Chapter 16

Digitization, automation, operation, and monetization: standardizing the management of sidewalk and kerb 2025–50

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16.1 Introduction

Dozens of companies are building and piloting small, electric delivery robots with a view to reduce the costs of delivering food and parcels over their final distance.[1] Amazon, FedEx, Postmates, and Starship are four among them (Fig. 16.1). Concurrently, cities are interested in reducing congestion and emissions associated with the use of trucks, vans, and cars for deliveries, which has more than tripled in the last decade. Growing expectations for instant delivery, high prices commanded by local delivery operators, and pressing urban traffic goals combine with accelerating digitalization to create demand for logistics-related innovation.

In addition to the four logistics operators just mentioned—and there are already many others—there will easily be several dozen more applications and manufacturers on a worldwide basis before a likely, late-decade market shake-out leaves only a few tens of significant players. These robots and their successors are expected to frequent pathways such as sidewalks and pavements over the next few years. As they become more capable, their adoption will become more pervasive. One of them, Starship, completed its first million commercial deliveries in January 2021. Within 4 months they completed another 500,000, and in mid-May of this year, they claimed 80,000 intersection crossings per day across the several locations in which they currently operate. Even if this accounted for 50% of the total number of commercial, robotic delivery trips worldwide, the other operators are not far behind. Once this technology matures, how can the express delivery operators such as DHL or UPS not add their machines to the mix? Seeing Swiss Post's success with its delivery robots, Canada Post, US Post Office, and many other national postal services can be expected to engage.

To date, each of the logistics companies using or trialing pathway robots operates in independent, closely constrained public spaces without spatial competition from other similar operators. Traditional logistics operators have long operated in common spaces—it is usual to see UPS and FedEx step-vans stopped in front of the same building—so we can expect to soon see multiple logistic-robot operators concurrently occupying the same pathways and crosswalks.

How can we prepare our cities for myriad robotic vehicles sharing public spaces with human-operated vehicles and human pedestrians? How will vehicles from various vendors operate simultaneously in these spaces? How can these vehicles be used to their greatest advantage within our cities? The chapter addresses these questions in three sections:

- Section 2 discusses reasons why mobile service robots will occupy the urban panoply of automated vehicles sooner and in greater numbers than will fully automated passenger vehicles.
- Section 3 outlines a draft, international standard designed to enable a mobility authority to manage, orchestrate, and monetize multiple, concurrent fleets of service robots. While this encompasses passenger and goods vehicles that use the roadway and kerbside (see Section 16.3.5), it predominately considers smaller

1. Pathway robots are being designed to perform several different services and are called by many names including sidewalk drones, delivery bots, and personal delivery devices (PDDs). In this chapter, they will be referred to pathway robots in general and as delivery robots in particular.

Smart Cities Policies and Financing. https://doi.org/10.1016/B978-0-12-819130-9.00006-1
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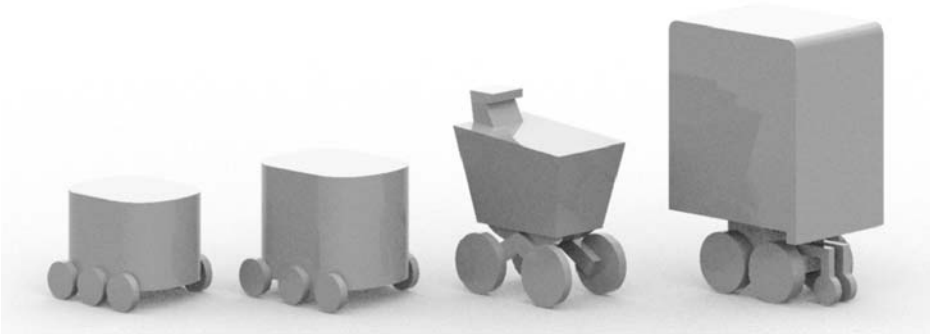

FIGURE 16.1 These are four of many pathway delivery robots in small-scale commercial use today. These range from 68 to 91 cm (length), 53−71 cm (width), 55−147 cm (height, without a flag), 33−136 kg (gross weight), and 5−24 km/h (max speed) [1]. Yet larger and faster delivery robots are planned for roadway use. Ambulatory robots are being developed to handle stairs. This is barely beginning. *Illustration commissioned by one of the authors.*

robots that will use pathways, footways, and active transport lanes (see Section 16.3.6).

- Section 4 describes one of the potential applications of this standard.

16.2 Delivery robot technology will out-disrupt the passenger robotaxi

Despite a decade and a half of investment, promotion, and anticipation about the coming of driverless taxis and shuttles, delivery robots will arrive sooner and in greater numbers than will robotaxis. These machines are essentially small containers on four or six wheels that use pathways such as footways, bikeways, crosswalks, or carriageway shoulders to move over modest distances (1−3 km), currently overseen by a human teleoperator (nonline of sight radio control) who can intervene if needed. These machines usually carry food or small express packages. The promise of their widespread deployment in driverless fleet operations is much closer to reality than is wide availability of passenger robotaxis. This is important because most cities are even less well prepared for robotic pathway systems than they are for driverless passenger vehicles on roadways.

There are a number of reasons tele-monitored delivery devices will become pervasive before driverless passenger vehicles. The barriers to deployment of delivery robot are far lower than they are for the robotaxi. Likewise, the accelerators driving development of delivery robots are more accessible to innovators, investors, and other participants. Several of these accelerators follow.

16.2.1 The safety barrier for delivery robots is much lower than for robotaxis

Delivery robots come in a variety of sizes and configurations. Smaller units for single deliveries are the size of a filing box and weigh less than 50 kg fully loaded. One of the most popular models, Starship, is a small cube less than 0.25 m. The top speed of these smaller robots is usually constrained to about 6 km/h, a hurried walk. Small and slow, they can stop quickly. Larger delivery robots—half the size and weight of a passenger sedan and perhaps traveling at 40 km/h—present greater safety challenges.

Considering only momentum, delivery robots pose less of a crash hazard than would a sedan-sized robotaxi. Because they carry only cargo, there would be no risk to human passengers. This, however, may not be entirely positive, as it could potentially affect unintended risk to pedestrians posed by algorithms that do not weigh passenger risk in their computations.

Like robotaxis, delivery robots are designed not to hit anything. If one of the smaller robots were to hit an adult human, it is far less likely the collision would be life-threatening. One exception to this is that a robot could precipitate a fatality in the same way that a pet running into the street might cause a vehicle to swerve and lose control. Or if a robot were struck by a bicycle, the cyclist could be seriously injured—or worse. Pedestrian-involved crashes with smaller, slower robots would be far less dangerous than crashes involving sedan-sized vehicles that may weigh 1400 kg and can travel at speeds exceeding 60 km/h.

The sheer variety of delivery robots presents challenges for protecting pedestrians and cyclists, and any regulations will need to account for a wide range of considerations. For example, smaller robots might best be kept off the roadway except when crossing at intersections, and the larger robots may need to be banned from pedestrian footways. While it is far too early to predict how this will play out, as of early 2021, approximately 20 US states have tabled legislation regarding Personal Delivery Devices (pathway delivery robots). At least 12 of these had been passed meaning there are already a number of somewhat variable regulations in place in that country [2].

16.2.2 The fear barrier for delivery robots is much lower than for robotaxis

According to the American Automobile Association, over half of people recently surveyed express fear of driverless vehicles [3]. This fear makes both makers and regulators sensibly conservative about removing the vehicle's safety driver. Notice that in all of the thousands of videos where a driverless-taxi safety driver is absent, the weather is especially clear, the roads are in excellent repair, and traffic is notably light.

Consumers may accept that the company using a delivery robot to deliver a meal or small package might delay for safety reasons until a downpour lets up or until a pathway is cleared of snow. They might not accept that from a passenger vehicle when they are late for an appointment. Fear of harm from crashes creates a much greater barrier for robotaxi acceptance and governance than it does for delivery robots.

16.2.3 Concerns for job loss from delivery robots are lower

Setting aside projections of driver shortages and arguments promoting "career retraining"—which are often not accepted by the people so employed—many workers and their families feel threatened by automation. In many cases, unions and associations can create effective, if limited, barriers to the deployment of larger, automated vehicles for passengers and goods.

Last-mile delivery—especially in the meal sector—generally provides temporary, part-time, or second jobs and employment for youths and gig workers. There are fewer coherent voices to speak out against automation of these jobs, implying that the union, social, and employment-equity barriers to the diffusion of pathway robots would be much lower than that for robotaxis.

16.2.4 Delivery robots will have fewer enemies and more friends than robotaxis

Standing against the robotaxi will be interests such as transit and taxi drivers and their agents and unions. Pushing against the delivery robot will be advocates for pedestrians, accessibility, and gig workers. These latter groups will have weaker voices than those potentially arrayed against the robotaxi.[2]

The delivery robot has the pedestrian pathway as a new space to exploit, and the exploiters of that space such as merchants, Amazon and FedEx, will have more power than any advocacy group that might wish to constrain the spread of these machines. The commercial weight of consumers demanding fast, cheap delivery that saves a trip to a shop or restaurant might outweigh pedestrian advocacy against the robots.

Until now, the footway has not been seen as a locus of employment as has been the case for the roadway and its kerbside. No municipality has monetized the footway as an entranceway or pathway to businesses as some have done with kerb parking. The footway has fewer powerful stakeholders as enemies of automation compared to the roadway, although it is possible that the coronavirus may have changed that.

16.2.5 Development and deployment costs for delivery robots is far lower

The investment required to build and prove delivery robots is far lower than that required to build and prove driverless passenger vehicles. The cost differential for a single robotaxi compared to a single delivery robot is currently in excess of an order of magnitude, exclusive of deployment and operations. While all these costs can be expected to drop over time, the relative differential will remain.

16.2.6 The regulatory barrier to delivery robot deployment is lower

In most countries, national and state/provincial governments consider regulations for automated passenger vehicles, mostly from a safety perspective. Regulations for robotaxi fleet deployment—which address issues that are quite different from matters of safety—generally receive little attention. To date, regulations for pathway robots appear to receive even less attention, although this may begin to change.

Pathway robots are generally seen as a municipal matter and that leads, as it did for ride-hailing and e-scooters, to regulatory outcomes that vary city by city. It is difficult to imagine this will not continue as the default. For that reason, opportunistic start-ups, which are currently a major source of innovation for pathway robots, will quickly target cities seeking smart-thinking reputations. These cities may turn a forgiving eye to the efforts of start-ups and innovators or even invite them to trial their devices in their municipalities.

Any laissez-faire attitude regarding regulations for pathway robots will shift rapidly once companies such as Amazon and FedEx deploy delivery robots monitored remotely by unseen human operators. The push to deploy, even at a modest scale, is likely to grow in response to congestion and environmental concerns driven by the demands of e-commerce. This will ensure closer attention from regulators.

16.2.7 The travel environment for pathway robots is a more complex

A robotaxi is often framed as "just a taxi with a silicon driver," and we are often told these machines will use the same roads and the same parking spaces as human-operated

2. This point is one of economic bias rather than social justice suasion.

vehicles. This is generally expected to apply to automated goods-delivery vans, as well. While this assumption is only partially true, it is true that the physical infrastructure for road vehicles is already well developed. We will need to address automated loading and unloading rules (see Section 16.3.5), but we should expect to build very little new infrastructure if the technology is delivered as has been promised.

While this last point remains to be seen, the relative comparison with small pathway robots is germane. While delivery robots are expected to operate on existing infrastructure, there is a critical difference in that the rules governing the configuration, condition and certification of pedestrian clearways, and the systems to manage and broadcast information about any construction or changes thereon are neither as consistent nor as frequently complied with as they are for roadways.

Pathway robots will have to run a gauntlet of human legs, barking dogs, baby strollers, planter boxes, sandwich boards, tree roots, and uneven pavement—a much more disorderly environment than the more highly regulated roadway where robotaxis will operate.

Cities will have many more undigitized and nonconforming footways than they will have such streets. This constitutes a relative, but important barrier for operating delivery robots that exceeds that for robotaxis. This will need consideration in order to manage the arrival of these robots (see Section 16.3.7).

16.2.8 Psychotechnical barriers around full autonomy favor delivery robots

There is now a widespread understanding that the SAE Level 5, Fully Automated[3] vehicle has been overpromised by marketers, exaggerated by mass media, and misunderstood in the popular imagination. An object of engineering aspiration and popular fantasy, we are finally coming to understand what Professor Steven Shladover meant when he told us that the last stages of readiness for automated road vehicles—vehicles that can handle every driveable circumstance and mix with existing nonautomated vehicles on our roadways—are very difficult [5]. We see that while some robotaxis have begun to operate without a safety driver, they have so far been limited to operating design domains (ODD) where the road environment is relatively well organized, enjoys mild weather, and has low levels of traffic congestion.

Fear and negative perceptions evoked by fully autonomous vehicles create a significant barrier for widespread adoption of the robotaxi. Without full autonomy, fleets of these vehicles necessarily have limited operating domains, constraining their applicability, and reducing their profit potential. The delivery robot, also not fully autonomous, does not suffer to the same extent.

Robotaxis, with the recent exception of a minuscule number of driverless vehicles, require safety drivers in the vehicle who may intervene increasingly less frequently as these machines improve. Delivery robots also require the oversight of teleoperators, but these may be nonline of sight, situated several kilometers distant, with one person operating multiple robots at once.

As pathway robot technology improves, the number of robots that a single teleoperator manages will increase. With intelligent, collaborative, multiuser teleoperation systems, the ratio of machines to humans—now perhaps two or three per teleoperator in the more advanced instances—will reach 5 or 10 to 1 and eventually many more. In cities that are suitable and prepared, delivery robots will be able to diffuse sooner, in more places, and scale up much faster than will robotaxis.

The likely outcome is that none of these technologies will achieve *full* autonomy except in YouTube videos—humans will always be somehow in the loop. For this reason, delivery robots are better suited than robotaxis to overcome the constraints of working in environments with noninvolved humans and be able to operate effectively in a variety of settings without being fully autonomous.

16.2.9 Delivery robots evoke fewer perceived privacy issues

Will robotaxi trips be tracked, recorded, and remembered? Will data be searched, correlated, and sold? Will private conversations be recorded and passengers filmed? The capability to track, record, and film may be considered necessary to provide safe passage without a driver overseeing every part of the trip, but how can passengers know their data is secure and protected? Will it be destroyed at the earliest appropriate moment?

Similar questions can be asked of the purchases that are delivered by a robot. But that has not stopped e-commerce of all forms from growing dramatically. The greatest fear most people express about e-commerce is the fear of entering credit card information online—and that is a concern for property or financial security as opposed to personal privacy. The concern for privacy about what one eats, wears, or reads seems less significant than the concern for having one's trip behavior tracked, modeled, and sold. We do not need to debate the credibility or utility of these relative concerns. Differential perception is all that needs to be acknowledged.

3. The SAE "levels" of automation [4] span from 0 (no automation) to 5 (full automation). Level 4 (high automation) is generally thought to be suitable as a robotaxi, a vehicle that can be driverless in a defined area known as its "operational design domain." A pathway robot that requires a responsible teleoperator would be at SAE level 2 (partial automation) or level 3 (conditional automation).

16.2.10 Delivery robots gives rise to fewer perceived security issues

While imperfectly understood and still unexperienced, robotaxi security issues are clearly imaginable: vehicle hijack, passenger molestation, robbery, rape, or worse. If something is lost in the vehicle, will it be recoverable? Would parents be able to entrust the safety of young family members to a trip in one of these vehicles?

These concerns apply far less to the delivery of a pizza or a bag of vegetables in a robotic grocery cart. This means fewer, if any, psychological barriers to consumer acceptance of delivery robots compared to robotaxis depending on the demographic context of their deployment.

But there is a security concern that would more likely apply to delivery robots than to robotaxis. We might fear that a swarm of such robots could be commandeered for purposes of malfeasance. Systems for managing cybersecurity are currently being developed and standardized to address these concerns, but so far these efforts are incomplete, unproven, and unenforced. Worse, much of the current US state legislation permitting these devices provides no cyber guidance. This will need to be addressed for widespread adoption of service robots in public spaces.

16.2.11 The total risk equation for delivery robots is a magnitude lower

The issues above — cost, acceptance, liability, investment, ROI, privacy barriers, security concerns, and regulatory matters—combine to form a total risk picture. Because the payoff for products and services in the passenger transportation sector is projected to scale between US 7−10 trillion dollars annually, there is much more media, investment, and municipal focus on robotaxis and personal driverless vehicles than on delivery robots. But the first phase of automating mobility—using delivery robots for light, last-mile movement of goods—is a clear winner from the perspective of risk.

Governments, typically risk-averse, maintain an appropriately high barrier for driverless passenger vehicles. But small projects for teleoperated delivery robots are easily approved and may sometimes not even require approval, as was the case for one start-up in Toronto in 2019. And such delivery robot projects—given the comparatively little setup required—are far more easily decommissioned than are the more demanding driverless taxi or passenger shuttle trials.

16.2.12 The risk of nonreadiness to cities and towns

The greatest immediate risk facing cities is to ignore pathway robot technology until it is upon them. For cities that fail to prepare appropriately, the likelihood of repeating the chaotic introduction of ride hailing and e-scooters is high—and the likelihood of getting off easy this time is far lower.

Before these machines are available in volume, there are many aspects municipalities and retail communities (see Section 16.4) might consider in advance. In alphabetical order, some of these are:

- Business district opportunities
- Environmental goals
- Infrastructure readiness
- Licensing of fleets; registration of robots
- Pathway accessibility (i.e., relative to current legislation)
- Pathway maintenance (good order)
- Pathway pricing (similar to road or parking pricing)
- Safety
- Traffic goals

16.3 An international standard to manage pathway robots

The arrival of automated vehicle fleets in public urban spaces mixed with human-operated vehicles and pedestrians such as at the kerbside and on public pathways requires an overhaul of how public authorities operate and monetize these spaces. This challenge will involve increased digitalization, new communication technologies for operation and coordination, and highly coordinated collaborations between governing bodies and system providers.

16.3.1 ISO 4448

ISO Draft Technical Standard 4448: "Ground-based automated mobility systems" [6] is being prepared to create the requisite definitions for operating data and procedures that can impact ground-traffic management[4] and inform relevant vehicle operators, system makers, insurers, as well as community standards.

> ***Disclaimer***: *ISO 4448 is in an early draft state as of this writing. As a technical standard, 4448 will comprise data and procedural definitions covering critical elements of operations, security, and machine behaviors for automated passenger vehicles and service robots in public spaces shared with humans whether or not involved with the machines. The content of this section should be read as an*

4. The standard addresses loading and unloading at the kerbside as well as pathway reservation relative to service robots. It does not address machine control which is presumed to be with the vehicle operator and/or its software.

informal outline and implying no obligation on the part of the ISO to publish this as here described.

ISO 4448 sets out procedures and behavioral rules to make regulating, governing, and operating systems of automated fleets a coherent regional process. In addition to addressing automated data and procedures for loading and unloading goods and passengers, it provides the common data and procedures that would enable a robot *pathway reservation system* (PRS, see Section 16.3.6.5 in this chapter) and the monetization of its use for commercial purposes.

While the data and procedures within a PRS would be expressed using common definitions and forms, the local jurisdiction would set appropriate local behavioral constraints. An analogy is posted speed limits for automobiles—such signs use common sizes, shapes, and colors, as well as agreed metric units, but a local jurisdiction usually decides posted speeds. In an environment of digitalized, automated machines such as robotaxis and especially pathway robots, information is provided using telecommunications rather than analog signs. ISO 4448 is designed to enable:

- Makers to develop robots and their communication systems that can operate in multivendor environments,
- Planners to design deployments,
- Local jurisdictions to ensure appropriate infrastructure and governance guidelines,
- Insurance companies to provide coverage, and
- Transportation and logistics operators to proceed safety and profitably.

This section provides a preview of the draft, its intention, scope, and its critical components as currently configured.

16.3.2 The context for a standard for ground-based automated mobility

It is anticipated that in the very near future, many more urban and suburban jurisdictions will consider preparations for robotic cars, taxis, and trucks and other forms of robotic vehicles to move passengers and goods. At the same time and in the same places, service robots may be deployed for maintenance activities such as snow removal, trash pickup, sweeping, or surveillance. The location for these services will be in public spaces in towns and cities where kerb and pathway space are already under increasing pressure for access by a growing variety of uses, innovations, devices, businesses, and services.

Over the past decade, digitalization of mobility and commerce has brought rapid growth in new forms of taxi-class operations loading and unloading passengers at city kerbs as well as a dramatic rise in goods delivery from e-commerce systems. In some areas of larger cities, this change has been rapid and has already become unsustainable. Some of these are being addressed on a local and urgent basis often without consideration of future change, growth, or innovation. In addition, the rise in active transportation has added cycling, scooter, and e-bike lanes at the kerbside in many cities, as well as storage for these vehicles at the edge of the footway [7].

Since early 2020, the onset of the COVID-19 pandemic imposed yet more demands on these kerbside and footway spaces, including social distancing, an uptick in micromobility, and in some cases increased demand for outdoor dining space. This tended to create wider nonautomotive rights of way to accommodate the new demand. Additional width invites more variety and creates an even greater need for access management as social distancing continues, micromobility grows, walkability demand increases, and the need for cleaning, maintenance, and snow removal for these expanded and complex places grows.

To this mix, we expect to add the delivery of passengers and goods using driverless vehicles that load and unload at the kerb. And, as described above, we expect to add last-mile delivery of goods via pathway robots. Indeed, prior to 2020, such systems were already operating on a commercial basis, and they continue to do so.

All of this implies further increases in traffic volumes both at our kerbsides and our pathways. The introduction of automated vehicles without human accompaniment will necessitate highly automated (digitalized) management. Taken together this will change the nature of the interactions among these vehicles and their control systems—with each other, with the kerb, with payment systems, with active human mobility, and with our existing manual vehicles and devices.

The traffic and parking rules cities have relied on prior to 2020 represent governance that is already under stress, and their design and governance shortcomings have been made increasingly evident by the pandemic. Parking systems developed to date [7] are insufficient to support the loading and unloading of the anticipated automatic vehicle systems without additional data and procedures to support ground-traffic management systems.

Cities will need new operating guidelines as kerbsides and pedestrian spaces are joined by automated taxis and robots that arrive, stop, park, wait, and load under sensor, effector, and software control. Unaccompanied by human passengers or attendants, these machines will need to be prioritized, scheduled, queued, bumped, and placed in holding patterns, and all without blocking crosswalks, bicycle lanes, micromobility users, no-stopping areas, or transit stops that are common infractions by taxi and goods-delivery vehicles today. This must be done safely, mixed with human-operated vehicles, without inconveniencing active transportation users, pedestrian traffic, and those with accessibility challenges.

16.3.3 Five intentions for standardizing kerbside and pathway automation

Planning for the ISO draft technical standard 4448 was guided by several intentions for its use. These intentions span, safety and conflict avoidance, infrastructure planning, commercial use and activities, operational management, and legal, liability, and insurance matters.

16.3.3.1 Safety and conflict avoidance

As the number and variety of automated and nonautomated mobility vehicles and devices increase, so too does the potential for spatial and navigational conflicts involving vehicles arriving, stopping, parking, waiting, loading, passing, crossing, and overtaking. Spatial conflicts are already very common and cumbersome at many kerbsides and pathways. Machines that operate at kerbsides and on pathways must interact with each other and with human-operated vehicles and will be expected to operate without on-board human operators or even proximate human control and potentially without the spot- or lane-markings that often guide on-street vehicles. This requires a set of agreed-upon and tightly communicated behaviors and guidelines for real-time resolution. These guidelines require terminology, procedures, communications, and systems.

16.3.3.2 Planning

Projects to reformat and reorganize streets, kerbsides, or pathways will need to build and shape these spaces to be workable for vehicles and devices whose operating characteristics may be different, or differently constrained, than those vehicles and devices under human operational control. Such planning activities need guidelines and those guidelines need common data and systems. They will also need more detailed metrics and design parameter descriptions as more such spaces are prepared for automation.

16.3.3.3 Commercial

Some kerbsides and pathways can be expected to be used more heavily by commercial vehicles (taxis, shuttles, trucks, footway service robots, etc.), each with various automated capabilities. The use of automated (driverless) machines for loading and unloading passengers and goods requires forward planning for logistics. Such forward planning will need reservation systems updated in real time. The design and execution of such reservation systems require shared terminology, procedures, communications, and systems since we can expect multiple vehicle types, providers, and operators.

16.3.3.4 Operations

The kerbside and pathway comprise the spatial context for people who reside or trade in the buildings at or near such kerbsides or footways. People and goods that arrive or depart with the help of vehicles and devices, automated or not, expect to be able to arrive and depart in a timely manner without finding a pathway or loading facility blocked and without unexpected long waits. These spaces need to be managed in a reasonably smooth and coordinated fashion. This requires shared communications and systems.

16.3.3.5 Legal, liability, and insurance

Any kerbside or pathway is a public space shared by many types of users including local residents, vendors, visitors, and shoppers, whether able-bodied or not. Any conflict that causes injury, financial loss, or other harm or perceived harm may be subject to legal or claim action. Hence a common understanding and description for these spaces and the expected machine behaviors in those spaces are necessary to assign or determine liability. This shared understanding and description require common data, procedures, and system definitions.

16.3.4 Standard components

ISO DTS 4448 defines the data and communication systems needed to organize, expedite, and safeguard the flow of automated vehicular ground traffic relative to the loading and unloading of goods and passengers and the allocation and movement of service robots for delivery, garbage removal, sweeping, washing, snow removal, repair, food trucks, construction, etc., in public spaces such as kerbsides and pathways as shared with pedestrians and other automated or nonautomated vehicles. Such systems are intended to enable carefully defined and growing areas (operational design domains) of cities to manage any number of vehicles and vehicle varieties operated by any number of operators (public, commercial, private) for these various activities.

The remaining subsections of this chapter section look briefly at critical system components for managing public-system (urban) robotics. These roughly correspond to the current and planned parts of draft technical standard ISO 4448. Since this work is still in early draft stages, this outline may differ from its final form:

1. Robotic road vehicles for passengers or goods
2. Service robots for pathway and other public spaces
   - **a.** Guiding principles for operation of robots in public spaces
   - **b.** Guiding principles for governance of robots in public spaces
   - **c.** Similarities between pathway robots and human accessibility devices
   - **d.** Pathway robot access: surface conditions and path dimensions

  - **e.** Service robot access permissions
  - **f.** Service robot behavior
  - **g.** Service robot social communication
  - **h.** Integrating robotic kerbside and pathway access
  - **i.** Robot cybersecurity
3. Certification for use
  - **a.** Kerbside and pathway certification for automation
  - **b.** Robot weather-worthiness

16.3.5 Robotic road vehicles for passengers or goods

Robotic ground transportation systems for passengers and goods require far more than just automated vehicles. Appropriate locations to load and unload require algorithms for prioritization, reservation, scheduling, and queueing. They also need recovery processes for exceptions that may occur.

An urban area that intends to permit or encourage the use of automated road vehicles will need to intermix a growing number of these complex, interacting and increasingly digitalized (fast, precise) components. As a system to operate among multiple vendors, this will be analogous to an air traffic control for numerous airplanes, flight operators, airports, and runways.

Current systems that match passengers to vehicles are plural, competitive, and disparate. Examples are taxi-dispatch and ride-matching services, which are individually workable, but taken together, suboptimal. We can often observe spatial conflicts for goods movement systems matching shippers to couriers; it is commonplace to see two or more stepvans from competing express delivery operators standing adjacent on the same street each blocking a bicycle lane while delivering just one or two packages each. That is suboptimal from a traffic, environmental, and total delivery-cost perspective.

Local or regional coordination will be required to create collaborative systems that match robotic vehicles with load/unload spaces, such as in publicly shared parking areas at the kerbside. In other words, a single, effective management system is required to coordinate loading/unloading of all passenger and goods vehicles, regardless of the number of taxis, shuttles, or logistics providers operating within a bounded region.

To load/unload passengers requires procedures for vehicles, or their operators, to reserve, queue, and access spaces at the kerbside or other controlled locations—i.e., mapped spots suitable to a passenger's start/end goals. A singular system is required within a given spatial domain to accommodate the complexities of admitting multiple passenger and goods transport operators dynamically sharing a large number of loading/unloading places. This is analogous to a computer operating system managing an arbitrary variety of programs and memory locations.

A system to manage loading/unloading of passengers is primarily concerned with trip terminus events and less with the routes between them. However, traffic flow or congestion along those routes naturally affects the real-time management of terminating events. Uncertainty in trip times will cause rescheduling, requeueing, and complexities of storage for queues, such as "circling the block," double-parking, waiting areas (oversupply of parking areas), or queueing in-motion (a process of having vehicles alter their travel speed to time of their arrival at a spot).

Flattening peak load/unload times would help this queueing process considerably. One way to accomplish this is through the use of variable pricing of loading/unloading privileges. Since a load/unload management system will require computation, IoT devices, oversight, maintenance, and spatial infrastructure for the vehicles, it will need to be funded. The best way to match a transportation system's expense with its management is through variable use pricing that is designed to flatten peaks.

Two critical elements related to both robotic passenger and goods movement are safety and accessibility. Safety considers passengers, pedestrians, as well as nearby vehicles and their passengers. Accessibility concerns are likewise threefold: passengers, nearby pedestrians with accessibility challenges, and the accessibility considerations of nonautomated vehicles and their passengers operating in the same space.

This road vehicle load/unload aspect of the standard needs a small set of data elements describing the location, dimensions, properties, permissions, and availability of load/unload spaces and a matching set of data describing the vehicles requesting those spaces. In addition, a set of rules, procedures, and processes are needed to request, prioritize, match, enqueue, dequeue, and manage the inventory of load/unload spaces. Methods to price loading/unloading activities according to jurisdictional requirements can be added readily since these processes require real-time location, scheduling, and monitoring. Loading/unloading goods has all of the same ground-traffic control issues as does passenger loading and unloading including: requesting, prioritizing, matching, queuing, and inventory (space) management, as well as additional considerations such as size, noise, emissions, and hazardous materials.

While the standard is largely agnostic to whether a ground vehicle is carrying passengers or goods, it admits distinctions so as to permit a jurisdiction to manage goods delivery schedules or locations differently from those of passenger systems. In this way, the standard can support separate loading areas for goods and passengers, dynamic loading areas that admit different vehicle purposes throughout the day, or even variable, on-demand mixing among modes without distinction in spatial allocation. This is done because it is not possible to predict the degree of segregation or mixing among passenger and goods systems.

Indeed, it is possible that passenger vehicles may also transport goods independently, either having the same vehicle perform different duties at different times (serial work assignment) or in parallel work assignments similar to the way that regional bus-passenger or air-passenger systems also transport goods (see Section 16.3.6.8).

16.3.6 Service robots on pedestrian pathways

Robotic vehicles intended for services such as personal deliveries, snow removal, sweeping, surveillance, or other light duties on footways, bike paths, road shoulders, or other urban pathways are a novel urban management problem. For centuries, cities have managed the loading and unloading of road-vehicles on or at the kerbside of roadways. Repurposing current kerbside-management practices for automated road vehicles is relatively straightforward to contemplate. Unfortunately, the ability of most cities has been sorely tested as they have had to manage a combination of high volumes of parked vehicles, dramatic growth in e-commerce, multiple active transportation modes, and now social distancing during the pandemic.

Considering these existing, and growing pressures, the management of even modest numbers of motorized, automated vehicles on pathways will be an even more daunting challenge. Worse, the current design and status of urban footways are already challenging for many pedestrians.

At base, the fundamental last-mile logistical concerns for automated vehicles at the kerbside and on pathways are analogous: match and schedule vehicles to use identified spaces. At the kerbside, spaces are loading or parking spots. For the pathway, the space is a city block-face or a segment of footway between two intersections or points.

But there are also critical differences. At the kerbside, vehicles queue while in motion to become stationary in order to load/unload. On the footway, crosswalk, or bike lane service robots queue to operate (move, navigate, work, and wait) in ways that are mixed with pedestrians of all abilities or active-mode users such as cyclists or scooterists. Pedestrians occupying this space walk pets, carry packages, push, drag, or ride in wheeled devices, chairs, scooters, or boards. They travel in small groups, meander slowly, stand in clusters such as at intersections or transit stops, and they window-shop, line-up, run, dash-across, or weave from one side of the pedestrian clearway to the other. Such normal pedestrian behaviors are at risk of becoming less safe or more difficult due to the presence and movement of robots among these existing activities.

Depending on the prevailing view of the governance of public space (more below), such pedestrian behaviors may be protected or curtailed by the introduction of service robots. The standard described here is agnostic to governance style or theory; it is designed to formalize communication and operation of any intended governance style. The next three subsections outline operational, governance, and accessibility principles for pathway robots.

16.3.6.1 Guiding principles for operation of robots in public spaces

To guide the development of a formal standard for robot behavior, a series of guiding principles are used. They are as follows:

1. Robots should grant **rights of way** to humans in close proximity, but rules of engagement may consider how to prevent a robot from being immobilized for an extended period in crowded circumstances. There may be explicit exceptions in the case of service robots as actors in emergency (police, fire, ambulance, evacuation) contexts.
2. Robots must be deployed to respect the cultural and contextual, interpedestrian distance normally observed when walking or standing in a public place, known as **shy distance**. This may be extended to **social distance** in the event that robots are identified as a disease vector.
3. Robots must **not harm or alarm** humans or animals on the pathway.
4. Robots must be **apparent** (visible and/or audible) to all humans on the pathway (flags, lights, sounds, gestures). This is not only to accommodate people who may have visual or auditory challenges but to avoid mishaps with distracted pedestrians. This is related to not harming, confusing, or alarming humans.
5. Robots must **signal** their presence, priority, and certain properties to other machines. This enables rights-of-way decisions and can help differentiate autonomous mobility devices from human-operated devices, humans, and nonmobility entities.
6. Robots must not diminish the **privacy** of humans or businesses using or residing near pathways. This implies constraints on the recording and retention of data.
7. Robots must not diminish the **security** of humans, businesses, or other machines on the pathway. This is also in regard to the security of humans residing and trading near such pathways. This includes both cyber and physical security.
8. Robot infrastructure must not be **intrusive**. Robots may be guided by localized infrastructure, high-resolution mapping, and other data or technologies, but any additional infrastructure cannot negatively affect (make more cluttered, riskier, more confusing, or less accessible) the use of this shared space by humans.
9. Robot **occupancy** within a defined area must be controllable to prevent unacceptable congestion on public pathways.
10. Robot **waiting and stand-aside** behaviors must not create obstacles for pedestrians. This impacts how robots may position themselves when pedestrians pass, wait at intersections, or travel at the edge of a pathway.

16.3.6.2 *Guiding principles for governance of robots in public spaces*

Kristen Thomasen outlines three views of public space that might guide a regulator of pathway robots: Communal Public Square, Regulated and Orderly Public Square, or State-Owned Property [8]. Depending on how these views influence relevant regulations, robots would be governed locally in more or less restricted ways.

An international standard, to the degree possible, must be agnostic to disparate legal theories. The primary goal of standardization is its role in equipment and system design, operation, as well as process design and certification. However, since the machines, systems, and processes being standardized operate in public spaces, in large numbers, for many purposes, and among many pedestrians, the deployment of a standard must necessarily impact, and be impacted by, jurisdictional governance in fact rather than in style.

Hence, it is critical to ensure necessary and sufficient operating data and procedures so that the respective sociolegal preferences can be supported in any country, state, or city by way of constructions that allow legislators to adapt the standard to their governance needs and be able to communicate relevant rules to makers, operators of automated devices, and their users (shippers, carriers, and receivers). Correspondingly, makers and operators of robots can anticipate and comply with the resultant rules.

In the simplest view of safe personal space for pedestrians, a clear space in the direction of travel must be open in order for a robot to proceed. The proximate, real-time issue resolves to whether the size and comfort of that clear space are such that pedestrians are not made worse off in terms of access, safety, convenience, or peaceful enjoyment of that public space.

Rules requiring robots to yield right of way and respect shy distance imply an optimal, clear space in this immediate real-time sense, but such rules do not prevent robots from entering a dynamic space that could, after a short period, develop into a circumstance that inconveniences or delays pedestrians or adds to pedestrian congestion potentially made worse as a consequence of the presence of the robot(s).

Robot navigational rules that operate by opportunistically moving into clear spaces as they open up (greedy algorithms) are essentially how humans navigate on busy pathways and cars operate in traffic. If such was the only local-decision approach employed by robots, then as these machines become more capable, nimble, and numerous, human pedestrians—especially those who are older or less nimble—would become increasingly disadvantaged as robots are technically enabled to dart opportunistically wherever possible. Average human skill as a pedestrian is unlikely to improve, especially as populations age. But over the next decade, robot skill will improve dramatically. In unregulated, congested circumstances, this could become deleterious to human comfort and rights of way.

Several instances of current US state legislation that have been enacted since 2017 indicate that robots (called personal delivery devices in these documents) must always give way to pedestrians [2]. This behavioral constraint is necessary but insufficient in the case of the use of greedy spatial algorithms.

For this reason, the standard provides data and procedures to regulate the ingress of robots to a block-face or pathway segment in real time so that their occupancy (count) at any one time can be limited. This reduces, but does not eliminate, the effect of greedy spatial and navigation algorithms.

Related to this, it is possible for a robot that must always give way to pedestrians and to maintain a shy distance to find itself temporarily constrained for unexpected or unintended periods of time especially in congested foot traffic ("robot trap"). Naturally, operators of such robots would like to avoid such circumstances, but this may not be possible on every occasion. It is likely that a logistics operator may not, or may not even be permitted, to know the travel plans of the robots of another operator. This is another reason to consider occupancy-count control according to pathway configurations and times of day so as to minimize the likelihood of such events and minimize robot extraction time when one does occur.

As robots become smarter, we can imagine that they might acquire, through machine learning, more foresight to further reduce the probability of being trapped among pedestrians or other robots. In the meantime, the standard provides a way to minimize the likelihood of this occurrence and provides a level of governance that acknowledges local contexts so that occupancy limits may act locally and dynamically.

16.3.6.3 *Similarities between pathway robots and human accessibility devices*

There are a number of useful comparisons between wheeled pathway robots and pedestrian accessibility devices such as wheelchairs or assistive scooters. As a vehicle, the wheeled (nonambulatory) pathway robot has characteristics similar to a wheelchair—it can easily travel faster or slower than the average human (walking) pedestrian, and it confronts issues of traversing uneven, damaged, steep, sloped, or potholed pavement, and ramps (kerb cuts). It cannot readily step aside as an ambulatory, abled pedestrian normally can, and it cannot streamline its width by turning sideways while walking as most pedestrians can. Basically, the wheeled pathway robot exhibits many of the rigid physical and motion characteristics of a pedestrian wheelchair. Depending on wheel diameter, number of wheels, and their suspension system, a robot may have somewhat different constraints compared to a wheelchair.

As a machine, the mobile service robot might be relegated fewer social rights or diminished rights of way compared to a pedestrian. Conversely, it may be an actor in an entitled social role, i.e., it may be performing a service critical to someone with special social rights. Perhaps some specially marked robots might inherit those rights in the way that a registered service dog inherits certain social rights of way from the human it is helping. Such a robot may be unable to cross certain path elements that an able-bodied pedestrian can readily traverse, it may be subject to vandalism or mischief in ways that are different or more frequent than those confronting a wheelchair user, or it might have a very much lower height profile compared to a wheelchair user, making it less apparent to pedestrians who are a short distance away, unless specially equipped in some way (flag, lights, sound, or beacon).

As an automated machine, the pathway robot would have no onboard or proximate human to provide or receive social signals. It may be programmed to send and receive social or directional signals and to exhibit more patience than does the average human. As a semiautomated machine, it might be teleoperated, but the ability of a teleoperator to engage in social signaling would likely be limited. An example of this might be a teleoperated micromobility device such as a self-standing e-scooter being guided back to a docking station. The eventual introduction of ambulatory robots will add still other considerations, relieving some constraints and adding others.

These three comparisons suggest that a standard for pathway robots should consider alignment with existing accessibility standards relative to wheelchair use. Such goal-congruent alignment provides opportunities to address pathway design and configuration to intentionally benefit accessibility goals while standardizing robot access and flow.

16.3.6.4 Service robot access: surface conditions and path dimensions

A ground-based robot is designed to effectively and safely operate with respect to a given set of surface conditions. Because a standard for mobile service robots cannot anticipate all possible robot designs in terms of weight, wheel diameter, wheel design, leggedness, or other physical properties related to roadworthiness, the standard defines a way to describe the surface properties of a pathway such that a logistics operator can make a decision—likely automated—regarding the relative roadworthiness of a vehicle to travel on a particular surface.

There are many aspects to surface condition and path dimensions that make up a particular set of conditions. These may be built, transient, temporary, or environmental, such as pavement width, garbage bins, construction, or ice, respectively. The standard specifies metrics such as roughness, firmness, stability, friction, and several other elements related to surface attributes. It also specifies metrics such as path width, height, and gradient, which taken together with several others form the basis of a navigability or accessibility calculation to be used for real-time routing and logistics decisions. Separate aspects of the standard address climate and weather features below.

Many of these metrics and their defaults have been gleaned from accessibility manuals related to wheelchair use. That the standard is drafted this way means it is biased for robots that are similar in configuration and dimensionality to commonly specified wheelchairs. This implies that any infrastructural preparation for automated vehicles on pedestrian pathways could easily benefit accessibility users at the same time. It is currently the case that very many pathways in our cities do not fully comply with the accessibility guidelines of their respective jurisdictions.

Nonetheless, the standard sets the information needed to perform a standardized accessibility calculation for machines with specific attributes known to their operator. It is the governing jurisdiction that sets and certifies pedestrian zones for accessibility by either humans or machines. The point of using the same metrics and parameters is to ensure that a designer of a shared pedestrian–robot space can be guided *by default* to address human accessibility certification at the same time.

16.3.6.5 Service robot access permissions

Access permissions differ from access conditions. In the case of access conditions, above, a jurisdiction is declaring information about the pathway, the majority of which is likely to be static. In the case of access permissions, the jurisdiction is expecting conformance from a robot for a particular task, time, and circumstance. Based on the dynamic nature of public mobility spaces, the description of this conformance can change in near realtime.

A governing jurisdiction may constrain access by restrictions regarding weight, width, height, length, noise, emissions, and schedule. It might stipulate requirements such as lights, sounds, flags, and registration ID display. A three-way match enables the assignment between the robot and its route among pathways within its operating domain:

1. The conditions a pathway offers including then-current pathway-occupancy constraints or weather conditions
2. What a robot declares about its physical properties
3. What a logistics operator requests to fulfill a delivery requirement, such as origin, destination, size, weight, and schedule

Access permissions would be affected by the purpose of each service robot. The route plan and permissions for a delivery robot would be very different from that for a snowplough robot. For this reason, a *pathway reservation system* (PRS) managing information about conditions, dimensions, and permissions would be required to offer real-time management in public spaces hosting the work of robots performing a variety of tasks from a multiplicity of robot fleets from a plurality of operators and designs. Such a PRS would grant trip permissions, or a *trip contract*, which in turn would require real-time monitoring.

Such traffic control systems have been developed to manage multivendor robot fleets on many shop and warehouse floors. Mass Robotics in Boston is in the process of standardizing such systems [9]. Another is under development in Israel for multifleet aerial drones [10].

The key operating problem faced by each of shop floor, air space, and public pathway is multivendor, proprietary designs of multiple fleets of robots sharing a common space safely and optimally. But there are also crucial differences among these three operating spaces:

1. The shop floor is an exclusive space shared with humans trained to work with these machines. These robots share a job purpose with these humans and with each other.
2. Airspace is 3D. Robots (drones) must manage a unique set of risks and complexities operating in a constrained space above cities among buildings and other infrastructure. This space may only seldom be shared with humans, but it is still complex and dynamic.
3. The urban pathway, established as a human mobility space over 11,000 years ago, is shared with humans of every age and ability, the majority of whom may move in hard-to-predict ways and have no involvement with the mission of any particular robot.

Today ground-based (pathway) robots are either used in experimental trials or controlled by dedicated human operators within a constrained, single-provider operating domain, while tele-monitoring route conditions via onboard cameras. That is, as of this writing, such pathway robot fleet operators deploy a small fleet of identical machines within a small geo-domain of a few square kilometers shared with no other competitive robot operator.

We can expect to soon reach a plurality of fleets, operators, and service purposes. When that happens, intensive human teleoperation will become untenable except for emergency oversight and resolution. Fully digitalized real-time schedule and flow coordination will be required. This will likely come from ground control systems such as a PRS and include distributed sensors and IoT networks.

16.3.6.6 Service robot behavior

Once a robot's route is determined and granted, the device may be expected to behave in particular ways. Such rules would most likely be mediated by software within the machine as governed by local settings and limits. These behaviors include speed, travel side, travel direction, shy distance, schedule, and several aspects regarding waiting, rights of way, and clustering. As an example, Fig. 16.2 illustrates some rules that might apply to robots queueing at an intersection. These behaviors comprise what are essentially "rules of the road" for service robots in public, shared places/spaces. In this regard, the standard could inform many of the elements of a jurisdiction's "robot traffic act."

Importantly, there would be a need for local and variable changes to settings and limits—perhaps delivery speed or street-sweeper access changes by time of day or current block-face traffic. These changes need to be reliably communicated to the machines in near real time, and to be effective, they must be ensured or enforced.

16.3.6.7 Service robot social communication

Some of the special aspects under development for the standard are uniform movement indicators and social communications. Because pedestrian traffic can be more chaotic than motor vehicles in traffic lanes, robots will need a bounded and precise vocabulary of lights and sounds.

Simple examples would be to signal a turn or to grant a right of way. Other examples include signals for apology, request, gratitude, and alarm to act as a machine replacement for the glances, gestures, vocalizations, and body language that pedestrians use now. These are being designed for the safety of both pedestrians and the robots and to increase the social acceptability of these robots.

Robots need to signal their intentions and moods in language- and culture-independent ways. Such signals will be matched triplets (lights, sounds, and radio signals) so as to be understood by pedestrians with auditory or visual challenges, as well as by proximate robots.

16.3.6.8 Integrating robotic kerbside and pathway access

One of the projected use cases for robotic goods delivery is a larger delivery van ("mother-ship") stopping at a kerb or other suitable location proximate to several deliveries, and releasing one or more "child-robots" to complete local deliveries.

To make this workable, a degree of coordination is needed between the load/unload reservation for the parent delivery van and the reservation (permission) needed by its child robot(s) to travel on the intended pathway(s). This is provided in the draft standard. Such an operational real-time coordination between kerbside and pathway is new and will be a mapping and data challenge for those larger cities for whom these domains are currently handled by separate city departments.

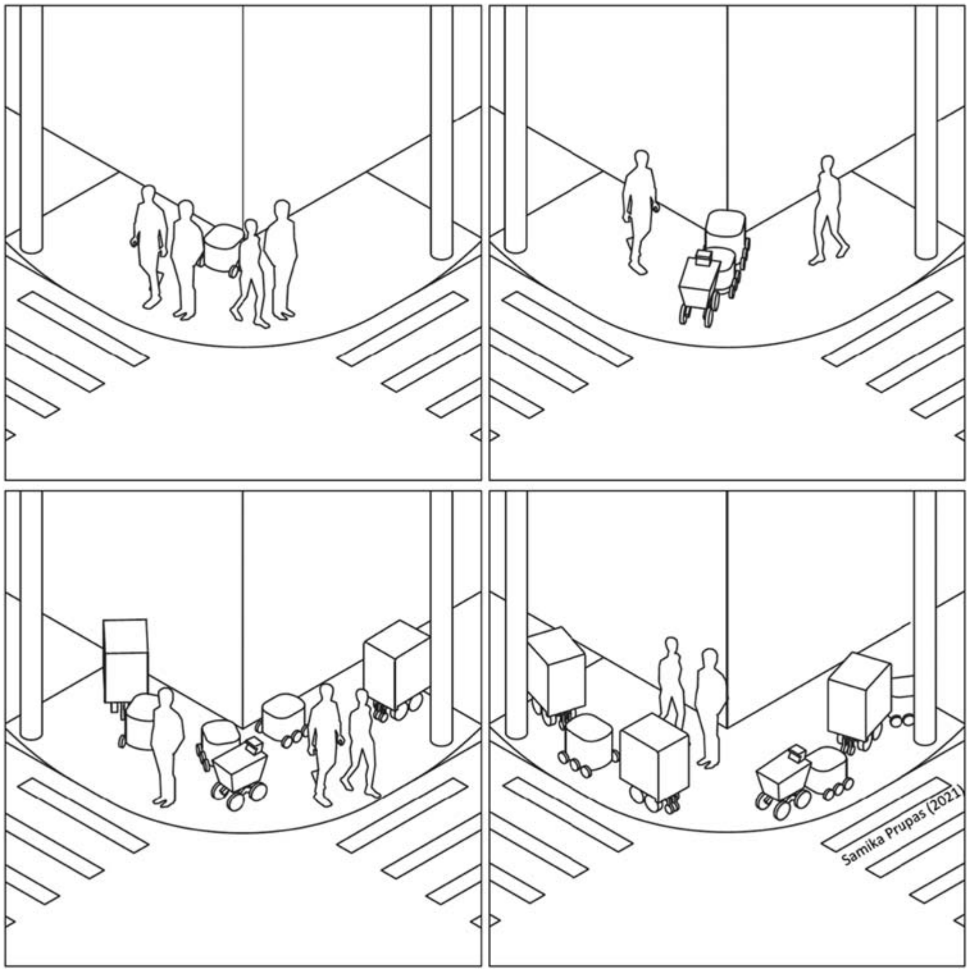

FIGURE 16.2 What rules should apply to robots at an intersection? ISO 4448 permits the managing jurisdiction to limit the number, to indicate shy distancing and where to wait. Still the jurisdiction must set these rules, as would differ from one city to another and possibly from one type of intersection to another. *Illustration commissioned by an author.*

16.3.6.9 Robot cybersecurity

The standard provides requirements and guidelines for secure application services data interfaces between vehicles and infrastructure. These are based on existing credentialing standards in ISO 21177 and ISO 5616.

16.3.7 Certification for use: kerbside and pathway certification for automation

A critical aspect of preparing for automated vehicles at the kerbside or pathway is to determine the readiness of a specific subset of such infrastructure or operating domain. This question can be asked in two ways: "Can a jurisdiction safely provide permission to deploy a described type of automated taxi or service robot at a particular kerbside or pathway?" or "What preparations must be made in order to safely attract deployment of a certain type of automated vehicle or service robot at this particular kerbside or pathway?"

Whether a jurisdiction is asked to permit these vehicles and devices or whether it, or a community association, seeks to attract them, a *gap analysis* is required based on a standardized readiness model. This involves considering multiple system and governance attributes for several classes of vehicle capabilities. Here are a few examples from a much longer list:

1. What must be done to ensure robotaxis are not loading or unloading in traffic or on bicycle lanes?
2. What human-readable signage is appropriate for a given level of automation to be permitted (or encouraged)?
3. What regulations should be in place for teleoperated robots? For fully autonomous devices?
4. What sounds, lights, signals, or markings should be regulated for these vehicles or devices to ensure compliance with accessibility guidelines?
5. When and how can city enforcement personnel (police) stop, examine, rescue, or seize a service robot?

Answers to such questions are dependent on the automation and IoT capabilities under consideration. Hence, the standard details multiply readiness attributes for each of several "maturity" classes for kerbside and pathway operating domains. These attributes and maturity classes define a readiness matrix to be used to gauge the automation readiness of a specific kerbside or pathway or a larger, contiguous domain comprising multiple kerbsides and pathways.

Kerbsides and pathways are independently assessed, so that a kerbside and any adjacent pathway may be categorized at different maturity levels. This has implications for automated logistics that may require integration between road vehicles and service robots.

16.3.7.1 Robot weather worthiness

Robots, especially smaller human-scale machines designed for pathway use at pedestrian speeds and weigh under 50 kg, may be less capable in extreme weather or climate conditions than would be larger robots intended for roadway use such as the cars or trucks we use today. Some of these conditions might disable such robots leaving them as pathway hazards. Severe weather conditions such as extreme winds might blow a robot into road traffic or cause one to become airborne and slam into a pedestrian, a shop window, or a car.

The standard identifies a body of weather-worthy and road-worthy criteria for matters of temperature, wind, rain, snow, ice, and sand. The standard describes criteria for certification of machines and conditions such that a jurisdiction or insurer can determine when various devices must suspend operations and return to a protected storage area.

16.3.8 Looking forward

While standards are critical, much more than standards are needed. Each of the *data elements* implied above needs to be parameterized by a governing jurisdiction. Updates to these parameters are sometimes required in near real time (e.g., occupancy, surface friction). Others require notice to allow logisticians to plan (e.g., construction, current maximum weight per location or conditions). Most, but not all, have tolerances (e.g., max height, ± 20 mm). All have update rules to guide their local maintenance.

If a PRS (see Section 16.3.6.5) is in place, there would be *procedures* for activities such as request, assign, enqueue, dequeue, yield, and reschedule. Many of these activities are precisely standardized; others such as impounding a robot are only suggested, and their specifics are not standardized. Hence, even with a comprehensive standard, much local thinking and preparation need to be carried out.

As of this writing, ISO/TS 4448 is slated to have approximately a dozen parts, three of which are in the working draft stage and the remainder are outlined. This work started in April 2020 and is expected to be published in stages for completion by 2024.

The importance of getting automated passenger and goods vehicles as well as service robots managed in a way that adds to our urban toolkit rather than its problem set cannot be overstated. We can only entreat cities to consider them seriously, to view them through an accessibility lens first, and to consider COVID recovery and global warming a close second.

16.4 Pathway robots and business improvement areas

As described in the two previous sections of the chapter, it is expected that in some places and times, and for a variety of objectives, multiple service robots will be permitted to operate on public footways, bikeways, and roadways. This section imagines ISO 4448 used within a Business Improvement Area (BAI) to maximize the economic value of these robots while mitigating their urban, societal, and personal risks.

> ***Disclaimer**: DTS ISO 4448 does not describe specific deployment aspects for any application. The material in this section is not part of a draft or description of any ISO-related matter. It is here for discussion purposes only.*

16.4.1 The context of a *business improvement district* for delivery robots

As described in section (see Section 16.2) of this chapter, unaccompanied pathway robots for personal delivery or maintenance activities are more likely to be ready for pervasive service in our cities and suburbs sooner than robotaxis will provide regular passenger service. Such robots are illustrated on the bottom of Fig. 16.3. The multiple barriers to deployment of these pathway robots are more easily surmounted than the equivalent barriers for the robotaxi.

Whether pathway robots deliver food and packages, keep the pavement free of debris and snow, or perform security and surveillance duties, a critical beneficiary of these machines will be the retailers whose shops line pedestrian footways. Depending on the nature of their businesses, the attraction of these robots for merchants will vary—some may become adversaries.

Many of these merchants will be members of local *BIAs (or Districts)*. This section speculates on a constructive relationship between these organizations and pathway robots. This includes potential benefits, harms, synergies, and acceptance.

16.4.2 Using pathway robots for consumer deliveries

Assuming personal, direct-to-consumer deliveries as the primary application for pathway robots, these may be deployed in a number of ways. Several might be loaded

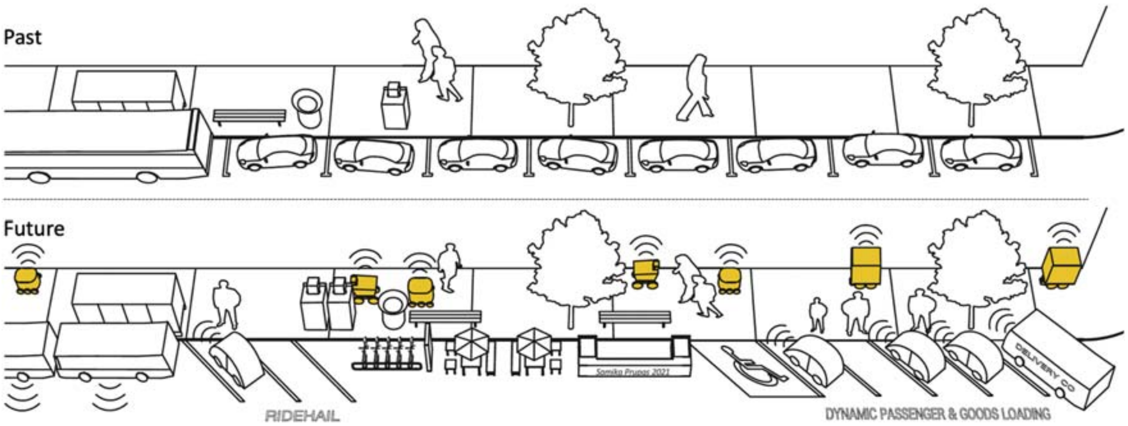

FIGURE 16.3 The evolution of preferred mobility in towns and cities (top) is expected to move away from personal vehicles toward multiple forms of automation and to make room for more social activities (bottom). COVID-19 moved us in both directions at the same time. It increased the relative use of private vehicles while boosting the use of delivery robots. This change will be a long process and may not always go smoothly. *Illustration commissioned by an author.*

inside a larger, specially fitted goods delivery van (sometimes called a "mothership"), brought to an area, then unloaded concurrently so that each delivers its packages within a radius of, say, 2 km. Some might be operated by individual retailers—perhaps a lunch shop or ghost kitchen—to make local meal deliveries. A larger number might be used by an e-commerce operator, such as Amazon or FedEx, to move goods from microwarehouses, strategically positioned staging areas, or from large, parked trailers to residents in a 2 or 3 km radius. Others could be used to deliver meals-on-wheels from a local charity kitchen, or be deployed as gig workers are now, moving on-demand from one delivery to the next, like a robotic *Uber-Delivers*. Still others might be used in an express-delivery service, such as DHL, FedEx, and UPS provide now when delivering packages for retailers and businesses, but in a strictly local environment suitable for personal-scaled deliveries, especially for residential deliveries, which have grown dramatically in the past few years. There are many dozens of such potential usage scenarios, each with varying advantages and disadvantages to merchants, residents, and pedestrians local to their operation.

What all of these types of delivery-service applications have in common is commercial trade. The more localized such trade—preferably in direct connection and without intermediary hand-offs between retailer and kitchen to consumer—the more this technology can act as an optimizer of time and cost. As well, pathway robots appear to fit well with ideas such as the 15-min city, the walkable neighborhood, and the car-free community in that they can help diminish the requirement for private automobile use and the contribution delivery stepvans make to congestion. Also central to the context of this section is whether the delivery robot can improve the post-COVID and eCommerce fortunes of BIAs and their communities.

16.4.3 Business Improvement Areas

The BIA, an innovation originating in 1970 in Toronto, Ontario, is a form of public−private partnership for local governance.[5] BIAs are important to the fabric of towns or cities, to their attractiveness, for the health of their commercial downtowns, and for their local communities. There are several thousand worldwide [11].

BIAs are "privately directed and publicly sanctioned organizations that supplement public services within geographically defined boundaries by generating multiyear revenue through a compulsory assessment on local property owners and/or businesses" [12]. Effective BIAs benefit both businesses and the community. "They can be an economic and social anchor to surrounding neighbourhoods and help to stabilize and add vitality to the local community … (they are an) important not-for-profit organizations which contribute to community development at a grassroots level [13]."

BIAs lobby for and channel local services on behalf of their members, according to their economic interests. Through various tax or business levies, these groups of private actors are able to execute local political decisions in public spaces. BIAs sometimes "intervene in strategic planning, e.g., land-use planning, that is a prerogative of local government [11]."

Each BIA focuses on their local programs, whether street furnishing, heritage preservations, reversing declines, attracting foot traffic, revitalization, managing panhandlers or graffiti, parking, and many others [14]. "Local businesses, working collectively as a BIA, become catalysts for civic improvements, ultimately enhancing the business

5. BIAs are known variously as *Business Improvement Districts* (BIDs) in the US and UK or Commercial Improvement District (CIDs) elsewhere. There are some 2250 of these in Canada, US and UK today.

climate and quality of life of the neighbourhood [15].” The 80-plus BIAs in Toronto are each a focal point of their respective communities taking on the characteristics of a local jurisdiction. They may be organized around income levels, ethnic groups, or sexual preferences, using their budgets for cosmetic improvements and branding. They generally work to attract visitors to their members’ businesses and to locations for walking, gathering, shopping, and cultural pursuits.

But, as a matter of first order, BIAs seek to protect the interests of their members. One of those interests involve matters of local infrastructure such as trade-offs between street parking and bicycle lanes. Another is staying competitive with other channels of consumer supply such as malls or big-box stores—a matter that often turns on the same issue of sufficiency and location of parking facilities, invoking a fundamental conflict between our car culture and a desire for downtown community-oriented commercial areas (see sidebar: **Some merchants’ concern for parking as critical to success may (or may not) be misplaced**).

Some merchants’ concern for parking as critical to success may (or may not) be misplaced.

According to one study nearly half of local business owners estimated that more than a quarter of their customers arrive by car, when in fact the actual number turned out to be 4%. It was cyclists and pedestrians who were the majority customers. They were also the higher spending customers [16].

On the other hand, the recorded portion of 4% may reflect that those preferring to shop in cars simply shopped elsewhere. That some factors are causal and others are correlations is often misinterpreted.

What is certain is that more footfalls mean more shoppers and active modes such as cycling bring more footfalls per unit of parking space [17]. Maybe a smarter approach is to maximize downtown commercial spaces for active transportation and the kind of social, community and shopping environment that implies—and stop trying to compete with box-stores using underpriced parking.

Prior to the pandemic, a rising threat was eCommerce. COVID-19 has not only made that abundantly apparent, but most prognostication about the return to a new normal state indicates that eCommerce is unlikely to decline. Do online behemoths such as Amazon represent an existential threat to community merchants or will the Internet complement local sales to give these merchants a new resource for survival? Or does the cost and complexity to set up and manage an online presence mean this is a false promise—especially for the merchant with only one or a few outlets? Shopify may answer this for some, but it is too soon to be certain [18].

16.4.4 Are pathway robots a good idea?

The inventors and promoters of delivery robots promise that these machines will enable many advantages suitable to the BIA context. From a community perspective, they would be smaller, quieter, and cleaner (CO_2) than the delivery stepvans that are common today in many cities. They could deliver food, groceries, and other goods to seniors and the disabled. They could enhance meals-on-wheels programs. They would improve consumer reach by extending the effective radius of walkable neighborhoods while simultaneously reducing the demand for private car ownership.

From the perspective of the local retailer, they could help address the e-commerce crunch and compete against the “amazons” by lowering costs for local delivery. This could mitigate the high delivery costs for meals that were a hardship for so many restaurants during the pandemic.

From the perspective of jobs, these devices would generate direct, local employment (teleoperators, maintainers, managers, and handlers), but more importantly they add indirect employment to the degree that the local retailers prosper. Interestingly, some of the new jobs involving teleoperation can be performed from a worker’s home including by employees with accessibility issues that might be confined to wheelchairs—people who would not have previously been able to engage in the logistics or delivery industry.

From the perspective of the urban environment, these devices would encourage better footway design and maintenance. John Kiru, the Executive Director of Toronto’s TABIA, in a recent conversation with the first author of this chapter made it very clear that many local sidewalks are still too narrow and do not yet comply with applicable accessibility regulations. He also made clear the critical importance of uncluttered pedestrian clearways, planters, and the ability to promenade.

All of these spatial attributes are in competition with each other and may be further constrained by the migration of goods traffic from the kerbside and roadway onto the pedestrian pathway. Based on the aspects of draft ISO 4448 that address pathway robots, any infrastructure upgrades for robots must target guidelines for accessibility and pedestrian access. There is clearly an opportunity for a win-win for both commercial interests and pedestrian accessibility (see Section 16.4.7).

16.4.5 Are pathway robots a bad idea?

As just noted, many pathways are already difficult places for pedestrians with accessibility challenges. Sometimes they are complex for the abled to negotiate, for example, when they are crowded or when people are walking pets, pushing strollers, dragging carts, carrying bags, and using skateboards. If we add to this mix robots of varying sizes and speeds, fledgling pedestrian skills, and nonexistent social skills, we could threaten perceived safety and detract from pedestrian comfort and enjoyment.

Added to this are considerations of privacy and security. In the matter of privacy, these devices will capture image and other data in order to navigate and document their journey. While the data can be managed, guidelines are not fully mature and even when they are, will they be adequately enforced? In terms of security, physical mishaps might injure pedestrians or pets, or worse, a bad actor might intentionally employ a robot in a criminal enterprise.

We also need to consider that many people have worked very hard during the past decades to reclaim urban space for pedestrians, cyclists, and other active forms of transportation. For this reason, many people will be unwilling to consider pathway robots unless their advantages clearly outweigh any loss of pedestrian or cycling autonomy.

Lastly, I return to the question of jobs. While many new jobs will be created, automation also replaces and displaces human workers; even as it creates numerous opportunities, it causes dislocation, requires re-training, and leaves some behind. The jobs question is neither easy to answer or to project. It is naive to see this going only one way and impossible to dismiss. There will be shortages of both skills and jobs, requiring government intervention with programs to smooth this transition, while insisting on a degree of flexibility and learning of new skills.

I am often asked: "Do we really want these robots on our sidewalks?" My answer is always the same: Not the way many sidewalks are now, not without *fully attentive teleoperation* (i.e., we are not ready for full autonomy, SAE Level 4 or 5), not beyond a trial of devices from a single operator (we are unprepared for multioperator systems) and not without a secure, IoT-based, *pathway reservation system* under municipal governance. Clearly, there are many circumstances, times, and places where pathway robots—a least those currently available—would be a questionable idea.

16.4.6 Business change and societal issues

Done right, any technology that lowers local delivery costs could help restore the fortunes of local businesses and begin to heal the economic harm merchants have endured from the coronavirus pandemic. According to FedEx, this is because "[o]n average, more than 60% of merchants' customers live within 5 km of a store location … demonstrating the opportunity for on-demand, hyper-local delivery [19]." In the scenario FedEx is describing, an on-demand service would move goods and food directly from retail merchants to customers using small robotic machines, with the local merchant acting as a microwarehouse.

Similar to the way people are incentivised to shop where parking is free, community residents would prefer to order from merchants where delivery is near-free rather than inflating the cost of goods purchased. One projection claims that last-mile delivery costs could be driven as low as a US dollar [20] presumably for deliveries under about 3 km. As of this writing, in the United States Starship and Kiwibot charge US$2. Toronto's Tiny Mile charges $C3 ($US2.50).

There are two economic concerns in this scenario. Fast, convenient, and inexpensive delivery service would tend to change customers' goods delivery expectations from next day to next hour and for meal delivery from one hour to half-hour. This may be good for business, but not for congestion. And if the devices used are smaller and constrained to the footway, congestion would shift from the roadway and kerb onto the pathway. This would exchange one congestion problem for another—and could especially impact pedestrians.

Secondly, near-free delivery services risk replacing human couriers on bicycles and tricycles with robotic couriers. This unintended consequence of replacing a form of active transportation with automated transportation would have both health and employment consequences. Another potential impact would be to accelerate ongoing changes in the nature of food retail—grocery, restaurant, and fast food. In the past year, each of these has moved sharply toward pickup and delivery of online orders.

Although online grocery delivery has been around for at least 23 years, it ramped up dramatically during the pandemic. Ghost and virtual kitchens became a common way to sell prepared meals in 2020 for the same reason. In this form, order delivery has been mostly handled by gig workers and self-pickup. If delivery robots become viable, remote food preparation, coupled with robotic delivery, will become a permanent and growing fixture of the food economy.

Inexpensive sidewalk robots would disrupt several things at once: express delivery (van), bicycle couriers, average shopping radius, delivery-time expectations, e-commerce preferences, average total cost of goods purchased, size and frequency of purchases, and other structural buying habits. The net effect of all these disruptions would tend to increase consumption at the expense of sidewalk space, possibly with unintended negative impacts on livability.

16.4.7 Can local thinking sustain local growth?

In communities with a sufficient local population, pervasive local infrastructure such as wider and better designed footways, cycling systems, and slower streets, as well as local technology such as same-hour delivery systems are more likely to engender an increase in footfall and to sustain local commerce than would continuing the more car-oriented approach suitable for big-box stores. Can local deliveries using pathway robots help the post-COVID recovery of BIAs?

Given the extensive value BIAs represent and the range of business and community efforts they undertake (see Section 16.4.3), it will be important to consider the impacts of delivery robots on each of these efforts. Same-hour delivery robots would help some local merchants compete against eCommerce, but this would need to be done is a way that those same robots would not be a nuisance for customers of neighboring businesses such as those sitting at a near-by sidewalk café. If local delivery systems became pervasive, that would increase the number of local purchases in zero-sum competition with box stores. But in a world that prizes footway and parklet cafes and restaurants, pathway robots cannot be permitted to discourage footfall with its promenading and impulse purchases.

Renewed pedestrian infrastructure such as wider pedestrian clearways and improved pavement surface conditions would benefit all parties: residents, accessibility users, merchants, local shoppers, and robot delivery operators alike. Done right, this could benefit desired livability metrics. There are many thoughtful planning steps, anticipated by ISO 4448, that may be taken to prepare BIAs, towns, and cities for the turns this technology will take.

16.4.8 Potential municipal and BIA responses to pathway robots

There are a number of ways BIAs might ask their host municipalities to respond to pathway robots. These will range between two extremes. The business innovations to be enabled in gradual stages can be expected to adjust as change rolls forward. The technology and the standards that are being created to manage this are agnostic to the choices that cities will make and BIAs might prefer. The following list is not advice, but a menu of choices:

1. Severe constraints on the type, number, and schedule of robots permitted, including none permitted at all.
2. No constraints. Whoever operates these devices and however/whenever they are operated is acceptable, provided operations are within municipal guidelines that may apply to other mobility devices.
3. Local (BIA) override on municipally set restrictions such as weight, size, speed, occupancy constraints preferred by the local community. (In early 2021, a community in Pittsburgh, Pennsylvania, held an online town hall to discuss community preferences. A view toward some constraint was prevalent.)
4. Conform to ISO/4448 as configured by the municipality. Add an annual registration fee.
5. Conform to ISO/4448 as configured by the municipality. Add per-trip usage fees.
6. Conform to ISO/4448 as configured by the municipality. Add dynamic (variable) usage fees (this is enabled by ISO/4448).
7. Conform to ISO/4448 as configured by the municipality. Add variable permissions differing by block face and time of day and orchestrated by BIAs (this is enabled by ISO/4448).

16.5 Summary

The message of this Section 16.4 is that pathway robot technology is coming to shared, public spaces, bringing with it both opportunities and risks. Only by engaging with intention can BIAs tip the scale to their advantage.

External factors, whether box-store competition, changing approaches to urban planning, growth in e-commerce, a pandemic, or new technologies such as online storefronts, ghost retail, micromobility, or pathway robots, can challenge the financial and social viability of local retail. It follows that threats or advantages to a BIA can easily become threats or advantages to its local community.

Robotic deliveries, if they increase local purchasing, would help to restore financial viability and reduce retail vacancies. It is conceivable that the use of local, robotic deliveries may help sustain social viability as well as sales. If robots are purely and only for delivery and cost is driven out, this could encourage people to shop more from home. But if robots can enhance a district, keeping it cleaner, making it more secure, be used in novel ways acting, say, as BIA ambassadors—even interacting with visitors as such robots already do in some indoor environments—to encourage more community engagement, then these would be a good thing for both community and commerce. What might such a balance look like?[6]

A critical, net positive would be to reduce the need to use personal vehicles to get to nearly every activity we engage in. If local delivery takes away one more reason to drive, we may find more occasions to walk, more reasons to seek out 15-min cities, more times to buy locally, more opportunities to engage locally—and more community. Delivery robots can surely get us out of cars, but will they also get us off our couches and to prefer exploring our communities?

A negative would be that robots could reduce the need to leave home to shop, implying a drop in social activities,

6. It is worth reading online stories about the concurrent operation of well over 100 delivery robots in Milton Keynes [21]. Caution: at this point as of this writing such cases involve only a single provider, hence not requiring the higher level of coordination needed for the case multiple logistics operators sharing a common space.

community activities, active transportation, and the like. As the capability of robotic delivery grows, it makes sense for e-commerce logistics operators to operate out of small local warehouses or staging points simply acting as distributed box stores, which would have the opposite effect of reinvigorating local retail. Can this be avoided?

Digitalization and new mobility pull the local merchant in many directions. The need to be online [18], the threat from e-commerce, the introduction of the pathway robot, numerous changes in parking supply and pricing, as well as micromobility storage and charging stations at the kerb combine to rattle the retailers' world, demanding that they be responsive at every turn in order that their businesses survive. In a conversation with the first author, Professor Kenneth Jones of Ryerson University, said: "retail is the most flexible form of human commerce — it responds very quickly to change and opportunity." The current decade will test that assertion.

The influence BIAs have on shared public-commercial space (and vice-versa) implies that BIA leadership will seek to influence the regulation of automated devices on the pathways within the geographical boundaries of each BIA. There is no reason to assume BIAs would adopt common, uniform rules in terms of robot sizes, speeds, weights, and traffic volume—as implied in several bills introduced and passed in some US states [2]. Depending on the nature of local footways, local budgets, and local retail mixtures, some BIAs may welcome these robots, and others may wish to ban them. Surely, most of them will seek a say in their governance.

But there is already a concern here. As of late 2020, about 40% of US states have tabled or passed legislation permitting "personal delivery devices" on their cities' footways, bikeways, and roadways. This was done in favor of lobbyists representing companies making and deploying these robots (firms such as Amazon, FedEx, Starship). This was often done by these states without conferring with their constituent cities or their subconstituent BIDs [22]. Some BIAs may guard against this by lobbying for the ability to moderate such rules of use in ways appropriate to their community. Such lobbying could consider accessibility, community, economic, and safety factors not all of which have been considered in the US state bills tabled as of this writing.

16.5.1 Afterword

Taken together, the extraordinary potential and matching complexity of service robots in public spaces are likely to engender a difficult and ongoing social debate. If you are an advocate of this type of automation—and there are many of you—you should progress cautiously, understanding that there are very many unresolved issues before you will be able to reach substantial deployment. If you oppose this type of automation—and you are also not alone—you should be aware that there are many important opportunities that you may be inadvertently rejecting.

Each city and perhaps each local community may reach a different conclusion. It is possible that some communities will reject these robots while in other cases, neighboring communities will undertake different deployments. The impact of such variations might be hard to project and have surprising consequences. The best approach is to be open to research, trials, and public discussion—and above all to guard against hype.

Finally, let us move on to the real interactive part of this chapter: review questions/exercises, hands-on projects, case projects, and optional team case project. The answers and/or solutions by chapter can be found in Appendix G.

16.6 Chapter review questions/exercises

True/false

1. True or False? Dozens of companies are building and piloting large, electric delivery robots with a view to reducing the costs of delivering food and parcels over their final distance.
2. True or False? Despite a decade and a half of investment, promotion, and anticipation about the coming of driverless taxis and shuttles, delivery robots will arrive sooner and in greater numbers than will robotaxis.
3. True or False? Delivery robots come in a variety of sizes and configurations. Smaller units for single deliveries are the size of a filing box and weigh less than 100 kg fully loaded.
4. True or False? According to the American Automobile Association, over half of people recently surveyed express fear of driverless vehicles.
5. True or False? Setting aside projections of driver shortages and arguments promoting "career retraining"—which are often not accepted by the people so employed—many workers and their families do not feel threatened by automation.

Multiple choice

1. Standing against the robotaxi will be interests such as transit and taxi drivers and their agents and:
   - **a.** Unions.
   - **b.** Infrastructures
   - **c.** Groups
   - **d.** Investments
   - **e.** Policies

2. The investment required to build and prove delivery robots is far lower than that required to build and prove driverless passenger:
   a. Planes
   b. Vehicles
   c. Boats
   d. Submarines
   e. Trains
3. In most countries, national and state/provincial governments consider regulations for automated passenger vehicles, mostly from a:
   a. Safety perspective
   b. Machine-to-Human perspective
   c. Cyber-Physical Systems perspective
   d. Artificial Intelligence perspective
   e. Digital Twins perspective
4. A robotaxi is often framed as "just a taxi with a silicon driver," and we are often told these machines will use the same roads and the same parking spaces as human-operated:
   a. Platforms
   b. Vehicles
   c. Vans
   d. Motorcycles
   e. Boats
5. Fear and negative perceptions evoked by fully autonomous vehicles create a significant barrier for widespread adoption of the:
   a. Delivery robot
   b. Autonomous vehicle
   c. Robotaxi
   d. Driverless vehicle
   e. Android

Exercise

Problem

Why is kerb space considered to be a prize for the increasing number of competitors that are bidding for their slice of it?

Hands-on projects

Project

Do research: Analyze why the kerb space is an area where many interactions take place, whether it is pickup, drop off, loading zones, bus stops, clearways, or parking spots.

Case projects

Problem

Who is in charge of the kerb?

Optional team case project

Problem

Why is monetization an outcome of management?

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