WHITE PAPER

Making room for robots

A Draft ISO Technical Standard for Ground-based Automated Mobility: Loading and Unloading at the Kerbside and Footway

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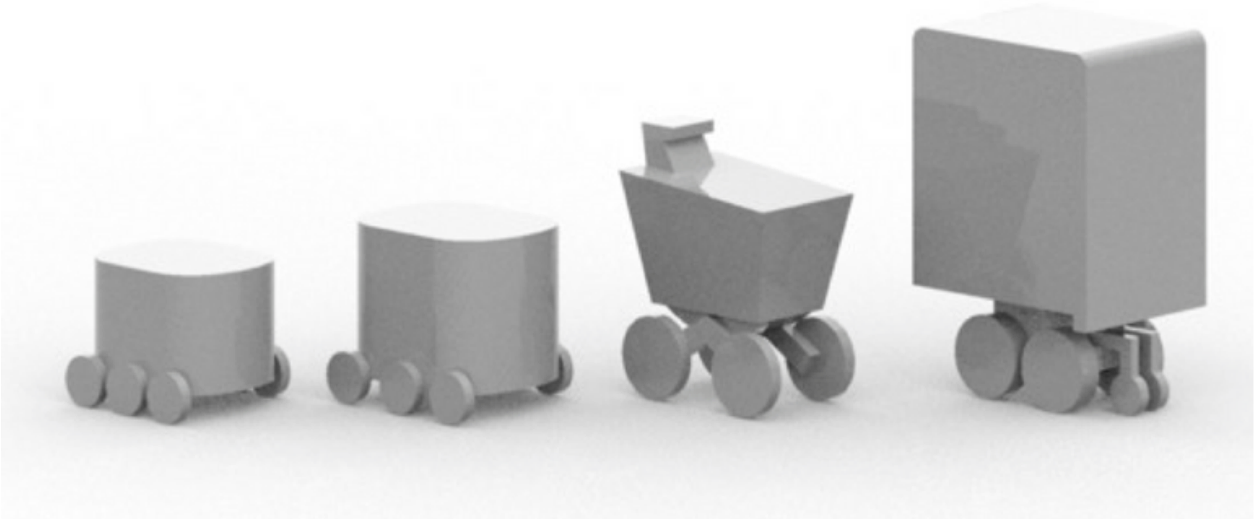
PREFACE

The arrival of automated vehicles at the urban kerbside and on our footways[1] requires an overhaul of how we operate and monetize these spaces. This challenge demands increasing degrees of digitalization, new communication technologies for operation and coordination, and new levels of collaboration between governing institutions and system providers.

A draft technical standard, ISO/TS 4448, is being prepared to define the operating data and procedures to guide potential ground-traffic[1] control operations and inform relevant vehicle operators and system makers. This paper provides a preview of the intention, scope, and critical components of this draft standard.



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[1] The usual meaning of "sidewalk" is too limited for this paper, as the draft standard, ISO/TS 4448, applies to every type of shared pedestrian space: pavement, crosswalk, pathway, walkway, laneway, etc. The draft standard uses the term "footway" to recognize that most of these spaces are pedestrian spaces. The ISO technical committee working group is still settling on a term that is inclusive of separated active mobility lanes that might admit robots, but exclude pedestrians.

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INTRODUCTION

It is anticipated that in the very near future, many urban and suburban jurisdictions will consider preparations for robotic cars, taxis and trucks and other forms of automated vehicles carrying passengers and goods. At the same time and in many of the same jurisdictions, service robots may be deployed for maintenance activities such as snow removal, trash pickup, sweeping, or surveillance. These vehicles and services will be located in public spaces in towns and cities where kerbside and pedestrian space is 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 reached unsustainable conditions. Some of these challenges 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 as well as kerbside storage for these vehicles in many cities.

Since early 2020, the onset of the COVID-19 pandemic imposed yet more demands on footway and kerbside spaces including social distancing, an uptick in micromobility, and in some places, increased demand for kerbside dining space. This tends to create wider pedestrian rights-of-way to accommodate 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 grows for cleaning, maintenance, and snow removal for these expanded and complex places.

To this mix, we expect to add the delivery of passengers and goods using driverless

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vehicles that load and unload at the kerbside, as well as a nascent industry for last-mile delivery of goods via footway robots.[2] Indeed, prior to 2020, such robot systems were already operating in several cities and several are now in commercial service.

All of this implies further increases in traffic volumes at kerbsides and footways. The introduction of automated vehicles without human accompaniment will necessitate highly automated (digitalized) management. Taken together, these developments 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 that cities relied upon prior to 2020 were already unsustainable — their design and governance shortcomings having been made increasingly evident by the pandemic. Conventional kerbside parking practices are insufficient to support the loading and unloading of the anticipated automatic vehicle systems without additional data and procedures to support ground-traffic control systems.

Cities will need new operating guidelines for kerbsides and footways that will be used by automated taxis and service 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. All this must be done without blocking crosswalks, bicycle lanes, micromobility users, no-stopping areas, or transit stops — common infractions committed by taxis and delivery vehicles now. Mixing these automated service robots with human-operated vehicles must be done safely, without inconveniencing active transportation users, pedestrian traffic, and with regard to human accessibility challenges.

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[2] These devices are also known as delivery robots, sidewalk robots, or personal delivery robots. The expression ‘footway robot’ is used here for consistency with the draft international standard and to be inclusive of all service robots that might traverse footways.

Five intentions for standardizing kerbside and footway automation

1. Safety and conflict avoidance

As the number and variety of automated and non-automated mobility vehicles and devices increases, 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 footways. Machines that operate at kerbsides and on footways 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 behaviours and guidelines for real-time resolution. These guidelines require terminology, procedures, communications, and systems.

2. Planning

Projects to re-format and reorganize streets, kerbsides or footways will need to build and shape these spaces to be workable for vehicles and devices whose operating characteristics may be different, or differently constrained, from 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.

3. Commercial

Some kerbsides and footways 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 requires shared terminology, procedures, communications, and systems since we can expect multiple vehicle types, providers and operators.

4. Operations

The kerbside and footway 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 footway 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.

5. Legal, liability and insurance

Any kerbside or footway is a public space shared by many types of users including local residents, vendors, visitors and shoppers, both able-bodied and 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 behaviours in those spaces, is necessary to assign or determine liability. This shared understanding and description requires common data, procedures and system definitions.

Standard components

Draft technical standard ISO/TS 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. It also addresses the allocation and movement of service robots for delivery, garbage removal, sweeping, washing, snow removal, repair, food trucks, construction, and more in public spaces such as kerbsides and footways that are shared with pedestrians and other automated or non-automated vehicles.

Such systems are intended to enable cities to manage carefully defined and growing areas (operational design domains) to accommodate any number and variety of vehicles operated by any number of operators (public, commercial, private) for these various activities.

The next sections 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/TS 4448.

Since this work is still in early draft stages, this outline may differ from the final form of the standard:

1. Robotic road vehicles for passengers or goods
2. Service robots for footways 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 footway robots and human accessibility devices
   d. Footway robot access: surface conditions and path dimensions
   e. Service robot access permissions
   f. Service robot behaviour
   g. Service robot social communication
   h. Integrating robotic kerbside and footway access
   i. Robot cybersecurity
3. Certification for use
4. Kerbside and footway certification for automation
5. Robot weather-worthiness

Layer	Parts of Standard	Purpose
Data & security	1: Parts overview 2: Data definitions 3: Communications & cybersecurity	Required base for all parts of the standard. Facilitates integration between roadway (kerbside) and footway systems, as well as governance across integrations, system instances and multi-vendor robotic fleets.
Application	4: Load/unload at kerb 5: Footway access by robots 6: Integrate kerb and footway goods movement	Support coordination and logistical management activities for multi-vendor robotic operation in public spaces that include non-involved pedestrians, motorists, and cyclists. Includes logistical matters such as access permissions, reservations, and queueing, as well as aspects of system setup, forms of exception handling, and inventory (space) updates.
Behaviour	7: Robot behaviour in public spaces 8: Robot-human communication	Define/communicate the behavioural rules of robots while operating in public, shared spaces. This includes rights-of-way, lights, sounds, gestural, motional, and directional.
Certification	9: Kerb readiness for automation 10: Footway readiness for automation 11: Weather-worthiness (small devices)	Either urban kerbside and footway spaces must be suitably prepared for robotic vehicles and devices, or existing spaces must be certified as suitable; small robotic devices must be determined able to operate safely in various weather and environmental circumstances.

Robotic road vehicles for passengers or goods

Robotic ground transportation systems for passengers and/or goods comprise vehicles, load/unload places, schedules, prioritization algorithms, and management processes. 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. A system to operate these will be analogous to a passenger airline traffic control system with 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 — each of which are sub-optimal, but workable. But we can already 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 in front of the same building, each blocking a bicycle lane while delivering one or two packages. 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 (region) to accommodate the complexities of admitting multiple passenger and goods transport operators sharing a large number of loading/unloading places. This is analogous to a computer operating system managing an arbitrary number of programs and memory locations.

A system to manage loading/unloading of passengers is primarily concerned with trip terminus events and less so with the routes between them. However, traffic flow and congestion along those routes

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naturally affect the real-time management of terminating events. Uncertainty in trip times will cause re-scheduling, re-queueing, 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 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 three-fold: passengers, nearby pedestrians with accessibility challenges, and the accessibility considerations of non-automated 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. [1]

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 cargo.

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 control 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 between 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 transport goods. (See "Integrating robotic kerbside and footway access," below.)

Service robots in pedestrian footways

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.

Cities have managed the loading and unloading of road vehicles on or at the kerbside of roadways for centuries. Repurposing the current kerbside-management practices for automated road vehicles is easy to contemplate, but most city planners recognize that their capacity to manage these issues has been sorely tested by high volumes of parked vehicles, upticks in e-commerce, active mobility modes, and social distancing requirements during the coronavirus pandemic.

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

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

But there are critical differences. At the kerbside, vehicles queue to become stationary in order to load/unload. On the footway, service robots queue to operate (move, navigate, work, and wait) in ways that are mixed with pedestrians of all abilities. People occupying this space walk pets, carry packages, push, drag or ride on wheeled devices, chairs, scooters or boards. They travel in small groups, meander slowly, stand in clusters at intersections or transit stops, and they window-shop, line-up, run, or weave from one side of the pedestrian clearway to the other. Such normal pedestrian behaviours 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 behaviours may be protected or curtailed by the introduction of service robots. While 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 section outlines operational, governance and accessibility principles for footway robots.

Guiding principles for operation & governance

Guiding principles for operation of robots in public spaces

To guide the development of a formal standard for robot behaviour, a series of guiding principles are used:

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 in emergency contexts (police, fire, ambulance).
2. Robots must be deployed to respect **shy distance**, the cultural and contextual, inter-pedestrian distance normally observed when walking or standing in a public place. 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 footway.
4. Robots must be **apparent** (visible and/or audible) to all humans on the footway. Equipping robots with flags, lights, sounds etc. is necessary 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 certain 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 humans or businesses using or residing near footways. 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 footway. This also applies to the physical and cyber security of humans residing and trading near such footways.

The deployment of a standard must necessarily impact, and be impacted by, governance.

8. Robot infrastructure must be **non-intrusive**. Robots may be guided by localized infrastructure, high-resolution mapping, and other data or technologies. But any additional infrastructure cannot negatively affect the use of this shared space by humans by making it more cluttered, riskier, more confusing, or less accessible.
9. Robot **occupancy** within a defined area must be controllable to prevent unacceptable congestion on public footways.
10. Robot **waiting and stand-aside behaviours** 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 footway.

Guiding principles for governance of robots in public spaces

In her 2020 paper, “Robots, Regulation, and the Changing Nature of Public Space,” Kristen Thomasen outlines three views of public space that might guide a regulator of footway robots:

- Communal Public Square
- Regulated and Orderly Public Square
- State-Owned Property

Depending on how these views influence relevant regulations, robots would be governed locally in more or less restricted ways.

An international standard must necessarily be agnostic to such legal theory. The primary goal of standardization is to create a level of consistency in the design and certification of equipment, systems, operations, and processes. However, since the machines, systems and processes being standardized operate in public spaces, in large numbers, for many purposes[1], and among many pedestrians, the deployment of a standard must necessarily impact, and be impacted by, governance.

Hence, it is critical for the standard to provide the necessary and sufficient operating data and procedures that legislators in any country, state or city can adapt to the governance needs and socio-legal preferences of their jurisdiction. They, in turn, must also 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.

Average human pedestrian skills are unlikely to improve but over the next decade, robot skills will improve dramatically.

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 comes down to whether the size and comfort of that clear space is 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 the 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 time, 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).

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

Several examples of current U.S. state legislation that have been enacted since 2017 indicate that delivery robots must always give way to pedestrians. 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 control the ingress of robots to a block-face or pathway segment so that their occupancy (number in a particular area at one time) can be limited. This reduces, but does not eliminate, the effect of greedy spatial algorithms.

Related to this, it is possible that a robot programmed to give way to pedestrians and maintain a shy distance may find itself temporarily constrained for unexpected or unintended periods of time, especially in congested foot traffic (a ‘robot trap’). Naturally, operators of such robots would like to avoid such circumstances, but it may not be possible to do so on every occasion. This is another reason to consider occupancy counts according to footway configurations and times of day so as to minimize the likelihood of such events, and minimize resolution 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 robot traps and provides a level of governance that acknowledges local contexts so that occupancy limits may act locally and dynamically.

Similarities between footway robots and human accessibility devices

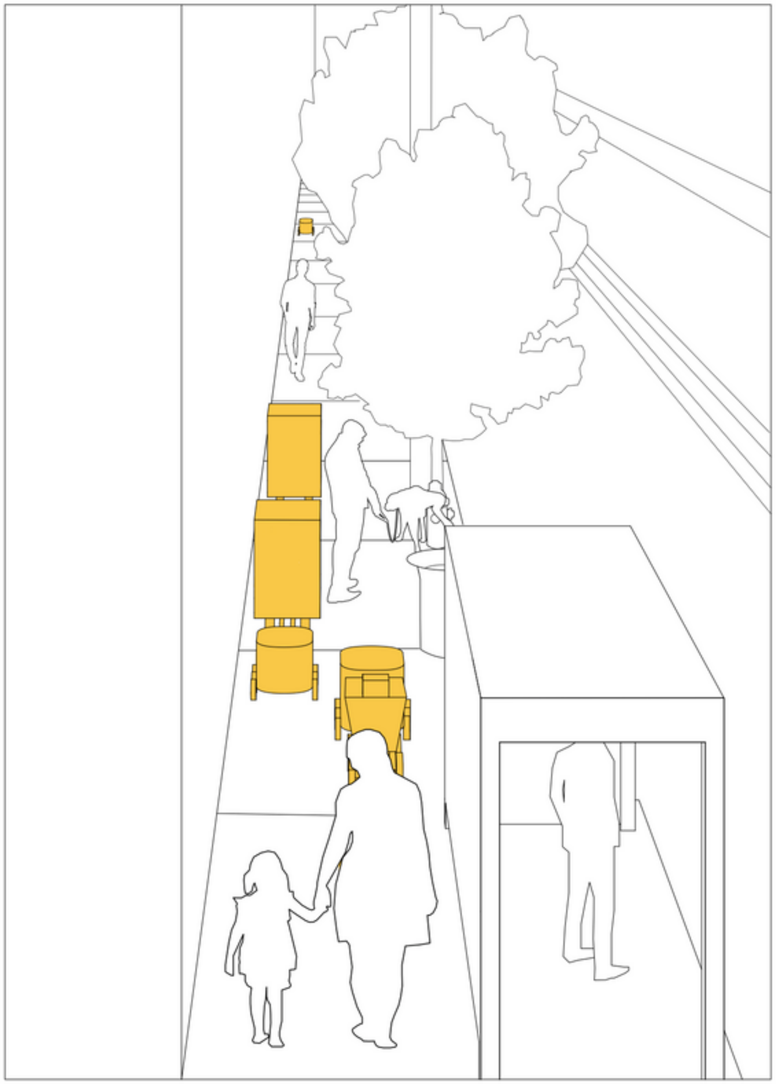
There are a number of useful comparisons that can be made between wheeled footway robots and assistive devices such as wheelchairs or scooters.

As a vehicle, the wheeled (non-ambulatory) footway robot has characteristics similar to a wheelchair: it can easily travel faster or slower than the average (walking) pedestrian and it must be able to traverse uneven, damaged, steep, sloped, or potholed pavement, as well accessibility features such as kerb cuts. Unlike[1] an ambulatory, abled pedestrian, a wheeled robot cannot readily step aside or streamline its width by turning sideways. Basically, the wheeled footway 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 footway service robot might be relegated fewer social rights or diminished rights-of-way compared to a pedestrian. Conversely, 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. A wheeled 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 much lower height profile compared to a wheelchair user, making it less apparent to pedestrians unless specially equipped in some way (flag, lights, sound, or beacon).

As an automated machine, the footway 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 the average human. As a semi-automated 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 micro-mobility 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 comparisons suggest that a standard for footway robots should consider alignment with existing accessibility standards relative to wheelchair use. Such goal-congruent alignment provides opportunities to address footway design and configuration to intentionally benefit accessibility goals while standardizing robot access and flow.



How will robotic traffic control work in shared pedestrian spaces? Walking with robots means non-involved humans of every physical ability competing with multiple vendors, each with a variable purpose and an independent schedule.

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 footway service robots cannot anticipate all possible robot designs in terms of weight, wheel diameter, or other physical properties related to roadworthiness, the standard defines a way to describe the surface properties of a footway such that a logistics operator can make a decision — likely automated — regarding the relative suitability of a vehicle to travel on a particular surface.

There are many aspects to surface features 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. A separate part of the standard, below, addresses climate and weather features.

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 size and configuration 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 footways 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 enabled by default to address human accessibility certification at the same time.

Service robot access permissions

Access permissions differ from access conditions. In the case of access conditions, described above, a jurisdiction would be declaring information about the footway. In the case of access permissions, the jurisdiction would be demanding information about (promised behaviour from) the machine.

A governing jurisdiction may constrain access by restriction (e.g., weight, width, height, length, noise, emissions, or schedule), and by requirement (e.g., lights, sounds, flags, registration display, or weather-worthiness). Some of these constraints might be time-dependent or even dynamic.

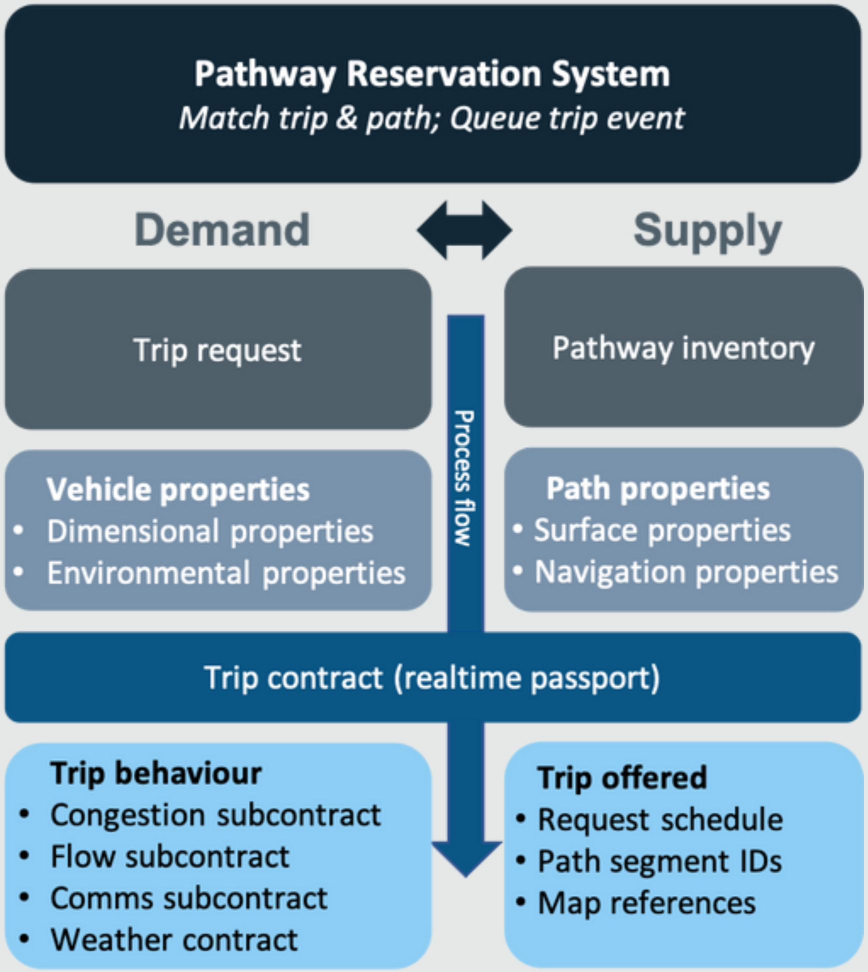
It is the three-way match among what a footway offers, what a robot declares about itself, and what a logistics operator requests (such as schedule and then-current footway occupancy counts) that enables the assignment between the robot and its route among footways in its bounded operating domain.

Access permissions are affected by the purpose of the service robot. The route plan and permissions for a small delivery robot would be different from that for a robot snowplough.

For this reason, a system for multi-vendor coordination and pathway reservations would need to manage information about conditions, dimensions, and permissions and would itself require a degree of real-time monitoring even if such robots became fully autonomous as individual machines.

Today, mobile robots are used within constrained operating domains monitored by a human operator that sometimes intervenes for one or two robots concurrently via onboard cameras. When we reach a plurality of fleets, operators, and service purposes, intensive human teleoperation will become untenable except for emergency oversight and resolution. Fully digitalized coordination from ground control systems using IoT networks and real-time scheduling systems will be required.

One critical problem when managing multiple machines from multiple vendors with each machine assigned to an independent project (delivery, sweeping, monitoring, etc.) is to ensure safe, continuous flow so that each machine can achieve its goal and that proximate, non-involved pedestrians and drivers are not inconvenienced or disturbed. One of the more obvious applications for ISO/TS 4448 would be a system to manage controlled access to sidewalks, footways, bikeways, and laneways.



Such a *pathway reservation system* could control congestion, manage flow, and distribute real-time situational updates.

1. Trip and vehicle properties (demand) and pathway parameters (supply) are each **defined** using ISO/TS 4448 standardized data and metrics.

2. The reservation system accepts a logistic **request** for a trip. This request would be matched with a system-optimal available pathway.

3. Each **match** involves multiple vehicle and pathway properties.

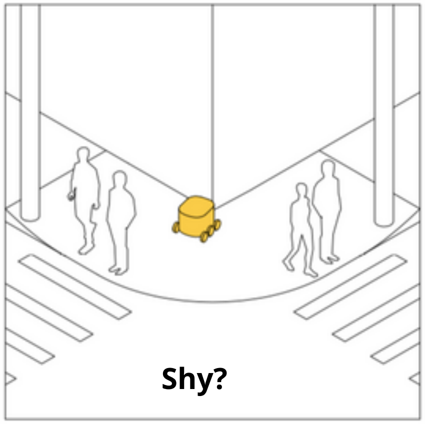
4. The resulting match would generate an agreement, a "trip **contract**."

5. The trip contract offers a specific pathway and time window. It acts as a passport for an agreed task. The logistics operator agrees to certain behaviours and properties regarding the robot to be used.

Service robot behaviour

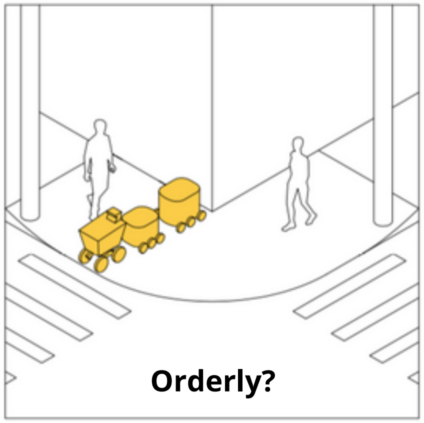
Once a robot’s route is determined and granted, the device is expected to behave in particular ways. This will mostly be mediated by software within the machine as governed by local settings and limits. These behaviours include speed, travel direction, shy distance, schedule, and other aspects regarding waiting, rights-of-way, and clustering. These behaviours comprise what are essentially “rules of the road” for service robots in public, shared places/spaces. In this regard, the standard would inform many of the elements of a jurisdiction’s “footway traffic act.”

Importantly, there would be a need for local and variable changes to settings and limits — perhaps delivery speeds 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.



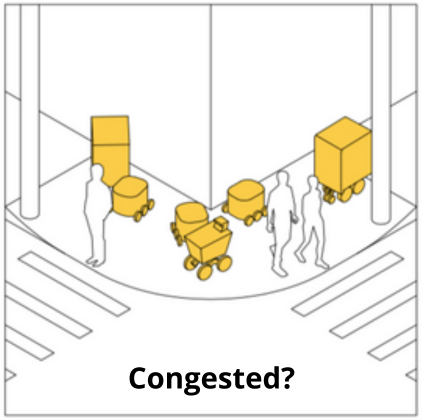
Shy?

Robots may be expected to stand back, to maintain a "shy distance," to always defer to humans. How would this impact delivery reliability, the effectiveness at ploughing snow, or the profitability of their operations?



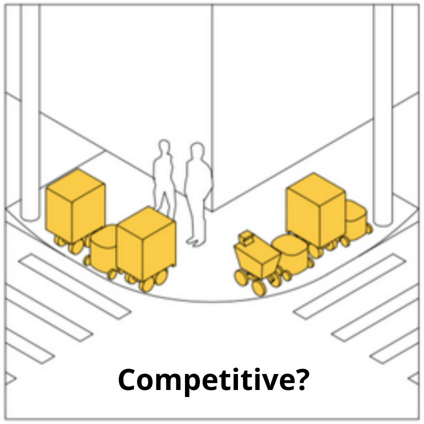
Orderly?

Robots may be expected to line up in an orderly fashion while waiting. How should such line-ups be organized? Oriented? Minimized? How might this impact spatial use by humans?



Congested?

Robots may be expected to stand aside from pedestrians (shy distance), but their numbers might not be limited. How might this impact spatial use by humans? How would numeric limits be determined?



Competitive?

Robots might have very few traffic-behaviour constraints besides, say, weight, speed and “don’t cross on red.” Their operators may be competitive for space, would they not? Then what happens?

Service robot social communication

Among the special aspects under development for the standard are uniform movement indicators and social communications. Because pedestrian movements can be more chaotic than vehicular traffic on roadways, 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 used by pedestrians. These signals 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 4-tuples (lights, sounds, gestures and radio signals) so as to be understood by pedestrians with auditory or visual challenges, as well as by proximate robots.

Integrating robotic kerbside and footway access

One of the projected use-cases for robotic goods delivery envisions a larger ‘parent’ delivery van, or ‘mothership,’ stopping at a kerb or other suitable location convenient to several deliveries, and then releasing one or more ‘child-robots’ to complete the last portion of the deliveries on the footway.

To make this work, a degree of coordination is needed between the load/unload reservation for the delivery van and the permissions needed by its child-robot(s) to travel on the intended footway(s). This is provided in the standard.

Such real-time operational coordination between kerbside and footway is new and will be a mapping and data challenge for those larger cities where these domains may be handled by separate city departments.

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.

Certification for use

Kerbside and footway certification for automation

A critical aspect of preparing for automated vehicles at the kerbside or footway is to determine the readiness of a specific location or operating domain. This question can be asked in two ways: “Can a jurisdiction safely provide permission to deploy a certain type of automated taxi or service robot[1] at a particular kerbside or footway?” 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 footway?”

Whether a municipality or community association is asked to permit these vehicles and devices, or whether it 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 bicycle lanes?
2. What human-readable signage is appropriate in order to permit or encourage a given level of automation?
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 police or other enforcement personnel 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 multiple readiness attributes for each of several “maturity” classes for kerbside and footway operating domains. These attributes and maturity classes define a readiness matrix to be used to gauge the automation-readiness of a specific kerbside or footway, or a larger, contiguous domain comprising multiple kerbsides and footways.

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

NAVIGATING OBSTACLES

Hourly obstacles may occur especially related to transit stops. Some blockfaces might be avoided at busy times, implying robots may have to take longer-than-optimal routes, or may not be able to deliver to certain addresses at certain times.

Weekly obstacles such as garbage collection are recurring and may require new rules regarding placement of waste bins or may mean that some footways cannot be used on certain days. Some robots will be able to circumvent them if they are able to use the roadway.

Permanent obstacles need to be addressed or avoided, such as especially narrow passages between a wall and a utility feature, or sidewalks that terminate mid block.

Random, short-term obstacles are common. Rules may be used to reduce these occurrences; alternatively, robots must be able to request detours or be permitted to enter the street to avoid obstacles.

Irregular, mid-term obstacles occur frequently and may remain for weeks or months. Some robots will be able to circumvent them, especially if they are able to enter the roadway.

Robot weather-worthiness

Robots, especially smaller, human-scale machines that perhaps weigh under 50 kilograms and might be designed for footway use at pedestrian speeds, may be less robust in extreme weather or climate conditions than would be the two-ton cars or trucks we use today. Some of these conditions might disable such robots and leave them as hazards along the pathway. Severe weather conditions such as extreme winds might blow a robot into road traffic, or cause a robot 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 temperature, wind, rain, snow, ice, and sand. It also describes criteria for certification of machines and conditions such that a jurisdiction can determine when various devices must suspend operations and move to a protected storage mode.

Parameters
Each of the data elements described in the standard needs to be parameterized by a governing jurisdiction. Updates to some parameters may be required in near real-time (e.g., currently available occupancy, current surface friction), and such information might require sensors and IoT capabilities. Others require notice to allow logisticians to plan (e.g., maximum weight). Most, but not all, have tolerances (e.g., max height, ± 20mm). All have update rules.

Procedures
When a ground control system is operating, there are 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[1] are not standardized. In 2022, the third white paper in this series will provide a progress-review for these procedures.

Severe weather conditions such as extreme winds might blow a robot into traffic.

One cannot overstate the importance of having these robots managed in a way that adds to our urban toolkit rather than its problem set.

SUMMARY

The development of ISO/TS 4448 will help governments and entrepreneurs prepare for the arrival of automated devices and vehicles.

The standard meets a critical need for a common set of guidelines, procedures and protocols to address the myriad planning and governance issues and potential conflicts — especially multi-vendor coordination issues — that will result as growing numbers of delivery bots and automated vehicles arrive, stop, park, load and unload cargo kerbside and on footways.

While these changes are certainly nascent, the standard anticipates some of the guidance authorities will need to determine rules of engagement so that communities can prepare to reap the benefits and avoid unintended consequences while striking a balance between the social and economic interests competing for access to public spaces.

One cannot overstate the importance of having these vehicles and service robots managed in a way that adds to our urban toolkit rather than its problem set. We can only entreat cities to consider them seriously, to view them foremost through an accessibility lens, while considering the priorities of COVID-19 recovery and global warming a close second.

As of this writing, ISO/TS 4448 is slated to have 11 parts, three of which are in the working draft stage and the remainder are outlined. This work started in April 2020. It is expected to be published in cascading stages and to be completed by 2024.

FOR MORE INFORMATION:

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