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# Intelligent transport systems — Public-area Mobile Robots (PMR) and automated pathway devices — Part 1: Overview of paradigm

**The draft version is:**

- **forwarded to ISO/TC204/WG19**
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# Systèmes de transport intelligents / *Systèmes du mobilité automatisés au sol* – Partie 1: Présentation de paradigm

# Draft TR

# Contents



 

## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 204 WG19.

The parts of ISO 4448 are proposed as deliverables, as a foundation for instantiation. Later, additional Standards deliverables may be required for specific applications.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

 

# Background

**Robotic vehicles at the kerb, among non-robotic users**

Mobile, robotic vehicles and devices designed to move passengers, goods and perform various delivery, surveillance and maintenance tasks are being deployed in towns and cities.

Some of these operate as motor vehicles on streets and roads as robotic taxis and vans or larger maintenance vehicles such as for street sweeping, snow clearing, or other maintenance. This ISO standard series is concerned how they will interact with humans and with each other at places for drop off and pick up of passengers and goods or similar human-machine interactions in places where they perform their assigned tasks.

The traffic and parking rules cities have relied on prior to 2020 represent systems already under stress — their design and governance shortcomings made increasingly evident by the pandemic. The data structures related to parking, as clarified and restructured under ISO/TS 5206:1, are insufficient to support the *automated vehicle* systems that are anticipated without additional data and procedures to support automated vehicles and ground-control systems.

Cities will need new operating guidelines as kerb lanes and sidewalks are joined by automated taxi and delivery vehicles that will arrive, stop, park, wait and load under sensor, effector, and software control. Possibly unaccompanied by human passengers or attendants, these machines will need to be prioritized, scheduled, queued, bumped, and placed in holding patterns regardless of the nature or proximity of human oversight, and all without blocking crosswalks, bicycle lanes, micromobility users, no-stopping areas, or transit stops as are common infractions now. This must be done safely, mixed with human-operated vehicles, without inconveniencing pedestrians and other VRUs, and with regard to human accessibility challenges.

At scale, large numbers of automated vehicles loading, unloading, and performing other tasks will require orchestration. Systems for this will need to be regional, operating above the level of private owners or commercial fleet operators and overseen by a traffic authority. Such systems are a core component of this series.

**Robotic devices operating in public spaces among pedestrian bystanders**

Other robotic devices and vehicles operate on walkways (pavements, sidewalks), bikeways, road shoulders, and inside public buildings such as hospitals, malls and airports — collectively “pathways.” Some are beginning to operate in either space, moving between indoors and outdoors, and some of those are beginning to open doors and use elevators.

The ISO 4448 series refers to these as “Public-area mobile Robots” or PMRs.

This is the first time in human history that mobile devices designed to operate without a proximate human attendant are being created to move among unprotected, untrained, and inattentive human bystanders that are not involved in the task or activity of the device. These devices may have numerous advantages for cities and people who live in cities.

As well, and at scale, this will have a profound impact on the management of public spaces which have heretofore been dedicated to pedestrians, and unpowered active transportation devices such as wheelchairs, scooters, bicycles, or skateboards. Such machines could impact safety, accessibility, existing rights, adequacy of infrastructure, street and pavement design, road crossing designs, active traffic flow, etc.

The innovation of the service-oriented mobile robot can be traced back to the middle of the 20$^{th}$ century. Since the beginning of the 21$^{st}$ century mobile robots with type-descriptors such as autonomous guided vehicle (AGV), industrial mobile robot (IMR), automated mobile robot (AMR), have had major productivity impacts in factories, warehouses, farms, and mines. Many of the innovations that have given rise to these various types of robots inform the innovation and industrial base for the public-area mobile robot (PMR).

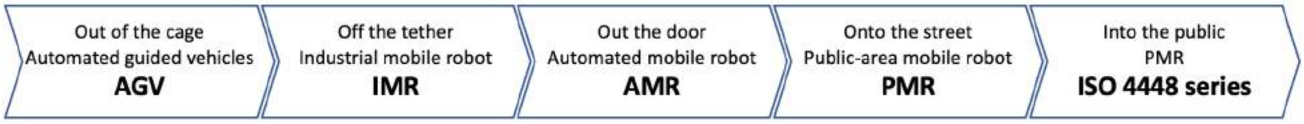


Figure 1: The principal innovation pathway to the “public-area mobile robot.”

**Why both types together in this ISO standard?**

These two types of automated vehicles or robots generally operate on opposite sides of the kerb — automated road vehicles such as passenger vehicles and trucks on the road-ward side, and PMRs on the pedestrian side on urban infrastructure that happens to be organized that way (which is not the case everywhere; often the “boundary” implied by a kerb is merely assumed and often variable).

These two types of vehicles are generally subject to different regulations. Those operating in the roadway would be subject to the motor code as it is applicable in their jurisdiction, and PMRs would be subject to newer, less established local bylaws, if any. The latter is the case because there is too little traffic management experience with the intention, deployment, and behaviour of PMR-type devices.

These two classes of robots are not entirely independent. Robotic road vehicles cross the same crosswalks that are used by human pedestrians and PMRs. Some types of PMRs use roads shoulders and bike lanes. Concurrent use of such infrastructure by both will create unique spatial conflicts.

Interactions between all such devices and non-involved humans is a core concern of the human-machine interaction focus of this ISO series.

 

# Introduction

The ISO 4448 "Intelligent transport systems – Public-area mobile robots (PMRs) and automated pathway devices" is expected to be published in 16 parts. This overview of the paradigm is Part 1 of this standard for the description, management and operation of automated vehicles at the kerbside, within walkways, and in integrated kerbside-pathway (walkway) systems. Operation of such vehicles is inclusive of arriving, stopping, waiting, loading, and unloading at the kerbside and arriving, proceeding, stopping, waiting, loading and unloading on walkways and other pathways.

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 unloading of goods and passengers at the kerbside, and the allocation and movement of robotic service vehicles for short-haul delivery, garbage removal, sweeping, washing, snow removal, repair, food trucks, construction, and any other service conducted on pathways or crosswalks.

Pathways may be in outdoor or indoor public spaces. Examples of the latter would be corridors in hospitals, shopping malls or airports. The two most important attributes of PMRs are that they operate in publicly-accessible spaces shared with untrained, uninvolved, unprotected, and inattentive pedestrians and that they move without a proximate human operator (a teleoperator at any distance is not proximate).

The ISO 4448 series, when completed, will comprise a set of terminology, guidelines, and real-time procedures for coordination of operations at the kerbside, on pathways and the integrated use of both kerbside and pathway. The data and communications standards being defined in this series of deliverables are intended to enable carefully defined (mapped) and expanding 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.

This deliverable (Part 1) focuses on an overview of the PMR paradigm, which outlines their intention and use at the kerbside and on human pathways inclusive of indoors, outdoors and roadway crosswalks.

 

# Intelligent transport systems — Public-area Mobile Robots (PMR) and automated pathway devices — Part 1: Overview of paradigm

## 1 Scope

This document is Part 1 of a multi-part standard for the description, management, and operation of ground-based automated vehicles and devices at the kerbside, within walkways, and in integrated use of both kerbside and walkway. Operation of such vehicles is inclusive of arriving, stopping, waiting, loading, and unloading at the kerbside and arriving, proceeding, stopping, waiting, loading and unloading on pathways used by inattentive, non-involved, untrained, and unprotected pedestrians.

The Scope of this deliverable (Part 1) is to provide an overview of the ground-based automated mobility systems paradigm, which covers such kerbsides, walkways, pathways, crosswalks as are suitable for co-temporal, collaborative use by various types and combinations of automated and non-automated, wheeled or ambulatory, motorized and non-motorized, mobility-related vehicles and devices as well as for various levels of automated operation of such vehicles. This includes vehicles and devices that move people as well as goods.

The term public-area mobile robot (PMR) refers to a wheeled or legged (ambulatory) ground-based device that is designed to travel along public, shared, pedestrianized pathways without the use of visible human assistance or physical guides

A general (non-prescriptive) overview of likely architectures is included in this Part ~~(and will be further detailed in Part 3)~~.

NOTE: This part (Part 1) is descriptive and therefore a Technical Report.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

*The list below is always included after each option:*

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

### 3.1 Aerial drone

Flying, remote-controlled, sometimes robotic device

### 3.2 AI

Artificial Intelligence

 

### 3.3 Ambulatory

Relating to or adapted for walking

### 3.4 Automated vehicle

A vehicle with an automated driving system (ADS) that communicates with other vehicles' ADS and the infrastructure in order to make its navigation decisions. See SAE J3016-2014

### 3.5 Autonomous vehicle

A vehicle with an automated driving system (ADS) that makes its decisions without the benefit of communications with other vehicles and the infrastructure. (Such a vehicle does not yet exist for reliable use. SAE J3016-2014 recommends against using this term

### 3.6 Block-face

The extent of sidewalk/pavement on one side of a street between two consecutive intersections crossing that street

### 3.7 Connected vehicle

Vehicle that connects with the infrastructure and possibly/probably with other vehicles

### 3.8 C-ITS

Cooperative- Intelligent transport systems

### 3.9 Curb

See Kerb

### 3.10 Dockless scooter

Rental e-scooter that may be left anywhere and does not require returning to a docking station to terminate the rental

### 3.11 DSRC

Dedicated short-range communications (based on IEEE 802.11p)

### 3.12 Footway

Infrastructure primarily designed for the movement of pedestrians (ISO 14812). Footway may variously be called sidewalk, walkway, pavement, path, pathway, or footpath. Crosswalk is a special case of footway that is used to cross other infrastructure, usually a roadway for motor vehicles. Within a building a footway would be a hallway, corridor, or passage

### 3.13 Ground-based delivery vehicle / robot / drone

Ground-based robotic vehicle used to deliver goods, food and other items. Aerial drones are out of scope. (Note, while the words 'drone' is correctly used to describe a wheeled robot, this document uses the term 'robot' and the specific acronym PMR (see definition))

 

### 3.14 ICT

Information and communications technology

### ~~3.15 ITS G5~~

~~European implementation of WLANp based on IEEE 802.11p or extended IEEE 802.11bd~~

### 3.16 Kerb (Curb)

Kerb: edge where a raised pavement (British and Singaporean English; pavement or footpath in Australian English, sidewalk in North America) or road median/central reservation, meets a street or other roadway

Curb: edge where a raised sidewalk (pavement in British and Singaporean English; pavement or footpath in Australian English) or road median/central reservation, meets a street or other roadway

### 3.17 Micromobility

Last mile forms of transport including e-scooters, bicycles, segways, etc.

### 3.18 ODD

Operational Design Domain

### 3.19 Pathway

Infrastructure designed for the movement of both pedestrians and/or cyclists within the same space. Within ISO 4448 this expression might be designated for any combination of pedestrians, cyclists and PMRs. Backlanes and human passageways within buildings are also types of pathways

### 3.20 PMR - Public-area mobile robot

A wheeled or legged (ambulatory) ground-based device that is designed to travel along public, shared, pedestrianized pathways without the use of visible human assistance or physical guides

Note 1 to entry: Physical guides include rails and kerbs.

Note 2 to entry: Pathways includes outdoor, walkways, bikeways, road shoulders, and indoor passageways, corridors, hallways, etc.

Note 3 to entry: While the term "PMR" excludes devices with visible human assistance, a PMR can be teleoperated by a human.

Note 4 to entry: While the term "PMR" excludes devices with visible human assistance, PMRs can carry humans as passengers (e.g., an automated wheelchair).

Note 5 to entry: While the term "PMR" excludes devices with visible human assistance, PMRs can be electronically tethered to follow a human.

### 3.21 PUDO

Pick up / drop off

### 3.22 Robotaxi

Remotely monitored driverless taxi

### 3.23 Scofflaw

User of an illegally parked vehicle

### 3.24 Service Alley

A roadway that exists primarily to provide utility access to properties, usually located behind properties. Also known as a back lane or back alley

### 3.25 VRU

Vulnerable road user

## 4 Purpose and justification

The purpose and justification of the ISO/4448 series of work items is five-fold:

### 4.1 Safety and conflict-avoidance

As the number of innovative types of mobile vehicles and devices, automated or non-automated enter into common use, there is increasing potential for spatial conflicts while arriving, stopping, parking, waiting, loading, and task performance such as cleaning, monitoring, delivering, guiding. As well, navigational conflicts when passing, crossing, or overtaking can be expected to grow with the number and variety of such vehicles and devices. These conflicts are already very common and cumbersome at many kerbs and on many sidewalks. As increasing numbers of such vehicles and devices can be expected to operate without on-board or proximate human operators, and potentially without the lane- or path-markings such as those that guide on-street vehicles, machines that operate at kerbs, on sidewalks, in building corridors and sometimes any of these, must interact with each other, with human-operated vehicles and devices, and with pedestrians. This requires a set of agreed and tightly-communicated behaviours and guidelines for real-time resolution (rules) and those behaviours and resolutions require terminology, taxonomy, categorizations, and architecture.

### 4.2 Planning

Some projects to re-format and reorganize streets, kerbs or sidewalks, and other projects to design large, indoor pedestrian spaces, may need to build and shape such spaces to be workable for vehicles and devices whose operating characteristics may be different, or differently constrained, than would be vehicles and devices under direct human operation. Such planning activities need guidelines and those guidelines need common terminologies, taxonomies, categorizations, rules, and architectures. They will also need more detailed metrics and design parameter descriptions that follow in later TS-4448 Parts.

### 4.3 Commercial

Some kerbs, sidewalks and other pedestrianized spaces are expected to be used more heavily by commercial automated vehicles (taxis, shuttles, trucks, public-area mobile robots, etc.) each with a variety of task capabilities. These would be loading and unloading passengers and goods and the execution of an extensive number of service tasks. The use of machines and devices with a proximate human operator for these activities, means forward-planning will be required. Such forward planning will need transparent spatial-understanding rules and pathway or resting-place reservation systems operating in near real-time. The design of such reservation systems requires the terminologies, taxonomies, categories, and rules developed in TS-4448.

### 4.4 Operations and management

Kerbs, sidewalks and public building corridors form an interface between people who are residing, visiting, or trading at buildings at or near these infrastructures. People and goods who 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 a footway, pathway or loading facility blocked and without unexpectedly long waits or difficult passage. These spaces need to be managed in a coordinated fashion. To agree to methods for this management, the terminologies, taxonomies, categories, and rules of TS-4448 are required.

### 4.5 Legal, liability, and insurance

Public spaces may be shared by many classes of mobile users including local residents, vendors, visitors, shoppers, workers, whether able-bodied or not. Any physical conflict involving an automated or autonomous device or vehicle that causes bodily harm, financial loss, or other harm or perceived harm may be subject to legal action. Hence a common understanding and description for these spaces, and the interactions therein, is necessary to determine liability for legal and insurance purposes. This common understanding and description requires the terminologies, taxonomies, categorizations and rules of TS4448 and it parts.

## 5 Parts outline

The following lists the component parts of the ISO 4448 standard:

### 5.1 Definitions and data about PMRs

#### 5.1.1 TR 4448-1 – Overview of the Paradigm

TR 4448-1 describes the full suite and purpose for all remaining parts. It provides a description and justification for each part, allowing the municipal or commercial implementer to determine which of the suite of parts will be important to their design, manufacturing, regulatory, deployment or enforcement task(s).

#### 5.1.2 TS 4448-2 – Data Definitions

TS 4448-2 describes terms and definition, including data definitions used throughout TS 4448. Data definitions include units, defaults and ranges where appropriate. Consistency throughout constrains development discipline, and makes integration among systems and across jurisdictions easier.

#### 5.1.3 TS 4448-xx- Cybersecurity, privacy, testing & data: Threat, vulnerability, and risk profiles

[to be assigned a new part number]

1. Describe communications and **cybersecurity** issues that are necessary for secure and assured connectivity, location determination, teleoperation, IoT, recovery, and enforcement override. Reply on existing standards for ensuring cyber security

 

2. Describe the maximum **privacy** issues and guidelines for PMRs. Recognize that privacy is determined by the local jurisdiction

3. Describe **testing** guidelines for PMRs. These are high level (because of unknown innovations) and dependent on existing standards (usually determined nationally)

4. Describe **data** capture, use, retention and sharing guidelines for PMRs operating in public spaces. Recognize that data retention and use is determined by the local jurisdiction

## 5.2 Behaviour of PMRs

### 5.2.1 TS 4448-5 Public-area mobile robot access on human pathways

TS 4448-5 describes trip reservation and queueing for public-area mobile robots in public spaces (footway, bikeway, roadway and crosswalk). This standard for PMR orchestration provides two methods:

1. Zones and time slots (“TripZone”)
2. Start and end points, pathway segments, segment behaviours, and start time (“TripPlan”)

Method 2. provides much more traffic control, and a finer degree of management by monetization.

### 5.2.2 TS 4448-7 Public-area mobile robot behaviour on human pathways

TS 4448-7 describes the “rules of the road” for PMRs on public pathways or in public spaces. This includes the full range of behaviours related to sharing space with humans, pets, other robots, and infrastructure. It also describes a standardized enforceable traffic code for the sidewalk.

### 5.2.3 TS 4448-8 Public-area mobile robot-to-human communication signals

TS 4448-8 describes the sounds, light, haptics, and gestural (motional) displays for social communication between PMRs and bystanders; including those with sight/hearing challenges.

Key purposes are:

- transparency of a robot’s intentions when near bystanders
- socialize the robot’s presence

## 5.3 Municipal readiness for PMRs

### 5.3.1 TS 4448-10 Suitability of pathway infrastructure for public-area mobile robots

TS 4448-10 describes the methods/metrics to determine whether a footway, bikeway, roadway or crosswalk segment is suitable to a particular type or intensity of PMR use.

### 5.3.2 TS 4448-11 Environmental worthiness of public-area mobile robots

TS 4448-11 describes the methods/metrics to determine extreme weather and other environmental conditions for safe PMR operation (scaled to PMR capability).

### 5.3.3 TS 4448-12 Post crash procedures for public-area mobile robots

TS 4448-12 describes PMR crash clean-up, description and reporting.

 

#### 5.3.4 TS 4448-13 Mapping maintenance for public mobile robots

TS 4448-13 describes mapping parameters such as resolution, update frequency, and error tolerances required for PMR TripZones or TripPlans as developed in 4448-5

### 5.4 Governance of PMRs

#### 5.4.1 TS 4448-14 Personal assistance robots for tasks and goods movement

TS 4448-14 describes standards for e-tethered robots:

- personal “follow-me” PMRs transporting loads
- maintenance robots in “follow me” operation

#### 5.4.2 TS 4448-15 Personal assistant robots for human transport

TS 4448-15 describes standards for small personal passenger robots such as wheelchairs or PMRs moving passengers within public facilities such as airports or hospitals

#### 5.4.3 TS 4448-16 Safety and reliability for public mobile robots

TS 4448-16 describes physical, mechatronic, and operating safety for PMRs. This includes sensors, effectors, fire & chemical, hazardous goods – and more

Safety is organized into three categories:

- location safety
- device safety
- safety for proximate humans

#### 5.4.4 TS 4448-20 Journey data recorder for public mobile robots

TS 4448-20 describes Journey Data Recorder (JDR) functions for PMRs. This addresses:

- measurement of shyDistance compliance
- comparison of shyDistance compliance among fleet operators
- social compliance for license renewal
- a tool for investigating complaints
- a record for event reconstruction
- a tool for measuring congestion regarding the granting of TripPlans
- a method for testing software

#### 5.4.5 TS 4448-xx Journey Planning Sufficiency

[Moved out of 4448-16 and expanded]

This 4448-proposed part specifies capability in terms of the perception field, range and maximum blindspots for journey planning competency. It focuses on the planning range between the full trip (macroplan or path planning) and the immediate next decisions (microplan or trajectory planning). This intermediate range, called meso planning, ensures that a PMR can perceive well in advance any pending barriers to the completion of the macro plan. This avoids:

- Being trapped by navigating into unexpected events
- Exhibiting unexpected (alarming) behaviour in the presence of bystanders

 

The standard does not specify equipment or methods.

### 5.5 Loading/unloading of goods and passengers at the kerb

#### 5.5.1 Original 4448-4, -6, -9 be combined into one new part

[to be assigned a new part number]

[TS 4448-4] standard orchestration procedures to manage loading/unloading of passengers and goods. This applies to any publicly accessible loading (parking) location for the vehicle in question. While developed for driverless vehicles, 4448-4 can be used by human-driven vehicles. It orchestrates the endpoints of a trip with an electronic document called a LoadPlan that describes multiple features about “A” and “B”, related to queueing for spot use.

[TS 4448-6] procedures and protocol for the case of vehicles constrained to the kerbside or other designated loading area to load and unload PMRs to move goods or passengers along public pathways that do not admit larger vehicles (for example transferring from truck/van into PMRs). 4448-6 integrates the orchestration plans of 4448-4 and 4448-5.

[TS 4448-9] methods/metrics to determine whether a kerb (curb) on a block-face is suitable to a particular type or intensity of use of automated vehicles or devices.

## 6 Context

### 6.1 Automated vehicles

#### 6.1.1 Automated vehicles at the kerb

In recent years there has been much focus on automated and connected vehicles, in popular parlance, “driverless cars” or “autonomous vehicles.” Automated and connected vehicles interact with each other and their operating environment, notably the road infrastructure and its agents.

Passenger cars and goods-transport vehicles are gradually becoming connected. While the automated robotaxi is being piloted in a few carefully managed and constrained areas, since 2019 automated taxi technology has advanced more slowly than promised a decade earlier. Furthermore, the fully autonomous (“level 5”) vehicle will be delayed even longer — possibly never reaching the full capability so frequently promised in 2010-2015.

The reasons for this are clear. The rapid developments in ICT and AI have enabled the ‘dream’ of automated servant vehicles to be realisable in respect of their mechanical instantiation, but the barriers to delivery of automated passenger vehicles in a high volume/high speed multi-agent road system lie as much or more in the traffic management and operator behaviour than in the mechanical manipulation of the vehicle; and the speed and impact forces at 50 or 100 kph, of a mass exceeding one ton, usually has life threatening consequences that have to be safely and reliably managed before driverless cars — including robotaxis — become a common reality.

Within the context of this series, ISO 4448 will be concerned only with the behaviour of automated road vehicles in terms of PUDO (pick up/drop off) management, usually at a kerbside. This standard series will be silent about the road behaviours such as speed and navigation controls, etc. of road vehicles such as automated robotaxis or delivery vans. There are many other sources of standards for those aspects.

 

### 6.1.2 Automated vehicles on pedestrian infrastructure

*The promised large-scale arrival of automated passenger vehicles in our cities has slowed considerably. However, the introduction of PMRs for delivery and numerous other services are advancing rapidly as they face many fewer deployment, cost, safety, and regulatory barriers.*

For several reasons—differences in teleoperation being a major one—there are many fewer and far less dangerous challenges to be overcome for PMR deployment to be safely achieved. There are also far fewer and less daunting challenges than those faced by the driverless car or robotaxi. Additionally, the accelerators promoting the development of delivery robots are more accessible to innovators, investors, retailers, and other participants.

Concerns for road-congestion and global-warming reveal the benefit of using small, electric robots in place of sedans and delivery vans, in appropriate operational design domains (ODDs). The rapid increase in e-commerce and the demand for rapid, cheap delivery is another growth driver.

PMRs, already engaged in surveillance and package delivery, are expected to soon engage in sweeping, de-icing, snow removal, measurement, monitoring, repositioning dockless scooters for recharging, and many other services. They will likely arrive in cities at scale far sooner than automated cars or robotaxis. Without deployment standards (i.e., less transparent, harder to govern) when scale has been achieved, it is easy to imagine unanticipated impacts of these devices in the foreseeable future.

As of 2023, worldwide there are a several hundred companies—mostly start-ups—engaged in developing small, teleoperated and increasingly highly automated devices for operation on city walkways and bikeways. Already thousands of small retailers and several large delivery operators use these systems for last-mile delivery. Already, many more cities have a small number of such PMRs than have robotaxis in pilot operation. This implies that cities are far more likely to face demands to govern these smaller PMRs long before robotic cars and trucks.


**Figure 2:** Personal Delivery Device (discontinued instance)

As a specific case, personal delivery devices (sidewalk delivery robots, **Figure 2**) are essentially small containers on wheels that can travel on sidewalks, intersections and roads over modest distances — without a human attendant on hand — to carry food and other small packages. The four robots caricatured in Figure 2 are among early designs. At least one has been discontinued, and several hundred similar designs are already in trials or deployment. These PMRs and their successors—including legged robots—are expected to increasingly frequent pedestrianized pathways. As they become more capable, their adoption will become more pervasive.

 

This ISO 4448 series will predominately address the characteristics and behaviour of PMRs in pedestrianized spaces. However, in addition to the concern for PUDO for road vehicles, the intersection between orchestration for PUDO at the kerb and for PMRs entering and exiting larger goods vehicles (sometimes referred to as motherships) will be addressed by this standard.

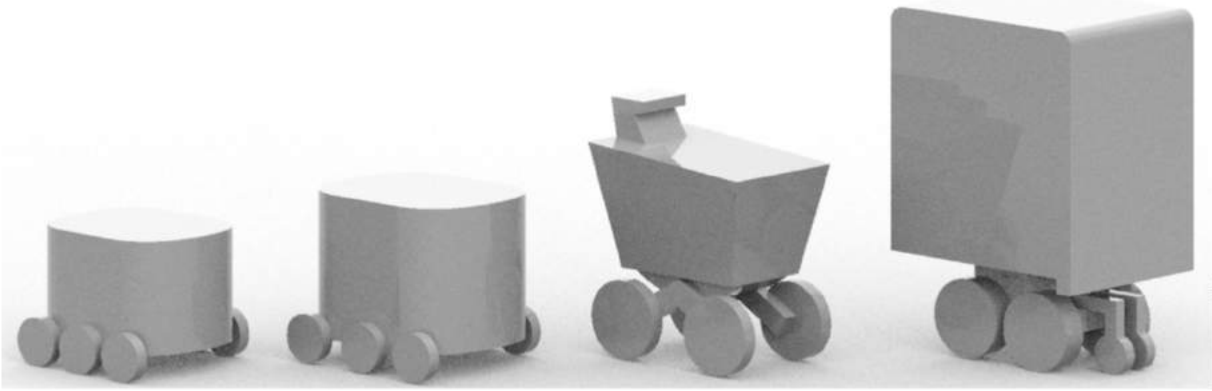

**Figure 3:** Example PMR forms for small-package delivery (the largest one was discontinued in 2022)

## 6.2 The evolution of the sidewalk and considerations for PMRs there

### 6.2.1 History

The kerb/curb is the edge where a raised sidewalk/pavement/footpath or road median/central reservation, meets a street or other roadway.

Pavements/sidewalks are a relatively modern development that has evolved as cities have developed and been populated by an ever-expanding mixture of pedestrians and faster-moving, powered vehicles.

**Figure 4:** Roads before sidewalks
(Images courtesy CSi Library)

As cities grew larger, with larger populations walking the streets, and ever more and ever faster vehicle movements, sidewalks (pavements) have become the norm, are built into most planning applications, and in the wide variety of widths and forms that we know today.

Some parts of kerbsides/sidewalks may be reserved for loading zones and the occasional bus stop, or to house a bus shelter. Street furniture (signs, lamp posts etc) are more normally set into the sidewalk than the roadway. Nearer to buildings, the remaining space tends to be the area used by pedestrians, and, to the widespread annoyance of pedestrians, routes atop the sidewalk are increasingly used by cyclists (although in some places these are constrained to the roadway). The remaining sidewalk space is interrupted by driveways, fire hydrants, bus shelters, and sometimes a tree, places to sit, or posts to park and lock bicycles. In many cities, cars, both legally and illegally, park on sidewalk space.

This 20th century description of the kerb/curb and pavement/sidewalk, while still dominant in our communities, is slowly giving way to a much greater variety and more organised/managed usage of sidewalks such as ride-hail pick-up and drop-off, segregated cycle/micromobility lanes, ecommerce delivery, micro-transportation docks, and al fresco dining.

There are calls for wider sidewalks and more cycling lanes in many places, especially Europe. Widened sidewalks often result in fewer traffic lanes and on-street parking spaces, in some places leading to the removal of road traffic within so-called ‘pedestrian’ zones, although these zones usually also allow bicycles and micromobility passage.

The removal of road traffic from ever larger town centre zones in some cities will further increase the demand for PMRs for last-mile deliveries.

### 6.2.2 Safety

One reason that PMRs, especially for delivery, will become endemic before driverless vehicles do so is that the safety barrier for PMRs is much lower.

Delivery PMRs 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. The top speed of these smaller PMRs is usually constrained to about six kilometres an hour, a hurried walk. Small and slow, they can stop quickly. Even if the system fails to avoid a collision with a stationary object or pedestrian, the damage is usually slight as the impact speed and thrust of such devices are minimal.

Larger delivery PMRs—half the size and weight of a passenger sedan and perhaps travelling at 40 km/h—present greater safety challenges and may therefore largely be confined to cycle/micromobility routes and roadways except for very low speed operation in the final metres to delivery.

The sheer variety of delivery PMRs presents challenges for protecting pedestrians and cyclists. Any regulations will need to account for a wide range of safety considerations. For example, smaller PMRs might best be kept off the roadway except when crossing at intersections, and the larger PMRs (as described above) may need to be banned from sidewalks.

One safety advantage that delivery PMRs have over e-scooters and bicycles is that they are designed not to hit anything (e-scooters and bicycles rely on the judgement of their riders, and bicycle riders around the world are noted for the frequency with which they ignore or disobey regulations), and delivery PMRs are generally well protected. If one of the smaller PMRs were to hit an adult human, it is unlikely the collision would be anything more than light bruising, and certainly not an injury that was fatal or even life-threatening. (However, an exception to this is that a PMR could precipitate behaviour that causes an action that results in a fatality in the same way that an animal running into the street might cause a vehicle driver to swerve and crash.)

### 6.2.3 Low fear factor

The fear barrier for delivery PMRs is much lower than it is for robotaxis or driverless vehicles.

Many people express fear of riding in an automated vehicle, or being in the presence of automated vehicles sharing the same road-space, or being harmed by a robotaxi or having security concerns if using one. This fear causes both manufacturers and regulators to sensibly be conservative about removing the vehicle’s safety driver. Note that in all of the thousands of videos where a driverless-taxi safety driver is absent, the weather is always especially clear, the roads are in excellent repair, and traffic is notably light.

Consumers may accept that the company using a delivery PMR to deliver their sandwich or parcel from a logistics operator such as Uber Eats or Amazon might wait until a downpour lets up. They might not accept that from a passenger vehicle when they are late for an appointment.

Pedestrian feedback in trials show that they affectionately compare the threat presented by delivery PMRs more to that presented by well-trained small pet dogs than risks presented by vehicles, and considerably lower risk than bicycles.

**Figure 5:** Starship Technologies PMR in Milton Keynes UK
(Image courtesy CSi Library)

### 6.2.4 Jobs

Concerns about job losses for those impacted by delivery PMRs carry less political weight than similar fears about robotaxis or automated 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 well-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 employment of larger, automated vehicles for passengers and goods.

Short-haul delivery — especially in the fast food, e-commerce and delivery van sectors — more frequently utilises 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 operation of PMRs should be much lower than that for robotaxis or driverless trucks.

### 6.2.5 Cost

The cost barrier to developing and deploying ground-based delivery PMRs is much lower than that for automated vehicles because the investment required to build and prove driverless passenger vehicles is far greater than that required to build and prove unmanned delivery PMRs. These devices are generally relatively low cost, like short-life drones with processing ability. Consider how the cost of recreational aerial drones has fallen dramatically while their capabilities have significantly increased. Flying, self-homing, camera and wi-fi-equipped devices are available at hobbyist prices, and prices continue to fall. A ground-based delivery PMR costs a small fraction of an automated vehicle.

This low cost-barrier means that the majority of mechatronics graduate students contemplate starting a delivery robot company—and many hundreds of them have already done so in dozens of countries worldwide.

### 6.2.6 Infrastructure

While complex, shared-traffic and infrastructure issues are common to both robotaxis and PMRs, even for PMRs, infrastructure is a complex barrier to consider.

PMRs will have to negotiate a gauntlet of human legs, barking dogs, baby strollers, planter boxes, tree roots, people waiting at the bus stop, uneven pavement, kerb edges, ramps, and crosswalks — a much more disorderly environment than the highly regulated city streets where robotaxis will operate. (Figure 6)

PMRs 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 have many more undigitized and non-conforming sidewalks than roadways. This constitutes a relative barrier for operating delivery PMRs.

Figure 6: A PMR tries to navigate a sidewalk in Pittsburgh that has overgrown foliage and other sidewalk obstructions*. (From the Knight Autonomous Vehicle Initiative, Piloting Sidewalk Delivery Robots in Pittsburg, Miami-Dade County, Detroit, and San José: August 2022)*

Fewer people would be offended if a cycling lane is shared with delivery PMRs than would be offended if such devices 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 many footpaths would be better handled by robots that can walk.

 

In other words, if this technology is to be truly successful, sustainable and widely adopted, eventually many, if not a majority, of PMRs will be walking (ambulatory) rather than rolling. If this sounds fanciful see the demonstration video at this link:

https://www.youtube.com/watch?v=M8YjvHYbZ9w

Among all the ground-based robots, the quadrupedal robot is a legged robot, and is superior to wheeled and tracked robots because of its ability to operate in any terrain in the same manner as the human and animal, making traversing kerbs, or mounting stairs achievable, and better equipped to manage being impacted, kicked or shoved. The demonstration video above shows, 'Spot' and its colleagues, (Boston Dynamics {recently acquired from Alphabet Inc. by Hyundai Motor Corp}) which is only one of a number of research projects in this area.

Figure 7: Ambulatory terrestrial robots
(Images, courtesy Boston Dynamics)

### 6.2.7 Illustration (from UK) of how existing regulations might encumber robots on sidewalks

One initial catchpoint is that there are already a number of somewhat contradictory regulations that are currently in place that were written in an age when no-one could have seriously imagined ground-based delivery PMRs. For instance, an analogous, but close, example is the position of e-scooters, indeed, any scooters, in the UK.

The Highway Act 1835 Section 72 (England and Wales) states "*.....If any person shall wilfully ride upon any footpath or causeway by the side of any road made or set apart for the use or accommodation of foot passengers; or shall wilfully lead or drive any horse, ass, sheep, mule, swine, or cattle or carriage of any description, or any truck or sledge, upon any such footpath or causeway; or shall tether any horse, ass, mule, swine, or cattle, on any highway, so as to suffer or permit the tethered animal to be thereon…*"

Peculiarly, it is this section, which concerns animal herding, that renders bicycles illegal on the pavement (bicycles were classified as 'carriages' in 1888) and also renders cars illegal on the pavement (cars were classed as 'carriages' in 1903). Because of this catch-all definition of "carriage", it is presumed that kick-scooters are probably illegal on pavements unless a local by-law permits them, but they have never officially been classed as 'carriages.' As they, to date, have more or less exclusively been ridden by small children, this has never been tested in court.

The painting of bicycle lanes on pavements is of course legal, but the riding of bicycles on those bicycle lanes is technically illegal unless a local authority bylaw has specifically re-designated that bicycle lane to be something other than a "*footpath or causeway by the side of any road made or set apart for the use* *or accommodation of foot passengers*". If the local authority fails to do this, users are transgressing the law.

Highway Code rules 37 and 38 apply to wheelchairs or "invalid carriages" as it is legal for wheelchairs to share the road and pavement and state:

> *"Rule 37: When you are on the road you should obey the guidance and rules for other vehicles; when on the pavement you should follow the guidelines and rules for pedestrians.*
>
> *Rule 38: Pavements are safer than roads and should be used when available. You should give pedestrians priority and show consideration for other pavement users, particularly those with a hearing or visual impairment who may not be aware that you are there."*

But in respect of powered scooters, they clearly fit under the law as a "*carriage of any description*". So, at the moment, they are classified as Personal Light Electric Vehicles (PLEVs), so are treated as motor vehicles and are subject to all the same legal requirements - MOT, tax, licensing and specific construction, and as motorised vehicles are banned from use on the pavement (sidewalk). But because they don't always have visible rear red lights, number plates or signalling ability, they can't be used legally on the roads either.

It is hard to see how robotic motorised delivery vehicles, or robotic vehicles used for any of the purposes described above will be classified differently, and so a change of law will be required before they can be used. Similar, but different, laws exist in most countries. At least UK law permits anything unless it is prohibited or limited by law, so it is simply a matter to modify the restriction imposed by Section 72 of the 1835 Act. Many other countries will require completely new regulation(s) to allow and permit these devices, otherwise there is an assumption that it is a prohibited activity.

## 6.3 The challenges

As discussed above, kerb 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 the kerbside as well as a dramatic rise in goods delivery from e-commerce systems, exacerbated by our response to the pandemic.

In many areas of some cities, this change has already reached unsustainable conditions, and some of these tend to be addressed on a local and urgent short-term 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 kerb in many cities, as well as scooter and bicycle storage spaces on the sidewalk.

The onset of the COVID-19 pandemic created rapid and unexpected demands for these sidewalk and kerb spaces to accommodate social distancing, an uptake in the use of micromobility vehicles such as scooters and e-bikes, and increased demand for al fresco dining space.

Wider sidewalk areas are being created to accommodate these new demands. These areas sometimes extended temporarily beyond the kerb 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 kerb — soon using driverless vehicles and the final-block delivery of goods via PMRs. Indeed, such systems are already in successful 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 kerb, with payment systems, with active human mobility, and with our existing manual vehicles and devices.

It is logical that such digitalized management systems will use communication and security systems compatible with those used for C-ITS. Indeed, there is strong logic to use similar architecture and communications means since loading and unloading passengers and goods interacts with kerbside and delivery PMRs will need to cross roads therefore needing to be aware of approaching vehicles, and likely interact with them.

In addition to the required attention to communication and security systems, 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 PMRs arrive on our sidewalks and kerbs 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 achieved safely, mixed with human-operated vehicles, without inconveniencing active transportation or pedestrian traffic, and with regard for human accessibility challenges.

Consider how pedestrians use the sidewalk now. 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, today, by social behaviours and low speeds.

The coming use of PMRs on the sidewalk implies a purely path-oriented use, except for departure and arrival terminus points. Functionally and navigationally, we can compare this to a pedestrian in a wheelchair using the sidewalk as a pure travel path.

PMRs that navigate sidewalks and pathways must recognise and accommodate others using these as a place.

Wheeled PMRs (such as the wheeled delivery robot) have some characteristics similar to a wheelchair: they can easily travel faster or slower than the average human pedestrian; they must confront issues of climbing over uneven, damaged, steep, sloped, or potholed pavement or ramps to sidewalks; they often have difficulty managing a step of significant height and generally cannot negotiate multiple steps; they cannot easily "step aside" as an ambulatory human, or ambulatory robot normally can; and they cannot streamline their width by turning sideways while walking as an abled pedestrian can.

This video demonstrates the difficulty of climbing a step. (It also shows a robot taking most of a width of a sidewalk meaning that a wheelchair or a second robot could not pass. Sidewalk widths are also described in the standard, Part 3.)

https://www.youtube.com/watch?v=vQ3k9By3Kl4

 

Basically, wheeled PMRs exhibit many of the constraints and properties of a wheelchair. Depending on wheel diameter, number of wheels and their suspension system, a non-ambulatory PMR may have slightly fewer or more constraints than a wheelchair. Indeed, several models of these PMRs already in pilots exhibit such variations.

By comparison, an ambulatory PMR might have none of these disabilities, but is inherently more complex and therefore a more expensive device.

As a machine, it might be expected that the delivery PMR (wheeled or ambulatory) 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-permitted PMRs might inherit such protected rights in a way similar to a guide-dog that inherits some social rights-of-way from the human it is helping.

A wheeled PMR will 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.

Although it is expected that a PMR will be a 'connected' vehicle, it may be frequently required to operate autonomously; a PMR having no onboard or accompanying human to provide or receive social signals, must rely on information from other connected ITS-stations, and its own calculations. It may be programmed to send and receive social or directional signals and to exhibit more patience than the average human.

Semi-autonomous PMRs might be teleoperated, but the ability of a teleoperator to engage in social signalling might be quite limited. (An example of this might be teleoperated micro-mobility devices such as three-wheeled e-scooters being guided to a docking station.)

# 7 Operating principles for PMRs

## 7.1 General

To provide a proper grounding for operations in a shared, human social environment, operating standards need to be able to rely on a list of general rules for PMRs on the pathways mixed with pedestrians of all abilities. Such pedestrians may have pets, carry packages, push, drag or ride in wheeled objects, containers, carts, chairs, scooters, and more.

### 7.1.1 Contrasting Pathway and Kerb

While the purpose of TS 4448 is to govern and manage operations of automated vehicles and devices and while the core matters of scheduling and pairing Vehicles with Places is similar for both kerb and sidewalk, Place (block-face or pathway) in the case of the pedestrian pathways is very different from Place (Space) in the case of the kerb.

At the kerb, vehicles are queuing to become stationary while loading or unloading. At any permitted pathway, PMRs are queuing to operate (move, navigate, work) in ways mixed with pedestrians or cyclists of all abilities. Pedestrians may have pets, carry packages, push, drag or ride in wheeled devices, containers, chairs, bikes, scooters or boards. Pedestrians may travel in small groups, walk slowly, stand in clusters such as at intersections or transit stops. They might window-shop, line-up, run, or weave from one side of the pedestrian clearway to the other. Such pedestrian behaviours are at risk of being made less safe or more difficult due to the presence and movement of PMRs.

Depending on the prevailing view of the governance of public space [Thomasen], such pedestrian behaviours may be protected or curtailed by TS 4448. The standard is agnostic to governance style or theory but is designed to formalize communication and operation of any intended governance style.

Certain PMRs, especially maintenance bots such as sweepers or snowploughs, might be constrained for use at places or times when few or no pedestrians are present. TS 4448-5 will enable a method for this.

#### 7.1.2 Contrasting Cycle Lane and Footway

Cycle lanes offer the possibility of PMRs to travel to their destination at higher speeds as well as avoid potential conflicts on footways with pedestrians, which are often more crowded. However, utilizing a cycle lane presents its own unique set of challenges.

First, PMRs will need to travel at the speed of cycle lane traffic flow in order to minimize disruption to other users. Second, PMRs may need to overtake stationary or slow-moving cycle users. Depending on the nature of the cycle lane and the disruption, this may require the PMR to temporarily stop, travel in a lane going in the opposite direction or hop onto the sidewalk. Third, PMRs will need a method for dealing with pedestrians who cross the cycle lane, such as when accessing a parked car. Depending on the nature of the pedestrian crossing, the PMR may need to stop or slow down and alert the pedestrians of its presence (similar to a cyclist ringing its bell). TS 4448-5 will enable a method for this.

#### 7.1.3 Contrasting Service Alley and Footway

Service alleys, like cycle lanes, offer the possibility of PMRs to travel to their destination while avoiding potential conflicts on footways with pedestrians. PMRs travelling on service alleys may be able to travel faster than on a footway, however, they will need to deal with conflicts with road vehicles and likely a more challenging travel surface. Procedures will be needed for yielding to oncoming vehicles as well as alerting vehicles backing up that may travel into the path of the PMR. TS 4448-5 will enable a method for this.

### 7.2 Proposed rules

The following (Informative) are a guide to key rules for the development of the Normative Parts of the standard.

#### 7.2.1 Rights of way

PMRs to grant rights-of-way to humans in close proximity; but rules of engagement may consider how to prevent a PMR from being immobilized for an extended period in a crowded circumstance.

#### 7.2.2 Respect shy distance and social distance

PMRs to respect the cultural and contextual interpersonal distances normally observed by humans walking or standing in a public place, known as *shy distance*. This may be extended to *social distance* in the event that PMRs are identified as a disease vector.

#### 7.2.3 Not harm

PMRs not to harm or alarm humans or animals on the sidewalk. A PMR may behave defensively using sound, light, or evasive movement in the event it is threatened. For example, a sound to indicate fear or alarm.

 

### 7.2.4 Be apparent

PMRs to 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.

### 7.2.5 Be legible, transparent

PMRs to behave in ways that are consistent and understandable to proximate humans. This may include capturing information that allows unambiguous post-mortems after any event (transparency).

### 7.2.6 Use signals

PMRs to 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.

### 7.2.7 Not diminish privacy

PMRs not to diminish the privacy of people using or residing near sidewalks. This implies constraints on the recordings and retention of data.

### 7.2.8 Not diminish security

PMRs not to diminish the security of humans or other machines on the sidewalks. This is also in regard to the security of humans residing and trading near such sidewalks. This includes both physical and cybersecurity. PMRs that are compromised might be subject to arrest, inspection, disablement, or being impounded or destroyed, as may be appropriate by local enforcement officers.

### 7.2.9 Not obstruct pedestrians

PMR guidance methods, stopping/waiting-area infrastructure, and navigation manoeuvres shall not compromise pedestrian access. PMRs shall avoid standing and waiting on kerb cuts and at intersections. PMRs should stand aside from kerb cuts and wait until clear of pedestrians before dismounting or mounting a kerb. The standard defines a stand-back shy distance parameter.

### 7.2.10 Not overwhelm the network

PMR occupancy (device count) within a specific area may be controlled. When this is the case, a PMR or PMR operator shall be aware of, and conform to, prescribed limits.

### 7.2.11 Not rely on intrusive infrastructure

PMRs may be guided by localized infrastructure, high-resolution mapping, and other data or technologies, but any additional infrastructure cannot negatively affect (make more cluttered, riskier, more confusing, or less accessible) the use of this shared space by humans.

### 7.2.12 Use paths that minimize conflict

PMRs should prefer pathways that avoid pedestrians or minimize conflicts with them, such as travelling on the other edge of the sidewalk that avoids building doors or using cycle lanes. PMRs shall travel in single file on the outer edge of a crosswalk. How drivers in the country concerned drive (right or left) will determine which edge should be used. This would also translate to a clockwise or anti-clockwise rule on the block-face (drive-right means clockwise).

 

#### 7.2.13 Not loiter in public spaces

PMRs must avoid loitering in public spaces as much as possible as to not obstruct pedestrians and other pathway users. Upon ending a trip, a PMR must commence a new trip or relocate to a designated location where it will not obstruct other users.

## 8 Governance principles for PMRs

### 8.1 General

The paper: Robots, Regulation, and the Changing Nature of Public Space (Kristen Thomasen, 2020), outlines three views of public space that might guide a regulator of PMRs: Communal Public Square, Regulated and Orderly Public Square, or State-Owned Property. Depending on how these views influence relevant regulations, PMRs would be governed locally in more or less restricted ways.

TS 4448-5 is agnostic to such legal theory. Rather its goal is to ensure necessary and sufficient data and procedures so that the respective socio-legal preferences can be supported in any country, state, or city by way of constructions that allow legislators to adapt the standard to their governance needs and be able to communicate relevant rules to makers, operators of automated devices, and users (shippers). Correspondingly, makers and operators of PMRs can anticipate and comply with the resulting rules.

In a simple view, a clear space in the direction of travel must be open in order for a PMR to proceed. The proximate, realtime 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 public space.

Rules that have PMRs yield right of way and respect shy distance imply an optimal, clear space in this immediate realtime sense, but such rules do not prevent PMRs 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 PMR(s).

PMR navigational rules that operate by opportunistically moving into clear spaces as they open up (greedy algorithms) are essentially how humans navigate on busy sidewalks and cars operate in traffic. If such was the only local decision approach employed by a PMR, then as these PMRs become more capable, nimbler, and more numerous, human pedestrians, especially those who are older or less nimble, would become increasingly disadvantaged. Average human pedestrian skill is unlikely to improve, but over the next decade PMR skill will improve dramatically. In unregulated, congested circumstances, this could become deleterious to human right-of-way.

Several instances of current U.S. state legislation that have been enacted since 2017 indicate that PMRs (called personal delivery devices in these documents) 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 PMRs to a block-face so that their occupancy (count) at any one time can be controlled. This reduces, but does not obviate, the effect of greedy spatial algorithms.

Related to this, it is possible for a PMR that must always give way to pedestrians and to maintain a shy distance to find itself trapped for unexpected or unintended periods of time especially in crowded circumstances (“robot trap” problem). Naturally, operators of such PMRs 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 at block-faces according to sidewalk configurations and times of day so as to minimize the likelihood of such events.

As PMRs become smarter, we can imagine that they might acquire, through machine learning, more foresight to further reduce the probability of being trapped. In the meantime, the standard provides a way to minimize the likelihood of this outcome.

### 8.2 Similarities between PMRs and human assistive devices

This section explores similarities and differences between a wheeled PMR and devices such as a pedestrian wheelchair or an assistive scooter. These similarities suggest that a standard for PMRs should consider alignment with existing standards for access by wheelchairs and assistive scooters. Such goal-congruent alignment provides opportunities to address sidewalk design and configuration to intentionally benefit accessibility goals while standardizing PMR access and flow.

The approach for TS 4448-5 is to start with an understanding of best practices for accessible sidewalks and to reason from there.

**As a vehicle**, the wheeled PMR has some characteristics similar to a wheelchair, it can easily travel faster or slower than the average human (walking) pedestrian, it confronts issues of traversing uneven, damaged, steep, sloped, or potholed pavement or ramps (kerb cuts). It cannot “step aside” as an ambulatory, abled pedestrian normally can, and it cannot streamline its width by turning sideways while walking as an abled pedestrian can. Basically, the wheeled PMR exhibits many of the rigid physical and motion constraints and properties of a wheelchair. Depending on wheel diameter, number of wheels and their suspension system, a wheeled (non-ambulatory) PMR may have somewhat different constraints compared to a wheelchair.

**As a machine**, the wheeled PMR might be relegated to 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, as it may be performing a service critical to someone who has specific social rights. Perhaps some specially-marked PMRs might inherit those rights in the way that a service dog inherits certain social rights-of-way from the human it is helping. A PMR may be unable to cross certain path elements 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 apparent to other pedestrians who are a short distance away, unless specially equipped in some way (flag, lights, sound, or beacon).

**As an autonomous machine**, the PMR might have no onboard human to provide or receive social signals. It may be programmed to send and receive social or directional signals (see 4.1.3.7) and to exhibit more patience than does the average human. As semi-autonomous machines, some 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 self-standing scooters being guided back to a docking station.

The eventual introduction of ambulatory PMRs will add still other considerations, relieving some constraints and changing others.

## 9 Environmental and Social Considerations

### 9.1 Environmental (climate and weather) resilience certification

Resilience attributes regarding climate and weather conditions for small machines operating in a shared, outdoor space is required. This is to provide a PMR certification checklist, including guidance about its parameterization, so that a regulating or operating authority, such as an insurer or a municipality, can confirm that any PMRs permitted, licensed or insured to operate on sidewalks, crosswalks, cycle lanes, etc. will be sufficiently resilient to matters of climate such as temperature, precipitation, wind, or blowing sand so as to be not to be disabled, blown off course, into traffic, or become airborne to become hazards in those public spaces.

These descriptors would be employed by the appropriate authority(ies) to describe conditions under which relevant machines would be permitted to operate (e.g., wind gusts under a certain speed, temperatures bounded by defined values, etc.). Such descriptors and definitions would also be relevant for insurance and liability. Critically, some values, such as those for wind, might be set relative to either the curb-weight or gross-weight of the vehicle or design of the device or vehicle being regulated or operated. For example, some aerodynamic designs with a low centre of gravity might be expected to withstand stronger wind gusts; hence some machines could be rated at higher resiliency ratings, so that the matter of guidance during particular environmental conditions would be nuanced by such technical specifications. Either way this is a multidimensional issue.

Note that the standard does not set fixed values since those would vary from latitude to latitude and from climate to climate. There would be no cause to insist on machines that are able to operate reliably at extreme temperatures in a locale that could not reasonably experience such extremes. Rather, the standard sets definitions, units, ranges, and defaults and allows operating parameters to be determined locally.

How these will be interpreted will be contextual. For example, a permitting, operating, or insuring authority will need to define criteria for operating in high winds so that a PMR is not blown off course, into traffic, pedestrians, or windows. That will depend on the weight and physical profile of the machine, as well as on friction related to pavement conditions (water, ice, sand, gravel) (see TS 4448-11). Hence the challenge in using the standard will be to set out descriptions for safe operating space/conditions for cities to manage constrained-use guidelines and to gauge liability for insurance purposes.

In addition to wind and temperature, the matter of environmental resilience descriptors applies to snow depth, ice cover, heavy or blowing rain, standing water, accumulated leaves, and other ground factors. All of this is needed to manage safety and risk in near real-time. Authorities need to be able to define when to discontinue operation where it is unsafe. Because of the low weight (and potentially low friction coefficient) of PMRs — often weighing from 25-100 kg — the nature of the risk/safety parameters differs from that of a passenger automobile or truck that might weigh one or two orders of magnitude more. That needs to be mapped out, and TS 4448-5 needs to provide complete details.

For 100% certainty: the standard describes terms, definitions, ranges, limits, and procedures. It does not determine operating values or liability. Any subsequent System Controller system would use definitions, procedures, and protocols from the standard, in conjunction with the values, schedules and computed rules from appropriate permitting or insuring entities. Furthermore, while the standard does not require that an authority sets any technical requirement regarding machine behavior under specific ground conditions, this is clearly an area of divided and possibly disputed liability among regulator, operator, manufacturer and insurer; hence a common definition is necessary to inform the language used to ascertain those liability issues and to eventually know how to apportion liability.

## 9.2 Social Considerations

"People are quite good at being pedestrians. They can often execute evasive manoeuvres without breaking stride or visibly losing composure. Interactions proceed without problems, until the tacit, mutually held expectation that people behave like pedestrians does not get tested. Even when interactions require the active involvement of participants, unproblematic resolutions often occur."

Nicholas H. Wolfinger (1995) Passing Moments: Some Social Dynamics of Pedestrian Interaction. Journal of Contemporary Ethnography, Vol. 24, No. 3, October 1995 323-340

When human pedestrians, whether fully ambulatory or using assistive devices, pass each other on a sidewalk or crosswalk, whether in the same direction, opposite direction, or even when one crosses the path of another, they may rely on peripheral vision and grant minuscule, inconsequential amounts of attention to the task or they may send and read facial, gestural or body signals that facilitate uneventful passage. These may range from subtle body movements without eye-contact, to more assertive gestures or vocalizations, and on rare, extreme occasions more aggressive gestures involving hands, arms, or voice. This range — or at least a human-like expression of this range — is not currently available to PMRs.

This section addresses the gap between pedestrians and PMRs in proximity navigation. We consider that some pedestrians have sight or hearing deficits or may not be ambulatory or if ambulatory, may be insufficiently nimble to respond quickly to the approach of a PMR, perhaps causing alarm or confusion for some pedestrians.

We describe PMR behaviours as a critical (necessary and sufficient) set to be deployed in every PMR to be used in public spaces shared with uninvolved and untrained human pedestrians. This section describes mutually-reinforcing auditory and visual signals so that hearing or sight impaired pedestrians each receive identical-meaning signals as do unimpaired pedestrians.

We standardize four (?) social signals using both sound and light. In all cases where a vehicle movement (“body language”) signal has a redundant audio or light signal., they must always be performed/played together for consistent understanding by (nearly) all pedestrians. This does not address pedestrians who are both blind and deaf, nor does it address pedestrians who are severely cognitively challenged.

We limit the number of signals to a critical minimum to achieve effortless universality and ease of learning. These signals are designed to communicate either or both navigational intention or request as well as sociality. Public acceptance of PMRs is a critical aspect of this simple “language.” These signals only work as a package — i.e., only if all PMRs use them and only if all PMRs deploy sound and light in the same way. This is analogous to the common organization, interpretation and use of automatic traffic signals (ATS) for motor vehicles.

## 10 Use Cases

These are **scenarios** of ideas that are current, of trials, of potential, or of marketing hype. They are ***meant only to be illustrative***; none are being advocated — in fact, if several such scenarios became pervasive, without appropriate regulation, they could challenge cities in significant ways.

### 10.1 Package delivery from “motherships”

Tom orders some goods online from Amazon. The Amazon delivery van, making several deliveries in the area, parks in the town centre car park, programs the relevant delivery addresses into a number of PMRs and sends them on their way. An automated phone call is sent to Tom and the other recipients to notify them of their expected delivery arrival, and again as the delivery arrives. The PMR then proceeds to the next delivery or homes back to the delivery van in the town centre car park for more packages or departure.

**Examples:**

https://www.youtube.com/watch?v=peaKnkNX4vc&feature=emb_logo

https://www.youtube.com/watch?v=7oUxX431y4I

 

## 10.2 Coffee in the park

Jane is sitting with her friend Jill on a bench it the park. They have been exercising their dogs and really fancy a coffee while they chat. Jane calls cup-a-chino, the local coffee bar, who get her location from her phone, which she also uses to pay, and for a small service charge send a PMR to the park bench to deliver a latte and a cappuccino.

## 10.3 Street sweeping

Utopia Borough Council uses a fleet of street sweeper PMRs to clean the high street and central park overnight. A specially adapted PMR is used by Utopia Borough Council to clear the streets of rubbish, and remove dog and bird faeces, blasting the soiled site with antiseptic spray once cleared.

## 10.4 Inspection services

See the following link and its video for an in-the-market-today example

https://www.bostondynamics.com/spot

## 10.5 Snowploughing

After an overnight snowfall, Utopia Borough Council re-fits its street sweeper PMRs with snow ploughs and de-icers to clear snow and ice from the high street roads, pavement and three car parks before the morning rush.

## 10.6 Garbage assistants

It is bin day. Utopia Borough Council sends out its ‘fetch bot’ PMRs to collect garbage bins left outside by householders to a central point where a garbage truck empties them. The PMRs then return the emptied bins to their address (identified by a barcode on the bin).

## 10.7 Al fresco food service delivery

Utopia city centre and cathedral is a magnet for tourists, and restaurants have sprawled al fresco dining into the city park nearby making an open-air food court with some fifteen different catering bars serving every type of food, and the council have set out many tables and benches to accommodate the tourists. When ordering, guests are given a radio tag to take back to their chosen table. When the food is ready it is loaded into a delivery PMR that homes into the radio tag. When guests place the tag on the PMR, it opens its warmed food compartment and the guests unload their food and drinks before the PMR returns to its base.

## 10.8 Washing services

Washing shop windows is a necessary chore. Utopia Borough Council offers a subscriber service to its high street shops, where the shop front windows of subscribing shops are washed and wiped every morning at 6am by a council owned PMR adapted for this purpose.

## 10.9 Construction site materials delivery

The UrbanSpace Development company is redeveloping a row of three shops in the high street. But space is limited. The company has hired some space in an adjoining street to store building materials such as bricks, sand, cement, etc. Ruggedized PMRs move materials from this staging area to the building site on a just-in-time basis. As of 2021 Capra Robotics provided such a PMR.

### 10.10 Valet service

Bob lives in Utopia and owns a personal PMR. He orders a take-away snack from the shop in the high street, and sends his valet PMR to collect it. The local laundry has washed some shirts and dry cleaned his suit, so he puts his clothes hanger rail on his valet PMR and sends it to the shop to collect them, while he cooks the evening meal. He realises that he needs unsalted butter for the dessert he is cooking, but there is none in his fridge. So, he calls the local grocery shop, and, once he has unloaded the cleaning and removed the hangar rail from his valet PMR, sends it to the shop to collect the butter.

## 11 Actors

### 11.1 Cyclist/micromobility user

Rider of a bicycle, e-scooter, e-board, Segway, etc. and therefore potentially sharing pathway space with a PMR.

### 11.2 Ground-based robot / drone / device

Intelligent robotic device, wheeled or ambulatory, under the overall control of a remote operator, capable of limited autonomous decision making within its programmed limitations, used to provide the service. Such a device, here called a PMR, has been called a sidewalk drone by some.

### 11.3 Pedestrian

Person who is walking or using a helper animal or device (wheelchair, assistive scooter), especially in a town or city, rather than travelling in a vehicle, and therefore potentially sharing the pathway with a PMR.

### 11.4 Regulatory Authority

Regulator that determines the regulations and constraints within which robotics vehicles and devices are allowed to operate.

### 11.5 Road user

Vehicles and other carriages or persons using the road space adjacent to the kerb/sidewalk that may be encountered by a PMR when crossing a roadway from one sidewalk blockface to another.

### 11.6 Service provider

The party who owns/leases and deploys PMRs.

### 11.7 Service recipient

Beneficiary/recipient of the service provided by PMR.

### 11.8 Vulnerable sidewalk/pathway user

User of a mobility assistance device, a vision or auditory-challenged or other challenged person possibly under the supervision of another who may be sharing the pathway space with the PMR.

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