, which could be explained by sense of security, gender, age, marital status, household structure, availability at home, expectation, emergency, etc.

Acknowledgment

This work was financially supported by JSPS KAKENHI Grant Numbers JP22H00874 and JP 23K22145.

References

Allen, J., Piecyk, M., Piotrowska, M., McLeod, F., Cherrett, T., Ghali, K., Nguyen, T., Bektas, T., Bates, O., Friday, A., Wise, S. and Austwick, M. (2018), Understanding the impact of e-commerce on last-mile light goods vehicle activity in urban areas: The case of London, *Transportation Research Part D: Transport and Environment*, Vol. 61, pp. 325−338.

Goethals, F., Leclercq-Vandelannoitte, A. and Tutuncu, Y. (2012), French consumers' perceptions of the unattended delivery model for e-grocery retailing, *Journal of Retailing and Consumer Services*, Vol. 19, No. 1, pp. 133−139.

Kurata, H. (2023), Effectiveness of different pricing strategies at reducing the workload of home delivery services, *Proceedings of the 7th Asian Conference of Management Science and Applications* (ACMSA 2023).

Lorenzo-Espejo, A., Munuzuri, J. Pegado-Bardayo, A. and Guadix, J. (2024), A framework for analyzing service disruptions in last-mile and first-mile reverse logistics, *Research in Transportation Economics*, Vol. 18, 101485.

Mckinnon, A. and Tallam, D. (2003), Unattended delivery to the home: An assessment of the security implications. *International Journal of Retail & Distribution Management*, Vol. 31, No. 1, pp. 30−41.

Olsson, J., Hellstrom, D. and Vakulenko, Y. (2023), Customer experience dimensions in last-mile delivery: An empirical study on unattended home delivery, *International Journal of Physical Distribution & Logistics Management*, Vol. 53, No. 2, pp. 184−205.

Olsson, J., Osman, M.C., Hellstrom, D. and Vakulenko, Y. (2022), Customer expectations of unattended grocery delivery services: Mapping forms and determinants, *International Journal of Retail & Distribution Management*, Vol. 50, No. 13, pp. 1−16.

Reyes, D., Savelsbergh, M. and Toriello, A. (2017), Vehicle routing with roaming delivery locations, *Transportation Research Part C: Emerging Technologies*, Vol. 80, pp. 71−91.

Seghezzi, A., Siragusa, C. and Mangiaracina, R. (2022), Parcel lockers vs. home delivery: A model to compare last-mile delivery cost in urban and rural areas. *International Journal of Physical Distribution & Logistics Management*, Vol. 52, No. 3, pp. 213−237.

Song, L., Cherrett, T., McLeod, F. and Guan, W. (2009), Addressing the last mile problem: Transport impacts of collection and delivery points, *Transportation Research Record*, Vol. 2097, No.1, pp. 9−18.

〔Yoshiki Matsui, Specially Appointed Professor at the Open University of Japan〕

〔2025年12月１日受理〕