WHITE PAPER

The Last Block

TOWARDS AN INTERNATIONAL STANDARD TO REGULATE & MANAGE SIDEWALK ROBOTS

Harmonize MOBILITY

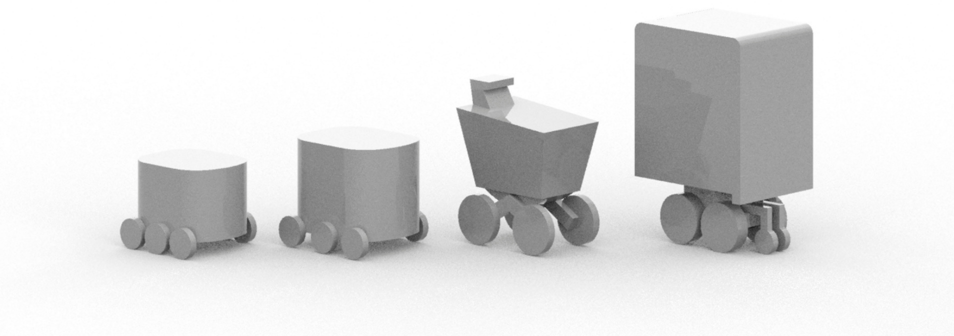
CONTENTS

INTRODUCTION

Of all the automated vehicle scenarios that our cities face in the foreseeable future, the one that is likely to come soonest and to have the most unanticipated impacts is the introduction of small robotic vehicles on the sidewalk. These machines will engage in package and food delivery, sweeping, snow removal, surveillance, measurement, monitoring, repositioning dockless scooters to where they can be re-charged, and potentially many other tasks.

This paper will discuss three aspects of this impending technology:

- why robotic sidewalk delivery will arrive in our cities before driverless taxis do;
- risks and benefits that sidewalk robots will bring, and
- an international standard to help cities regulate and manage sidewalk robots.

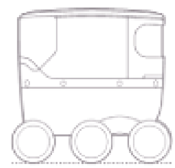


Dozens of companies such as Amazon, FedEx, Starship, and Uber are building and piloting small, electric sidewalk delivery robots with the goal of reducing the costs of delivering food and parcels over their last mile. At the same time, cities are interested in reducing congestion and emissions from the use of trucks, vans, and other motor vehicles for deliveries — which have more than tripled in the decade prior to the coronavirus.

The four robots illustrated above will likely be among the top 10 models by use — certainly from a North American perspective. These robots or their design successors are expected to frequent sidewalks over the next few years. As they become more capable, their adoption will become more pervasive.

Delivery robots are being developed in a wide range of sizes, configurations and payload capabilities.

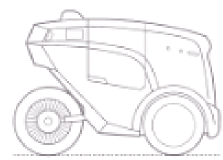
Amazon Scout
23 kg 24 km/h



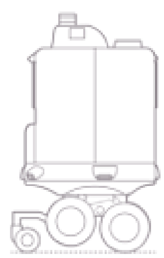
DeliRo
50 kg 6 km/h

Postmates Serve
23 kg 4.8 km/h

Refraction REV-1
127 kg 24 km/h

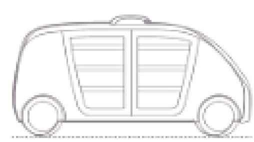


FedEx Roxo
45 kg 16 km/h



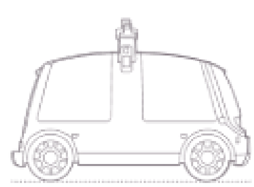
KiwiBot
18 kg 2.4 km/h

Robomart
40 km/h



Starship Robot
10 kg 6 km/h

Nuro R2
190 kg 40 km/h



TeleRetail Delivery Robot
35 kg 56 km/h

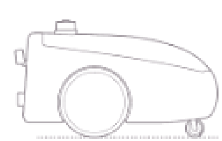


Image source for line drawings above: www.dimensions.com/collection/autonomous-delivery-vehicles

Other images courtesy of Starship, Amazon, FedEx, Tinymile.ai, Kiwibot and Postmates (now Uber).

The new context of curb and sidewalk

The 21st century has brought many changes to the urban space between traffic lanes and buildings. The prior century — the century of the automobile — had relegated much of this space to storing cars for owners as they lived, worked, shopped, or visited. Some would be reserved for loading zones and the occasional bus stop. Nearer to buildings, the remaining space would be for pedestrians, and even this space was interrupted by driveways, fire hydrants, bus shelters, and sometimes a tree, a place to sit, or a post to lock a bike.

This 20th century description of the curb and sidewalk, while still evident in our communities, is rapidly giving way to much greater variety and intensity of uses such as ride-hail pick-up and drop-off, ecommerce delivery, protected cycling lanes, e-bikes, micro-transportation docks, and — thanks to the COVID-19 pandemic — al fresco dining. Calls for wider sidewalks and more cycling infrastructure may result in fewer traffic lanes and on-street parking spaces, or they may be ignored and more activities squeezed into the increasingly crowded space of the curb and sidewalk.

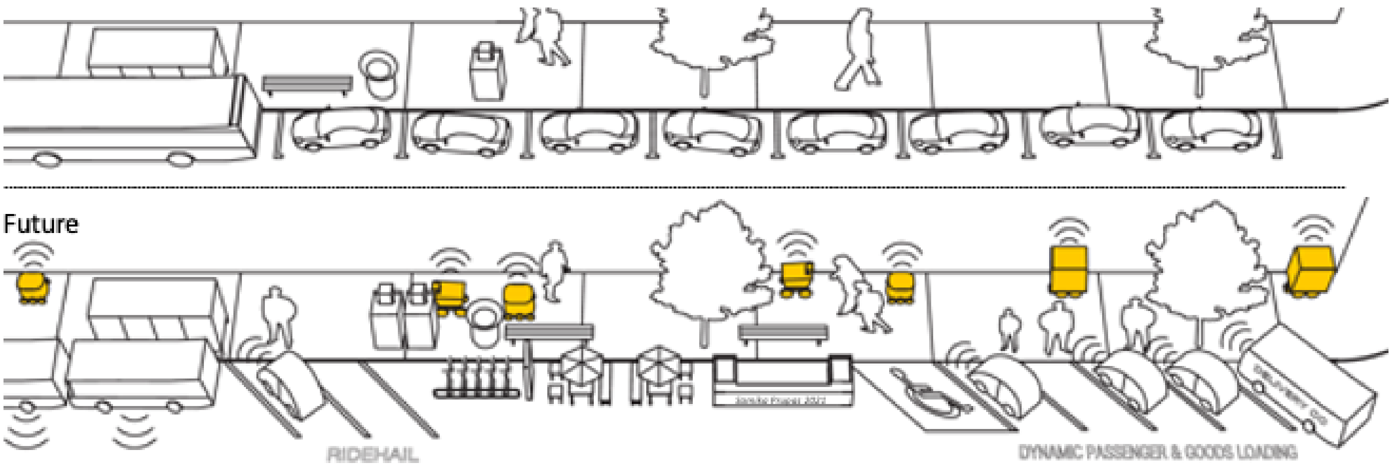
This change at the curb and sidewalk is just beginning. Ride-hailing, e-commerce delivery, and more active transportation infrastructure for e-scooters and bike sharing are still in their infancy. Increasing pressure on this space is coming from a variety of sources, including:

- shrinking motors and new battery technology;
- smarter fleet management;
- declining affordability of new automobiles, especially among families disadvantaged by the pandemic;
- concerns over global warming, and
- demographic factors as younger generations delay marriage and children while choosing life in the city core over the suburbs.

These factors will spur ongoing innovation and rising demand for new services provided by greater varieties of smaller vehicles and automated devices. This implies more pressure on the sidewalk and curb. Increasingly complex demands will follow. The next wave will come from various forms of automated vehicles and devices that will transform the movement of passengers and goods.

Last year marked the debut of the first truly driverless robotaxi fleet from Waymo. Now that the safety barriers to driverless taxis have been breached, we can expect the shift towards widespread acceptance of robotic mobility-as-a-service to accelerate.

While the hype and promise of the driverless car has captured our collective imagination, the nascent sidewalk robot portends imminent change — and many impacts of this change will be unanticipated, partly due to the distracting clamour promoting the driverless automobile.



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Robotic sidewalk delivery will arrive in cities before driverless taxis do

Ground-based, delivery robots will arrive sooner and in greater numbers than will robotaxis. Delivery robots are essentially containers on wheels that can ply sidewalks, intersections and roads over modest distances — without a human attendant on hand — to carry food, packages, and documents. The promise of their widespread deployment in driverless fleet operations is much closer to reality than it is for robotaxis.

There are a number of reasons why. The barriers to delivery robot deployment 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.

1. Safety: The safety barrier for delivery robots is much lower than it is 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 kilograms fully loaded. One of the most popular models, Starship, is a small cube less than 0.25 m^3. The top speed of these smaller robots is usually constrained to about six kilometres an hour, a hurried walk. Small and slow, they can stop quickly. Larger delivery robots — half the size and weight of a passenger sedan and perhaps travelling at 40 km/h — present more 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 don't weigh passenger risk in their computations.)

Most crashes involving smaller, slower robots would be far less dangerous than crashes involving sedan-sized vehicles.

Like robotaxis, delivery robots are designed not to hit anything. If one of the smaller robots were to hit an adult human, it's unlikely the collision would be fatal or even life-threatening. An exception to this is that a robot might precipitate a fatality in the same way that a pet running into the street might cause a vehicle to swerve and crash. Also, if a robot were struck by a bicycle, the cyclist could be seriously injured — or worse.

While it is unreasonable to assume crashes can never occur, most crashes involving smaller, slower robots would be far less dangerous than crashes involving sedan-sized vehicles that may weigh 1,400 kilograms and can travel at speeds exceeding 60 km/h.

The sheer variety of delivery robots presents challenges for protecting pedestrians and cyclists. Any regulations will need to account for a wide range of safety 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 sidewalks. It is too early to predict how this will play out; there are already a number of somewhat contradictory regulations in place.[1]

2. Fear: The fear barrier for delivery robots is much lower than it is for robotaxis.

Many people express fear of being harmed by a robotaxi or when riding in one. 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 sidewalk robot to deliver their sandwich or package of socks might wait until a downpour lets up. They might not accept that from a passenger vehicle when they're 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.

[1] As of this writing, 19 U.S. states have tabled legislation permitting Personal Delivery Devices (sidewalk delivery robots). 11 of these have been passed.

3. Jobs: Concerns about job losses for those impacted by delivery robots carry less political weight than similar fears about robotaxis or autonomous trucks.

Employment for truck, transit, and some taxi drivers is frequently permanent, full-time, and unionized. This means contracts and employee benefit packages. 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.

Short-haul delivery — especially in the fast food or e-commerce sectors — generally provides temporary, part-time or second jobs and jobs 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 sidewalk robots should be much lower than that for robotaxis.

4. Cost: The cost barrier to developing and deploying delivery robots is much lower than that for robotaxis.

The investment required to build and prove driverless passenger vehicles is far greater than that required to build and prove delivery robots. 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 everyone's costs will drop over time, the relative differential will remain.

Short-haul delivery, especially in the fast food or e-commerce sectors, generally provides temporary, part-time or second jobs and jobs for youths and gig workers.

5. Regulation: The regulatory barrier to the deployment of delivery robots is very much lower than for robotaxis.

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. Regulations for sidewalk robots appear to receive even less attention, although this is beginning to change.

Sidewalk 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 startups, which are currently a major source of innovation for sidewalk robots, will quickly target cities seeking smart-thinking reputations. These cities may turn a forgiving eye to the efforts of startups and innovators, or even invite them to trial their devices in their municipalities.

Any laissez-faire attitude regarding regulations for sidewalk robots will shift rapidly once companies such as Amazon and FedEx deploy delivery robots controlled 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 the attention of regulators.

6. Infrastructure: Infrastructure is a more complex barrier to consider, as delivery robots will have to run a gauntlet of human legs, barking dogs, baby strollers, planter boxes and uneven pavement — a much more disorderly environment than the highly regulated city streets where robotaxis will operate.

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 vehicles. This is generally expected to apply to automated goods-delivery vehicles as well. The physical infrastructure for road vehicles is already well-developed. We may need to address loading and unloading rules (more on this later) but we should need to build very little if the technology is delivered as promised.

While this last point is unproven, it is the relative comparison with small sidewalk robots that is key. Yes, delivery robots are expected to operate on existing infrastructure, but there is a critical difference in that the rules governing the configuration, condition and certification of sidewalks, and the systems to manage and broadcast information about construction and configurations in those spaces, are neither as well-formed nor as frequently complied-with as they are for roadways.

Cities will have many more undigitized and non-conforming sidewalks than streets. This constitutes a relative barrier for operating delivery robots that exceeds that for robotaxis. This will need consideration in order to manage the arrival of these robots.

7. Friends and enemies: The delivery robot will have fewer enemies and more friends than will 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 smaller voices than those potentially arrayed against the robotaxi.

The delivery robot has the sidewalk 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 wishes of consumers who would prefer fast, cheap delivery that saves a trip to a shop or restaurant might easily outweigh pedestrian advocacy against the robots.

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

8. Full Autonomy: The technological — and psychological — barriers to fully autonomous vehicles will remain higher for robotaxis than for delivery robots.

There is now a widespread understanding that the SAE "Level 5 - Fully Automated" vehicle[2] has been over-promised by marketers, exaggerated by mass media, and misunderstood in the popular imagination. We are slowly coming to understand what Professor Steven Shladover[3] meant when he told us that the last stages of

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[2] The SAE "levels" of automation 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 sidewalk robot that requires a responsible teleoperator would be at SAE level 2 (partial automation) or level 3 (conditional automation). See: https://www.sae.org/automated-unmanned-vehicles/

[3] Shladover, S. (2016) What "Self-Driving" Cars Will Really Look Like, Scientific American, June

readiness for automated road vehicles — vehicles that can handle every driveable circumstance and mix with existing non-automated vehicles on our roadways — are very difficult. 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 environments are relatively well-organized, enjoy mild weather, and have lower levels of traffic congestion.

The fear and negative perceptions evoked by fully-autonomous vehicles create a significant barrier for the robotaxi. Without full autonomy, fleets of these vehicles necessarily have limited operating domains. This constrains their applicability, and reduces their potential for profit. The sidewalk delivery robot, also not fully autonomous, does not suffer because of it to the same extent.

Robotaxis, with the recent exception of Waymo's driverless vehicle, require safety drivers who intervene less and less often as these machines improve. In the same manner, delivery robots began with safety attendants who walked with them during their developmental stages. Many of the companies that make these smaller machines are now able to operate in specific conditions without line-of-sight attendants. Remote teleoperators (humans using joysticks) can each manage a small number of these robots.

As the technology improves, the number of robots that a single teleoperator can manage will increase. With intelligent, collaborative, teleoperation systems, the ratio of machines to humans — now perhaps two or three per teleoperator — will reach five or 10 to one, and eventually more. In cities that are suitable and prepared, delivery robots will diffuse sooner, in more places, and scale up much faster than will robotaxis.

Even if neither technology achieves full autonomy, delivery robots are better suited than robotaxis to overcome the limitations and operate effectively in a variety of settings without being fully autonomous.

9. Privacy: The idea of robotaxis evokes a number of privacy issues.

Will 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 — and will be destroyed at the earliest appropriate moment?

Of course, 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. The concern for privacy about what one eats, wears, or reads seems less significant than the concern for having one's trips tracked and behaviour modeled. We do not need to debate the credibility of these relative concerns. Differential perception is all we need to acknowledge.

10. Security: Our image of the robotaxi has also given rise to perceived and actual security issues.

Few of these are perfectly understood but most are clearly imaginable: vehicle hijack, passenger molestation, robbery, rape, or worse. If something is lost in the vehicle, will it be recoverable? Would a parent be able to entrust the safety of a young family member to a trip in one of these vehicles?

These concerns apply far less to the delivery of a pizza or a set of bedsheets in a robotic box. 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.

11. Risk. The total risk equation for robotaxis is likely higher than that for delivery robots by an order of magnitude or more.

Issues such as cost, acceptance, liability, investment, ROI, privacy barriers, security concerns and regulatory weight 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 trillion and US$10 trillion annually, there is much more media, investment, and municipal focus on robotaxis than on delivery robots. But the first phase of automating mobility – using delivery robots for light, short-haul movement of goods — is a clear winner from the perspective of risk.

The greatest immediate risk facing cities is to ignore sidewalk robot technology until it is upon them. For cities that fail to prepare, the likelihood of repeating the chaotic introduction of ride hailing and scooter-sharing is high — and the likelihood of getting off easier this time is low.

Will sidewalk robots be for better or worse?

The widespread deployment of small, electric, autonomous, delivery devices promises to minimize congestion and pollution by reducing the need for larger delivery vehicles powered by internal-combustion engines, reduce delivery costs, and assist seniors and disabled people by delivering goods and groceries safely and efficiently to their door.

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."[4] In the scenario FedEx is describing, an on-demand service would move goods and food directly from merchants to customers using small robotic machines, with the local merchant acting as a warehouse.

Similar to the way in which 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 dollar.[5] (Starship currently charges US$1.99.)

There are two economic concerns in this scenario. Fast, convenient, and inexpensive delivery service would tend to change customers' delivery expectations from same-day to, say, next-hour delivery. This may be good for business, but not for congestion. And if the devices used are smaller and constrained to the sidewalk, that new congestion would shift from the roadway and curb onto the sidewalk. This would exchange one congestion problem for another — possibly worse — and would impact pedestrians especially.

4 http://cantruck.ca/fedex-begins-testing-autonomous-delivery-robot/
5 https://www.theguardian.com/sustainable-business/2017/may/31/delivery-robots-drones-san-francisco-public-safety-job-loss-fears-marble

Secondly, near-free delivery services would tend to replace 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,[6] 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 pick-up. 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.

Rights to the City or Rights to the Curb?

The past century featured an ongoing struggle over the allocation of rights to space and passage in our cities. These rights were variously divided and re-divided among private vehicles, transit vehicles, goods delivery, bikes, and pedestrians. The results are consistently declared inadequate by every participant, prompting familiar refrains such as: “parking should be free”; “more bike lanes are needed”; “loading zones are inadequate”; “pedestrians are being killed”, and “buses need a dedicated lane.”

In 2020, this zero-sum spatial game was dramatically disrupted by the coronavirus. Parking revenues plummeted. Bike lanes were added. Loading zones appeared everywhere. Pedestrian deaths rose. Bus ridership plummeted.

This zero-sum game will re-normalize as the economy recovers from the pandemic, and the arrival of delivery robots will add a new player. To the degree that robotic delivery technology is successful — and widely deployed — proponents will no doubt join the traditional players in complaining about the inadequacy of space allotted for their devices.

Because access to constrained streetspace is by default a zero-sum game, this new player will often take space from other players. Sometimes pedestrians will be inconvenienced. Perhaps some cycling lanes may be shared. Sometimes a sidewalk will be widened at the expense of a traffic lane,

[6] Grocery Gateway was founded in 1997.

or a pedestrian clearway will be altered or widened and then shared with these robots. Current guidelines concerning 'complete streets' may be modified to accommodate this type of goods movement. Perhaps some designs and regulations will intentionally exclude them.

Beyond exclusion, solutions will need a common, shared vision. Those solutions will require agreement on priorities for pedestrians, safety, commerce, health, pricing, and many other matters.

There are two opposing forces at play, argues Alanna Coombes of the Sol Price School of Public Policy at the University of Southern California:

- **Rights to the City** — referring to free, democratized use of public space unencumbered by property rights, and
- **Rights to the Curb** — referring to property rights in curb space, e.g., curb space that is regulated and monetized for parking.[7]

The best approach to addressing Coombes' assertion is to argue the merits of both, then seek designs and regulations that provide enough of each.

The core matter we face with the sidewalk robot is that the sidewalk is most often seen and enjoyed as a democratized public space. Unlike the curb, which is more often seen as reserved or assigned to a usually mechanized purpose such as parking, cycling, transit stops or food trucks, our access to the sidewalk is more social than commercial, a comparative safe zone rather than a place of caution and risk — a place of minimal mechanization. Coombes suggests this leads to an increasing need for government intervention to prioritize *Rights to the City* over *Rights to the Curb*.

...the sidewalk is most often seen and enjoyed as a democratized public space.

[7] Private communication regarding work in progress.

Any need to monetize Rights to the Curb would conflict with democratic Rights to the City, thereby challenging municipal governments to find optimal solutions. It may be appropriate to claim priority for Rights to the CIty, but raising the resources needed to manage this increasingly complex space likely requires monetization — which implies the sale of Rights to the Curb, which in turn provides the key lever needed to govern. These two rights are two halves of a whole, so some art will be needed to find and maintain this balance.

Fewer people would be offended if a cycling lane was shared with robotic delivery vehicles than would be offended if such delivery vehicles were added, without constraint, to pedestrian clearways. But a key expectation of this technology is to bring deliveries to doorways, and that implies at least crossing the pedestrian clearway. Furthermore, it is highly likely that the current "picnic-cooler-on-wheels" design will be a limited, even short-lived, solution to robotic last-block deliveries. This is because many aspects of navigating the sidewalk and curb would be better handled by robots that can walk.

In other words, if this technology is to be truly successful, sustainable and widely adopted many, if not most, last-block robots will be walking rather than rolling in a few years. The full issue we face is not merely addressing Coombes' critical observations about rights, but how to navigate the next two or three decades as the interface between humans-as-citizens and machines-as-assistants matures.

Coombes concludes: "A Rights to the City approach with bold action on access to curb and sidewalk space — as seen during the Covid-19 pandemic — could set the stakes for a more democratic use of space. It may yield the kind of town and city centres people want – both liveable and thriving. Designed and rolled out with care and in consultation with local businesses and people, they would set a marker for how cities and towns should develop in a world of automated vehicles. Leaving this to the market — to tech companies and vehicle manufacturers — will not deliver the town and city centres people want. They've led the way in the past — assisted by city officials or politicians such as Robert Moses — and failed to deliver the promise of tidy, uncongested streets and happy travellers."

City suitability and preparation

What will it mean to prepare for sidewalk delivery robots?

Banning is the easiest form of preparation.[8] But this would be a mistake that simply postponed the hard work needed to ensure this technology is safe, acceptable, non-intrusive of pedestrian rights, and improves livability by substituting some local truck and car traffic with small, slow, electric deliveries.

[8] San Francisco initially banned them, but has since determined an approach of restricting them to a very small number for testing-only purposes.

Will municipal regulators find a way to encourage the replacement of motorized van deliveries with electric robots, while not undoing this benefit by replacing bicycle couriers at the same time? Will there be a need to limit the number of robots on a blockface at a given time? Will it be possible to do so?

In another scenario similar to the e-commerce delivery approach we use now, specialized delivery vans would park and deploy a group of sidewalk delivery robots within a service area. This will require sufficient reservable space at the curb and sidewalk to allow for staging or waiting until deliveries are completed and all delivery robots returned to the van.

All of these scenarios will need rights-of-way rules, security and certification guidelines, emergency procedures, enforcement access rights to the interior of unmanned vehicles, specialized training for human enforcement personnel, and numerous other regulations and guidelines. Some form of pricing will be needed to pay for this operational infrastructure.

The next section of this paper discusses a standards approach to these questions and issues.

An international standard to help cities regulate and manage sidewalk robots

In early 2020, the International Organization for Standardization (ISO) launched an Intelligent transport systems project called "Sidewalk and kerb operations for automated vehicles."

ISO/4448 is designed as a four-part series that includes data for ground-traffic control systems, and regulatory guidance for municipalities to use for robotaxi and goods vehicles loading and unloading passengers and goods at the curb, and for sidewalk robots providing services, including loading and unloading (delivery) services.

As discussed earlier in this paper, the curb and sidewalk space in many towns and cities are under increasing pressure for access from a growing variety of users, 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 curbs as well as a dramatic rise in goods delivery from e-commerce systems. In many areas of some cities, this change has already reached unsustainable conditions, and some of these are being addressed on a local and urgent basis — often without a long-term framework for future change, growth, or innovation. In addition, the rise in active transportation has added cycling, scooter, and board lanes at the curb in many cities, as well as scooter and bike storage spaces on the sidewalk.

During the early development phase of the standard, the onset of the COVID-19 pandemic created rapid and unexpected demands for these sidewalk and curb spaces to accommodate social distancing, an uptick in the use of micromobility vehicles such as scooters and e-bikes, and increased demand for al fresco dining space. Wider sidewalk areas were created to accommodate these new demands. These areas sometimes extended temporarily beyond the curb and into cycling and parking lanes.

Additional width invites more variety and creates an even greater need for management as social distancing continues, micromobility grows, and demand for walkability increases along with a growing need for cleaning, maintenance, and snow removal for these expanded and complex spaces.

The near future will see growing demand for the delivery of passengers and goods to the curb — soon using driverless vehicles and the final-block delivery of goods via sidewalk robots. Indeed, such systems are already in trials and pilots. This will not only lead to increasing traffic volume requiring highly digitalized management, but also a change in the nature of the interaction of these vehicles and their mobility systems with each other, with the curb, with payment systems, with active human mobility, and with our existing manual vehicles and devices.

The traffic and parking rules that cities have relied on prior to 2020 represent governance that is already under duress — their inadequacy and shortcomings made evident by the pandemic. Neither current rules nor their temporarily-modified versions will support the new, automated systems that are anticipated. Cities will need new operating guidelines as automated taxis and delivery robots arrive on our sidewalks and curbs and stop, park, wait, load and unload under sensor, effector, and software control. Often unaccompanied by human passengers or attendants, these machines will need to be prioritized, scheduled, queued, bumped, and placed in holding patterns regardless of nearby human oversight, and all without blocking crosswalks, bicycle lanes, micromobility users, no-stopping areas, or transit stops. This must be done safely, mixed with human-operated vehicles, without inconveniencing active transportation or pedestrian traffic, and with regard for human accessibility challenges.

The purpose of ISO/4448 is to define the data and communication systems needed to organize and expedite the flow of vehicular ground traffic in cities, specifically with regard to the loading and

The near future will see growing demand for the delivery of passengers and goods to the curb — soon using driverless vehicles and the final-block delivery of goods via sidewalk robots. Indeed, such systems are already in trials and pilots.

unloading of goods and passengers, and the allocation and movement of service vehicles for garbage removal, sweeping, washing, snow removal, repair, food trucks, construction, and more. The data and communications standards being defined in this technical standard are intended to enable carefully defined (mapped) and growing areas of cities to manage any number of vehicles and vehicle varieties operated by any number of operators (public, commercial, and private) for these various activities.

The purpose and justification for ISO/4448

ISO/4448, when completed, will comprise a set of terminology, guidelines, and real-time procedures for coordination of operations at the curb and on the sidewalk. There are five key purposes:

1. ***Safety and conflict-avoidance.*** The potential for conflicts can be expected to grow with the number and variety of automated vehicles and devices, including: **spatial conflicts** while arriving, stopping, parking, waiting, or loading, as well as **navigational conflicts** on the sidewalk when passing, crossing, or overtaking. Such conflicts are already very common and cumbersome at many curbs and on many sidewalks. Increasing numbers of such vehicles and devices will be expected to operate without on-board human operators or even proximate, line-of-sight, human control. They will need to interact safely with each other and with human-operated vehicles and devices potentially without the lane markings that guide on-street vehicles.
2. ***Planning.*** Infrastructure projects that re-format and reorganize streets, curbs or sidewalks will need to shape and organize these spaces to be workable for vehicles and devices whose operating characteristics may be different, or differently constrained, than vehicles and devices under human operational control. Such planning activities need guidelines and those guidelines need a common expectation of procedures and communication protocols.
3. ***Commercial.*** Some curbs and sidewalks can be expected to be used more heavily by commercial vehicles including taxis, shuttles, trucks, sidewalk robots, etc., each with various automated capabilities for loading and unloading passengers and goods. The use of machines without a human operator for these activities requires forward planning and reservation systems operating in near real-time. The design of such reservation systems must admit multiple fleets and purposes which will require common descriptions, procedures, and protocols.
4. ***Operations.*** In general, curbs and sidewalks form an interface between people who are residing, visiting or trading at locations at or near these curbs or sidewalks. People and goods that arrive or depart with the help of vehicles and devices, automated or not, or simply on foot, expect to be able to arrive and depart in a timely manner without finding their pathway or loading facility blocked unexpectedly. These spaces need to be managed in a reasonably smooth and coordinated fashion, which will require common procedures.
5. ***Legal, liability, and insurance.*** Any curb or sidewalk that is a public space will be shared by many classes of users including local residents, vendors, visitors and shoppers, whether able-bodied or not. Any conflict that causes bodily harm, property damage, financial loss, or other harms — real or perceived — may be subject to legal action. Hence a common understanding and description for these spaces is necessary to determine correct use and assign liability for legal and insurance purposes.

These reasons indicate the need for a set of common and precisely-communicated guidelines, procedures, and protocols for real-time resolution.

Sidewalk robots: What problem are we solving?

Consider this scenario:

> *The city manager responsible for pedestrian safety is asked to prepare recommendations for city council regarding the use and regulation of autonomous sidewalk delivery robots, street sweepers, and snowplows. A pedestrian advocacy group has voiced concerns to disallow these machines or regulate them very strictly. There are several business improvement associations in the city that are asking for these devices to be liberally regulated because of associated positive expectations for their businesses. Finally, while the city council is convinced that this technology will help diminish the growing blight of e-commerce truck traffic, It is anxious not to create new problems for the management of traffic and pedestrian spaces, and they are especially concerned about compliance with legislation such as the Canadians With Disabilities Act (CDA) and Americans With Disabilities Act (ADA).*

On any urban sidewalk in a business or mixed business-residential area, a fundamental conflict is that some people use the sidewalk to get somewhere, while others are already there. For those walking to a destination or to make a delivery, the sidewalk is a **path**. For those who may be window shopping, sitting on a bench, paying for parking, meeting someone, sleeping, sipping coffee, begging, or walking their dog, the sidewalk is a **place**.

This fundamental conflict between *path* and *place* is mediated by social behaviours and low speeds. The coming use of delivery robots on the sidewalk implies a purely path-oriented use, except for departure and arrival terminuses. Functionally and navigationally, we can compare this to a pedestrian in a wheelchair using the sidewalk as a pure travel path.

The problem with this analogy is that a person using a wheelchair relies on a large body of associated social signals and behaviours shared with other users of the sidewalk while negotiating passage or place.[9] These social signals and behaviours enable human users of path and place to share this space. While this arrangement is not always fully equitable, it can be generally made workable for most users much of the time.

How can we accommodate driverless machines in these spaces?

Partial analogy of sidewalk robots to wheelchairs

> *The analogy between a wheelchair user and a wheeled sidewalk robot is used to explore the physical preparation required to enable and standardize access and flow. It may be noted that the rules of engagement*

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[9] Wolfinger, Nicholas H. "Passing moments: Some social dynamics of pedestrian interaction." Journal of Contemporary Ethnography 24.3 (1995): 323-340.

on a pavement necessary to deploy small, wheeled robots may be intentionally designed to benefit the wheelchair user by combining the necessary and sufficient design requirements for each and then imposing appropriate social priorities on those physical and logical requirements. For this reason, ISO/4448 starts with a set of best practices for accessible sidewalks, then extends the standard from there.

As a wheeled vehicle, the sidewalk delivery robot has some characteristics similar to a wheelchair: it can easily travel faster or slower than the average human pedestrian, and it must confront issues of climbing over uneven, damaged, steep, sloped, or potholed pavement or ramps to sidewalk grade. It cannot “step aside” as an ambulatory human normally can, and it cannot streamline its width by turning sideways while walking as an abled pedestrian can. Basically, it exhibits many of the constraints and properties of a wheelchair. Depending on wheel diameter, number of wheels and their suspension system, a non-ambulatory robot may have fewer or more constraints than does a wheelchair. Indeed, several models of these robots already in pilots exhibit these variations.

As a machine, the delivery robot might be regulated to have fewer social rights, or diminished rights of way compared to a pedestrian. Conversely, as a working machine, it may be playing an important economic role, or it may be delivering something critical to someone who has protected social rights. Perhaps some specially-marked robots might inherit those protected rights in the way that a helper dog inherits some social rights-of-way from the human it is helping. A sidewalk robot may be unable to cross certain barriers or obstacles that an able-bodied human can traverse; it may be subject to vandalism or mischief in ways that are different or more frequent than those confronting a wheelchair user; and it might have a very much lower height profile compared to a wheelchair user, making it less visible to pedestrians unless specially marked or equipped in some way with flags, lights, or motion alarms.

As an autonomous machine, the delivery robot has no onboard or accompanying 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 the average human. Semi-autonomous robots might be teleoperated, but the ability of a teleoperator to engage in social signaling might be quite limited. An example of this might be teleoperated micro-mobility devices such as three-wheeled scooters being guided to a docking station.

The eventual introduction of ambulatory delivery robots would add more considerations, such as robots that can navigate difficult terrain or stairs and doorways, or easily step aside for passersby — and perhaps even cooperative robots carrying shared loads.

Operating principles for robots on sidewalks

To provide a proper grounding for operations in a shared, human social environment, the standard must rely on a list of general rules for robots on the sidewalk mixed with pedestrians of all abilities. These pedestrians may have pets, carry packages, push, drag or ride in wheeled objects, containers, chairs, scooters and more. Some of the proposed rules are:

1. Robots must grant rights-of-way to humans in close proximity; but rules of engagement must consider how to prevent a robot from being immobilized for an extended period in a crowded circumstance.
2. Robots must respect the shy distance normally observed by humans walking or standing in a public place.
3. Robots must not harm or alarm humans or animals on the sidewalk.
4. Robots must be visible and/or audible to all humans on the sidewalk (flags, lights, sounds). This is not only to accommodate people who may have visual or auditory challenges but to avoid mishaps with distracted pedestrians.
5. Robots must signal their presence, priority, and properties to other machines. This enables rights-of-way decisions and can help differentiate autonomous mobility devices from human operated devices, humans, and non-mobility entities.
6. Robots must not diminish the privacy of people on the sidewalks; this would constrain recordings and retention of recorded data.
7. Robots must not diminish the security of humans or other machines on the sidewalks.
8. Robots might be guided by localized infrastructure, high-resolution mapping, and so on, but any additional infrastructure cannot negatively affect (make more cluttered, riskier, more confusing, or less accessible) the use of this shared space by humans.

A preview of ISO/4448

ISO/4448 "Intelligent transport systems – Sidewalk and kerb operations for automated vehicles" is expected to be published in four parts, approximately one per year starting in 2021.

Part	Title	Publication target	Description
4448:1	Data definition	2021	Part 1 sets out the full data definitions and structure for use-procedures and protocols for 4448:2 - 4448:4
4448:2	Kerb/Curb	2022	Procedures and protocols for using curb for loading / unloading (queue matching)
4448:3	Pavement/sidewalk	2023	Procedures and protocol for using sidewalk for delivery, including automated human-transport devices
4448:4	Integration of kerb and pavement/sidewalk	2024	Procedures and protocols for integrating automated vehicles and devices at curb and on the sidewalk

4448:1 addresses all the tools needed for the remaining three parts including: dimensions, permissions, properties, attributes, time-date definitions. It provides procedural communication, queue, and protocol structures.

4448:2 provides the procedures and protocols to find, prioritize, reserve, schedule, accept, queue, decline, bump, and release vehicles plus numerous other aspects of managing a ground control system for loading and unloading in allocated areas in urban ground environments. While designed for unmanned vehicles, 4448:2 can apply to non-autonomous taxi and ride-hail vehicles as well. Activities covered by this section are limited to matters of stopping in order to load and unload people and goods, as well as provisions to accommodate service vehicles that would provide maintenance services such as snow removal or street sweeping.

The data descriptive of stopping a vehicle to load or unload is very similar to that needed for vehicle parking. Hence, ISO/4448 uses as many data definitions as possible from existing standards for parking, in particular, ISO/5206. However, a key difference is that the focus of parking standards relates to short-term storage of vehicles while not being used, whereas 4448:2 relates entirely to a temporary pause for loading and unloading. Data systems that deal with both parking and loading will need to reference multiple standards.

Here is a simple scenario to illustrate:

> *The loading spot that was assigned for Alice's taxi to drop her off is withdrawn just prior to the taxi's arrival at the spot. This might have happened because the spot was claimed for a higher priority vehicle, or a previous vehicle was unable to evacuate the spot, a scofflaw parker, or some other unforeseen circumstance. While there would likely be a procedure for responding to each of those reasons, a solution in this case would be agnostic to the specific reason.*

The taxi requires a new space to drop Alice, but there is nothing available close enough to the requested time slot that is suitable to the original assignment. This can be complicated by the nature of congestion or the original assignment; for example, Alice might have a disability that requires something very close to the original spot that was assigned.

- *How should this be handled?*

4448:3 provides similar procedures and protocols for robotic devices providing delivery and other services in order to request, prioritize, reserve, schedule, accept, queue, decline, bump, or release access permission to a blockface. It also provides a number of rules to inform its micro-navigation behaviors along that blockface. Here is an example scenario:

A sidewalk robot from LunchBots is delivering several lunches to a building 400 meters away. It approaches a passage on the pedestrian clearway that is too narrow to traverse while any other pedestrian or robot is within that passage. The narrow passage in question was not included in the robot's internal map of the sidewalk features because the passage was made narrow just this morning by the placement of a sandwich board to advertise a sale.

- *What must this robot determine before it can proceed to move through this narrow passage?*
- *How quickly should it be permitted (or constrained) to execute that passage?*
- *What sound or signal should the robot display (if any)?*
- *How far beyond the narrow passage must the robot assess its ability to proceed without forcing a pedestrian to wait or step aside at the other end? In other words, what steps is the robot expected to take so as not to inconvenience or interrupt a pedestrian's progress?*
- *If the robot has entered such a narrow passage and a pedestrian subsequently enters from the other end, how must the robot respond?*

4448:4, the final part in the series, integrates the procedures and protocols from Parts 2 and 3 in order to coordinate the expected logistics systems needed to allow a delivery van carrying multiple packages to park and deploy one or more onboard sidewalk delivery robots. This will require sufficient space at the curb as well as reservations at both curb and sidewalk and, potentially, space for staging or waiting until all its mobile components are re-united.

The reason this integration needs particular consideration is that each delivery van and its robots are elements of a whole subsystem. Planning and positioning of all these elements must be coordinated among themselves, and also among other systems of automated and non-automated vehicles. Hence, the nature of requests, priorities, reservations, etc. are more complex than that for individual vans or individual sidewalk robots.

Maturity or readiness models

A critical aspect of preparing for automated vehicles at the curb or on the sidewalk is to be able to determine the readiness of a specific area within a city. This question can be asked in two ways: "Can I safely provide permission to deploy a described type of automated taxi or sidewalk robot at this particular curb or sidewalk?" or "What preparations must be made in order to safely attract deployment of a certain type of taxi or sidewalk robot at this particular curb or sidewalk?"

Whether a city council is asked to permit these vehicles and devices or whether it, or a business improvement district (BID), seeks to attract them, a gap analysis is required. That would involve considering multiple system and governance attributes for several classes of vehicle capabilities. Here are a few examples:

- What regulations should be in place if only teleoperated devices are permitted? What about regulations for fully autonomous devices?
- Depending on the level of autonomy to be permitted (or attracted), what human-readable signage would be needed for pedestrians and other vehicle operators?
- What must be done to ensure that robotaxis are not loading or unloading in traffic or on bicycle lanes?
- When and how can city enforcement personnel (police) stop, examine, rescue, or seize a robotic device?
- What sounds, lights, signals, or markings should be regulated for these vehicles or devices to ensure ADA/CDA compliance?

Answers to questions such as these are dependent on the technological capabilities under consideration. Hence several tens of readiness attributes are being detailed for each of the six classes of sidewalk operating domains. The tables on pages 24-25 show examples of several attributes summarized across the six classes. The details of this model are not yet settled, and are expected to change and expand as the draft standard matures in order to guide a governance process.

These attributes will populate a maturity model or readiness model to gauge the automation-readiness of a block-face or an area of block-faces. Such modelling involves the assessment of sidewalk and/or curb to rate its suitability for use by automated vehicles at various "levels," and the gap analysis required to operate a defined level of automation in those spaces. While gap analysis is not in scope of the standard, the descriptions of the sidewalk and curb that are necessary for machine operations are in scope and provide the necessary and sufficient input for such analysis. Hence, this is included as an Informative appendix to help ensure all requirements are discovered.

To be declared ***fit*** as a given maturity Class, a block-face must be physically suitable (arranged, dimensioned, graded, maintained, signed, marked, connected, and mapped) for the automation level(s) intended.

To be ***certified*** as a particular maturity Class, a blockface must be determined as fit for the intended level(s) of automation and ***governed*** for that Class.

To be said to be ***governed*** as a prescribed Class, a blockface must be certified, regulated and enforced at the intended level of automation for that Class.

Any lapse of fitness or governance must be recognized and made known to any realtime management system as a decrement in fitness or governance may cause delays or failures.

The sidewalk and curb are independent of each other, so that a curb and its adjacent sidewalk may be categorized in different maturity Classes. This has implications for automated logistics that may require integration between road vehicles and sidewalk vehicles such as delivery robots.

TABLE 1a

Class	Descriptor	Permission	Sign/Signal	Regulated
0	Unstructured ("wild west")	No structured consideration for any purpose. No restrictions	Nothing signed, marked or prepared	Existing bylaws, such as ADA or local, may be active, but less likely to be enforced. No effort to update is expected.
1	No hands-off automation permitted	Any machine must be directly operated by a human (no teleoperation, no AI operation)	No signage required, but any city where Class 1 is the current or expected default, it would be prudent to make this known.	ADA regulations (or country equivalent) and normal pedestrian regard should be expected.
2	Assisted automation permitted	Line of sight (LOS) Teleoperation, among likely mostly fully manual vehicles & devices	Signed for LOS-only: "Any robotic device must be accompanied by a human in direct eye contact" (make flags, light, sounds, speed limits, rules citywide.)	No automation without a proximate human in control (e.g., "safety operator" or "steward")
3	Conditional automation permitted	non-Line of sight (nLOS) Teleoperation, among other mostly fully-manual vehicles & devices	Signed, marked, including conditions for human use. If conditions are dynamic, variable signage is updated to match the frequency of the dynamic change. All analog information must match the digitalized versions. All this needs standardization, including the "twining" of analogue and digital signage/signals.	Permits [1] no automation, [2] teleoperation, and [3] conditional automation (= available on-demand oversight = teleoperation). "Conditional" means a bot operates on its own until it demands assisted operation from a human.
4	High automation permitted	Automated operation mixed withTeleoperation, and fully-manual vehicles & devices	Signed and marked for any human sharing this space. Vehicles have sound/light/ flags(?) for proximate human safety. All instruction to, or coordination of, vehicles much be digitalized, and realtime (V2X). All this needs standardization.	As Class 3 + High-Automation. "High-Automation" means a bot can operate in described areas, times or other conditions (e.g., weather) without active oversight. But there must be "Assisted Operation" available from a human within a defined lag.
5	Exclusively for full automation	Automated devices only. No other devices or non-involved humans.	No signs or marks required. Only machines that operate without analogue signage are permitted. Only humans trained to traverse or occupy this space are permitted. Optional: signs to warn untrained humans to "stay away."	Full automation permitted. (Should an area be exclusively for automation? I do not think exclusive "full" works for an area but only as a device description.)

Table 1a: This is a sample matrix extracted from a much larger matrix describing a number of sidewalk properties, behaviours and guidelines that differ as greater degrees of automation are permitted or supported. In this sample, permission and signage are defined. When this matrix is fully defined, the detail will be much greater. Classes 0-5 are sidewalk classifications. They define what is permitted/expected within each respective sidewalk Class.

TABLE 1b

Class	Descriptor	Min Failure Mode	Failure Resolution	Failure Reporting
0	Unstructured ("wild west")	Injury, serious mischief or crime requiring emergency aid or help	Local municipal guidelines	Local municipal method such as 911
1	No hands-off automation permitted	As Class 0, plus any pedestrian or ADA-related, complaint.	As Class 0	As Class 0
2	Assisted automation permitted	As Class 1, plus observation by an enforcement officer trained to recognize and report unqualified vehicles.	Fines are appropriate. Impounded device. (It is possible that the owner/operator cannot be located).	In addition to a 911 method, a manual on-line reporting system open to any user. Such a system implies a human or machine inspector, a citizen, would have access to a simple way to report a problem. 911 is crude in a highly digitalized environment. It would make more sense for a way for the person reporting use a smart device to send the location and a device QR code and have it automatically queued for resolution.
3	Conditional automation permitted	As Class 2, plus a robot without an operator, and stuck, stalled or otherwise unable to operate in the immediate conditions.	Signed, marked, including As Class 2, plus device must self-report its circumstances.	This is assessed by any form of conflict with another vehicle, a human operator, an element of infrastructure, etc. This may be reported by another vehicle/device (a tattle-tell app); this may be signalled by a common distress signal (not yet determined).
4	High automation permitted	As Class 3, plus a robot without an operator, and stuck, stalled or otherwise unable to operate in the immediate conditions.	Must signal fact of failure to other machines still operating within a radius. This is for safety and recovery reasons. This needs to be standardized in a way that protects manufacturer privacy AND protects the viability of the shared human space.	This must be assessed and reported digitally and in real time according to a procedure defined by the standard. In the event that cannot be executed, this may also be assessed by any form of conflict with another vehicle, a human operator, an element of infrastructure, etc. This may be reported by another vehicle/device (a tattle-tell app); this may be signalled by a common distress signal.
5	Exclusively for full automation	As Class 4, plus a robot requiring any human assistance.	As Class 4, but needs to be standardized in a way that protects manufacturer privacy AND protects the safety of any humans operating that space (usually trained maintenance and recovery personnel, since untrained human personnel are not permitted in the operating radius).	Same as Class 4

Table 1b: This second sample matrix details failure modes and failure recovery expectations.

SUMMARY

This white paper has argued for greater attention to the impending arrival of delivery and service robots on our sidewalks. It has described a ground-traffic control standard to address the loading and unloading of ground vehicles at curbs and the operation of robotic devices on sidewalks and at intersections. Without such standards, innovators will have insufficient guidance to develop the operational details of their technical solutions, fleet operators will be unable to collaborate effectively within tightly constrained urban spaces, and cities will be unable to express regulations in digital formats that will uniformly operate in the vehicle-to-everything (V2X) systems that control multiple fleets of large numbers of vehicles to move people and goods, as well as to provide services.

What is particularly problematic about preparing for automated vehicles and devices is the distance between the independent perspectives of municipal decision-makers and technology innovators. This is not new. Civil servants will be concerned with safety, public perceptions, enforcement, monetization, certification, infrastructure support, compliance with existing regulations, and the like; entrepreneurs will be focused on access, navigation, mapping, coping with terrain, sensors, avoiding transient obstacles, following traffic rules, vandalism, optimization, costs, and so on.

The holders of each of these perspectives may appreciate and even express an interest in the other's point of view, but each brings a different critical focus. Ideally, the relationship between city hall and entrepreneur would be a simple collaboration, but reality is always more complex. There are two significant and unavoidable issues: first, there are multiple players, such as the various advocacy groups that may take positions that differ from one or both of the main protagonists; second, monetization will be as critical to the city as to the entrepreneur. Together, these issues readily take on zero-sum behaviours.

The intention of this draft international standard is to provide a consistent and coherent framework from which entrepreneurs can innovate, cities can regulate, and advocacy groups can express preferences. It creates part of the urban mobility canvas for negotiating our way through the next three decades of overlapping automated and non-automated vehicle and robot technologies.

While the impending arrival of SAE Level 4 automation was the impetus for ISO/4448, this standard is technology- and automation level-agnostic. It is intended to enable the regulated operation of any level of automation — including Level 0 — in any city that wishes to govern and manage automated vehicles and devices.

At the same time, realizing that no two cities — or even two areas within a city — are completely alike, the standard offers few fixed measures or metrics. At best, ISO/4448 occasionally provides defaults or ranges. But for every operating feature, each city, and each local area within each city, can choose those data and measures that provide the operational properties required for that local area.

However, the operating data, procedures and communications protocols will need to be rigidly standardized for cities to express their regulations in ways that allow governance over the full range of participating vehicles and operators. The task cities need to undertake now is to ask how they wish this technology to be deployed and regulated and to determine how to do that.

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