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Efficient and sustainable last-mile logistics: Lessons from Japan

Delivery droids may be the solution to keep costs and environmental impact low, if stakeholders collaborate to pave the way.

by Takakazu Doi and Yuta Murakami

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Most people know what it feels like to wait for an online delivery. After making a purchase, there is a tendency to incessantly refresh the tracking page, virtually following the item from the warehouse to the sorting center to the doorstep. The anticipation linked to watching a package make its last-mile trek is an itch only an unboxing can scratch.

The surge in e-commerce volumes has put huge pressure on the last-mile delivery system, the process by which products are transported from distribution centers to final consumers. E-commerce sales worldwide grew sixfold in a decade, from $572 billion in 2010 to some $3.5 trillion at the end of 2019.[1]

The COVID-19 pandemic has only accelerated this trend, as more people demand contactless forms of shopping. Take e-commerce penetration in the United States as an example: ten years' worth of growth took place within three months when the pandemic broke out.[2]

As people continue to expect ever-swifter delivery times, last-mile delivery systems are becoming a bottleneck. Logistics providers are struggling to deal with increasing volumes of goods, resulting in slower delivery times, less flexibility in delivery time slots, and higher delivery costs for customers. Furthermore, as delivery traffic steadily rises, the negative effects on the environment will likely grow unless actions are taken to mitigate them.

In response, the World Economic Forum (WEF) and McKinsey have been researching ways to reform last-mile delivery for efficiency and sustainability, using Japan as a country to model simulated projections. Japan was chosen because the country is at the forefront of having to grapple with societal challenges such as labor shortages resulting from population decline and a hyperaging society—something many developed countries will face in the future—exacerbating pressure on last-mile deliveries. Better technologies and efficiency levers are needed to operate last-mile deliveries in Japan's collage of regions with different population densities. Understanding these issues—including at the policy and structural levels—and how they differ in urban and nonurban regions could be instructive for other countries.

This article projects the implications resulting from the continuing rise of last-mile deliveries in urban and suburban areas. By studying the effectiveness of various interventions currently employed to mitigate the negative consequences of rising costs and carbon dioxide emissions, the study finds that delivery robots—small, personal delivery devices that can transport packages weighing 100 kilograms or less at a maximum speed of five kilometers per hour or less[3]—may be the best bet to reduce carbon emissions and costs, while coping with issues like labor shortages.

But more needs to be done to pave the way for delivery robots. They could feature more prominently in last-mile deliveries, with three stages that could serve as entry points for logistics companies to scale smart interventions to optimize last-mile deliveries: joint delivery systems, including networking sorting centers, at the regional level; parking-space management at the neighborhood level; and the governance of robot operations on pedestrian walkways as the goods move from truck to door.

The implications of increasing pressure on Japan's last-mile delivery system

More last-mile deliveries will mean a larger carbon footprint

The WEF's *Future of the last-mile ecosystem* report forecasts trends in global e-commerce–related indicators.[4] We've leveraged the model in Japan to glean city-specific insights, factoring in local conditions such as demography and purchasing

[1] *Jilt,* "The eCommerce decade: How the 2010s changed online shopping," blog entry by Sam Greenspan, April 6, 2021, Jilt.com.
[2] "The quickening," *McKinsey Quarterly Five Fifty,* July 28, 2020, McKinsey.com.
[3] *Taxonomy for segmentation of autonomous delivery vehicles and personal delivery devices,* World Economic Forum, October 22, 2020, weforum.org.
[4] *The future of the last-mile ecosystem,* World Economic Forum, October 1, 2020, weforum.org.

behaviors. The WEF's report forecasts that e-commerce distribution volumes in central Tokyo's 23 wards will rise by 85 percent by 2030, which will require a 71 percent increase in delivery vehicles to travel 25 percent more in distance. In addition to placing greater strain on logistics operations, the rise in e-commerce would lead to a 20 percent increase in carbon dioxide emissions.

In suburban areas, the volume of last-mile traffic will also rise, but by 10 percent less than in Tokyo. Delivery fleets will need to be expanded by 51 percent, or 20 percent less than in Tokyo. However, the lower population density in suburban areas means that delivery vehicles will have to cover greater distances, emitting relatively higher levels of carbon dioxide despite smaller delivery fleets. These differences between urban and suburban areas mean that different forms of intervention would achieve different levels of effectiveness based on geography.

Depending on the level of urbanization, some forms of intervention work better than others

A number of interventions can be employed to cope with the increasing demand for online deliveries. We looked at a nonexhaustive list of feasible initiatives from the WEF report, taking Japan's context into consideration, including regulations and the current deployment status of these interventions, along with the expected impact on carbon dioxide emissions and delivery costs in urban and suburban areas (Exhibit 1). These initiatives were identified through discussions with experts to determine their applicability in Japan.

Electric vehicles and hydrogen fuel-cell electric vehicles (H2FCEVs) are likely to substantially lower carbon dioxide emissions in both cities and the suburbs. When it comes to delivery costs, parcel lockers and delivery robots may lead to modest cost reductions. In suburban areas, parcel lockers, the use of microhubs, and the retrofitting of parking-based infrastructure will likely lead to some cost savings. The reason is that the population in the suburbs is sparse and interventions that consolidate density (such as hubs) help to reduce the costs involved in distribution across a wide geographical area.

Based on maturity levels, delivery robots offer a promising space to explore

One way last-mile delivery stakeholders can prioritize initiatives is by exploring the potential of developing technologies. Analysis of the maturity levels of each initiative has indicated that increasing the use of delivery robots may generate significant positive environmental and efficiency impacts. Although it is necessary to have a number of delivery robots in place, they could help companies solve labor shortages and low productivity issues. This is especially relevant in Japan, where the transportation sector's productivity level is 40 percent below the industry average,[5] and the transportation sector faced a labor shortfall of 140,000 people in 2020. By 2030, this shortfall is expected to grow to 278,000 people.[6]

The Japanese government will allow the use of delivery robots on roads as of 2021 according to media reports.[7] But policy issues such as the standardization of vehicles and operating rules to prevent harms like additional congestion resulting from the low speed of the vehicles need to be worked out. So do infrastructure concerns such as the need for bigger curbside parking spaces for trucks to stop for delivery-robot deployment.

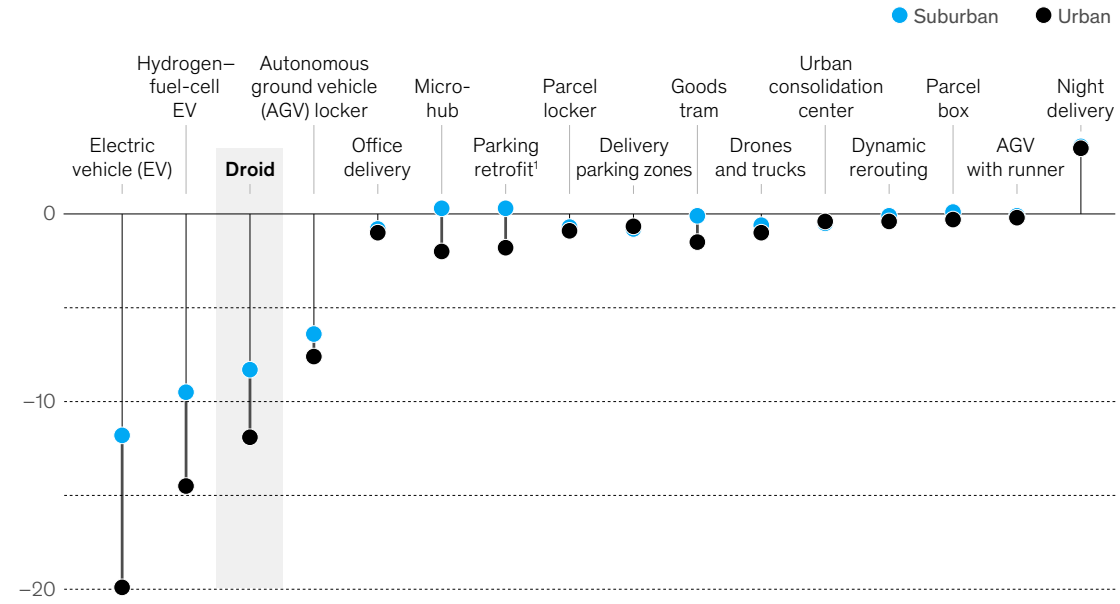
Other interventions, such as electric vehicles (EVs), H2FCEVs, and parcel lockers, will likely continue to generate cost savings and reduce carbon dioxide emissions, but they have already reached widespread consensus from a policy perspective. As such, discussions on governance systems for delivery robots are likely to have a greater impact in relative terms and should be explored further.

[5] *Trends in logistics and current logistics policy* (国土交通省, 物流を取り巻く動向と物流施策の現状について), Ministry of Land, Infrastructure, Transport and Tourism, May 2020, mlit.go.jp.
[6] Third expert panel on the outline of comprehensive logistics policies for the 2020s (国土交通省, 第3回 2020年代の総合物流施策大綱に関する有識者検討会), Ministry of Land, Infrastructure, Transport and Tourism, September 2020, mlit.go.jp.
[7] "Automatic delivery robots to be allowed on public roads in Japan in fiscal year 2021" (日経新聞 自動配送ロボ、公道走行可能に　21年度にも全国で), Nikkei, March 2021, www.nikkei.com.

Exhibit 1

The potential for droids to reduce delivery costs and carbon dioxide emissions remains largely untapped because of low maturity levels.

Simulated impact of various interventions on CO_2 emissions, % change



Change in delivery costs, %

	Electric vehicle (EV)	Hydrogen–fuel-cell EV	Droid	Autonomous ground vehicle (AGV) locker	Office delivery	Micro-hub	Parking retrofit[1]	Parcel locker	Delivery parking zones	Goods tram	Drones and trucks	Urban consolidation center	Dynamic rerouting	Parcel box	AGV with runner	Night delivery
Suburban	0	0	**0**	0	0	–1	–1	–1	0	0	0	0	0	0	3	4
Urban	0	0	**–1**	0	0	0	0	–1	1	0	0	0	0	0	2	3

Maturity rate,[2] %

	Electric vehicle (EV)	Hydrogen–fuel-cell EV	Droid	Autonomous ground vehicle (AGV) locker	Office delivery	Micro-hub	Parking retrofit[1]	Parcel locker	Delivery parking zones	Goods tram	Drones and trucks	Urban consolidation center	Dynamic rerouting	Parcel box	AGV with runner	Night delivery
Overall	100	50	**25**	25	100	100	100	100	50	50	50	50	100	100	25	75

Note: Adoption scenarios for the initiatives are estimated based on the best possible knowledge in 2021.
[1]Retrofitting of parking-based infrastructure.
[2]The higher the maturity rate, the more widespread the implementation of the respective interventions.

Key enablers for the use of delivery robots for last-mile delivery

The successful implementation of robots in last-mile delivery requires the reimagining of the entire last-mile ecosystem. Consensus building among private-sector and public-sector stakeholders from the regional level to the street level is critical to this transformation.

Various issues in three different stages of last-mile delivery need to be addressed (Exhibit 2). While some of these issues may not be directly connected to delivery robots, they are nonetheless foundational to creating an effective ecosystem that will allow for widespread deployment.

1. At the regional level: Joint delivery systems, including networking sorting centers

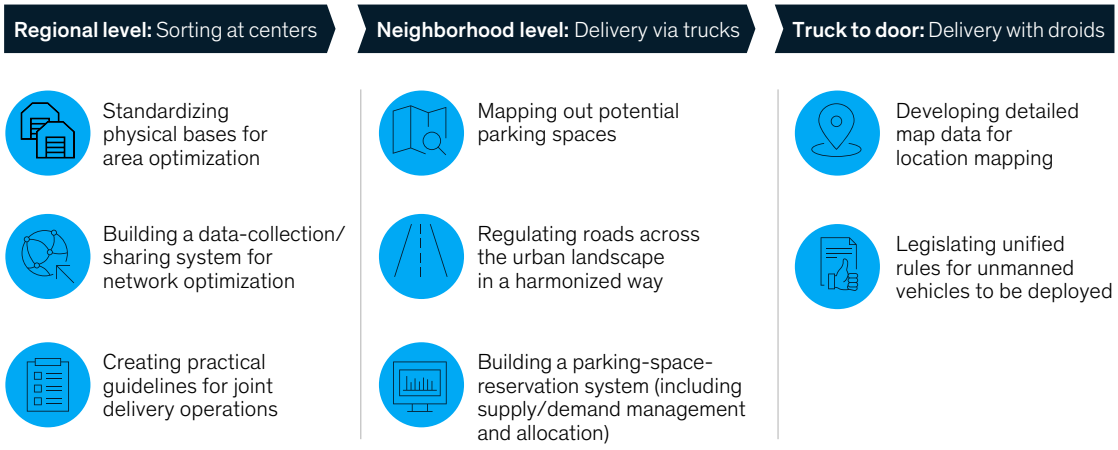
To cope with the increasing volume of goods, it is necessary to optimize individual sorting centers and to improve the efficiency of the overall regional network, which could mean building data-collection and -sharing systems for network optimization, and creating practical guidelines for joint delivery operations. Different logistics companies could find consensus on a number of fronts, such as standardizing physical bases by identifying the optimal locations for shared sorting centers and homogenizing container requirements; building shared databases by agreeing on types of shared data, and how to share the data, and designing new business models and incentives; and establishing the practical guidelines for joint operation by developing common rules and vehicle operations required for joint delivery and clarifying roles and responsibilities.

2. At the neighborhood level: Parking-space management

Assuming that trucks transport delivery robots to delivery areas, they would have to park for longer periods, which can exacerbate congestion and traffic jams. To increase the flexibility and efficiency of delivery operations, stakeholders need to map out

Exhibit 2

Stakeholders can collaborate in eight areas to prepare for widespread deployment of delivery droids.



potential parking spaces; create a reservation system that manages parking-space supply and demand options, including solving legal issues surrounding flexible curbside operations, as curbsides are traditionally not regarded as usable parking spaces; and citywide road-management coordination.

Dynamic pricing may also be a tool to optimize parking. This would reduce management costs, increase new business opportunities through the development of new infrastructure, and improve delivery-robot deployment convenience and safety.

3. From truck to door: Governance of robot operations on pedestrian walkways

As delivery robots may complete the final distances of last-mile deliveries unmanned, private companies and the authorities have to jointly agree on the rules for safe and efficient operations on paths shared by pedestrians. To do this, they need to build more detailed mapping databases for unmanned operations. In nonurban areas, the governance of robotic operations is relatively easier thanks to less-crowded pedestrian walkways. Yet, if the system is poorly executed, delivery-robot productivity would be low in such areas because the population is more spread out. Additionally, legislation is needed to unify rules for unmanned-vehicle operations.

Autonomous vehicles could lead to a more efficient and sustainable last-mile network in Japan and in many other regions worldwide. Some of the key issues that stakeholders in both the private and public sectors should be contending with now include:

— the public sector revisiting regulations to accommodate new technologies

— businesses cooperating to harmonize standards

— civil society navigating these two sectors from the perspectives of the general public

Finding consensus on policy standards, operating rules, and management systems before the technology is mature and widespread should help safeguard everyone's well-being and increase the odds of the successful deployment of delivery robots.

The transition to smart cities has begun in many places through the use of various technologies. By factoring logistics into such efforts and having stakeholders closely examine the infrastructure and institutional design necessary to actualize a more efficient future for logistics, it will be possible to realize a more convenient and sustainable society.

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