WD/ISO TR 4448-1:2024(e)

ISO TC 204/WG 19

Secretariat:-ANSI

Intelligent transport systems — Public-area Mobile Robots (PMR) — Part 1: Overview of paradigm

Systèmes de transport intelligents — Robots mobiles de l'espace public (PMR) –Partie 1: Présentation de paradigme

Draft TR

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Published in Switzerland

Contents

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This document was prepared by Technical Committee ISO/TC 204, *Intelligent transport systems*.

A list of all parts in the ISO 4448 series can be found on the ISO website.

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.

Introduction

0.1 Background

The ISO 4448 series[1] is focused on robotic road vehicles as they load and unload passengers and goods at the curb as well as robotic devices operating among unprotected pedestrian bystanders to perform tasks in public spaces such as delivery, inspection, maintenance, surveillance, and others.

Mobile robotic vehicles and devices have found uses in factories, farms, mines, and warehouses for well over half a century. For applications in constrained spaces, this history stretches back to the 1950s with the use of automated guided vehicles (AGV) that moved along fixed pathways guided by embedded magnets or similar techniques. Over time, this technology matured to use beacons and positioning signals, usually in structured work environments to become what are variously known as industrial mobile robots (IMR), and automated mobile robots (AMR) with increasing capabilities of moving from fixed, memorized pathways to navigating with increasing flexibility and eventually using indoor-GPS, hi-definition maps, and sophisticated algorithms to move safely and deftly among humans in those environments.

In the past decade, this technology has developed sufficiently to operate beyond such relatively structured spaces to provide services directly among humans. Multiple types of mobile robots now operate indoors among air travel passengers, restaurant users, hospital visitors as well as outdoors in public spaces such as footways, cycleways, and parks. Any such mobile robotic device operating among such bystanders is called a public-area mobile robot (PMR).

0.2 Robotic vehicles at the curb, among non-robotic users

Robotic motor vehicles such as cars and trucks operating in urban areas often need to load or unload passengers and goods at a curb. Deployment standards are needed to manage this access and queueing process of loading or unloading, often called “pick up and drop off” (PUDO) in the case of human passengers.

The traffic and parking rules cities have relied on prior to the mid-2020s 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 PUDO for automated vehicle systems. (See Reference [4] for a commonplace description of the PUDO problem.)

In the future, cities will need new operating guidelines as curb lanes and sidewalks are used by automated cars (such as taxis) and automated delivery vehicles that will arrive, stop, wait, and load/unload 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 needs to be done safely, alongside human-operated vehicles, without inconveniencing pedestrians and other vulnerable road users (VRUs), and with regard to human accessibility challenges.

As, and when cities experience large numbers of automated vehicles that are loading, unloading, and performing other tasks at the curb, they 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. The ISO 4448 series includes data and procedural documents to support PUDO orchestration for automated cars and trucks.

[1] The other parts of this series are under development.

0.3 Robotic devices operating in public spaces among pedestrian bystanders

Other than cars and trucks, smaller robotic devices designed to perform various delivery, maintenance, monitoring and other helper tasks can operate on footways, cycleways, and roadways including footpaths inside public buildings such as hospitals, malls and airports — collectively "pathways." Some are able to move between indoors and outdoors, and some of those are enabled to open doors and use elevators. These devices can have numerous advantages for cities and people who live in cities. This ISO 4448 series refers to these devices as "Public-area mobile robots" or PMRs.

PMR deployment represents the first time in human history that mobile devices (machines) designed to operate without a proximate human attendant are being used to move among human bystanders that are inattentive, uninvolved, unprotected, and untrained relative to the task or activity of the device.

On a large 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 PMRs could impact safety, accessibility, existing social rights, vulnerable road users (VRUs), adequacy of infrastructure, street and pavement design, road crossing designs, active-user traffic flow, etc.

0.4 Standardization of robotic vehicles at the curb vs. those operating among bystanders

These two types of robots generally operate on opposite sides of the curb — automated road vehicles such as passenger vehicles and trucks on the motor vehicle side, and PMRs on the pedestrian side. Urban infrastructure is organized this way for historical reasons, but is not unambiguous everywhere — in some locations the boundary implied by a curb is merely assumed and possibly variable.

These two types of automated vehicles are generally subject to different regulations, with the rules designed for road vehicles generally much more developed, explicit, and often more assertively enforced by governments(s). Hence, this ISO 4448 series will focus almost exclusively on PMRs with the critical exception of PUDO (pick-up/drop-off) at the curb.

Interactions among all such robotic devices, active transportation users and human bystanders is a critical concern of this ISO 4448 series.

0.5 Planned way forward

This document provides an introduction to the ISO 4448 series, which will cover the description, management and operation of automated vehicles at the curbside, within walkways, in integrated curbside-pathway (footway) systems and within any public pathway that permits PMRs to move among pedestrians and other VRUs. Operation of such vehicles is inclusive of arriving, stopping, waiting, loading, and unloading at the curbside and arriving, proceeding, stopping, waiting, loading/unloading, or any task performance on footways and other pathways.

The purpose of the ISO 4448 series is to:

1. define the operating and behavioural systems needed to organize and expedite the flow of vehicular and robotic ground traffic in cities, specifically with regard to the loading and unloading of goods and passengers at the curbside;
2. the allocation and movement of PMRs for short-haul delivery, garbage removal, sweeping, washing, snow removal, repair, food trucks, public works tasks, and human transportation in public spaces, among other services conducted on pathways or crosswalks.

For PMRs, standardization addressing numerous behavioural rules that act as "rules of the road" is needed.

The two most important attributes of PMRs are that they operate in publicly accessible spaces shared with inattentive, uninvolved, unprotected, and untrained bystanders and that they move without a proximate human operator (a teleoperator beyond line-of-sight is not proximate).

The ISO 4448 series is planned to comprise a set of terminology, guidelines, and real-time procedures for the coordination of operations at the curbside, on pathways and the integrated use of automation on both curbside and pathway. The operating and behaviour standards being defined in this ISO 4448 series 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.

0.6 PMR capabilities, agency, and rights

PMRs are machines. They are mobile hardware devices that use the capabilities of sensors and software to move and to perform tasks with varying level of automation. They have no ability to reason or to “decide” anything beyond what their electro-mechanical systems permit whether controlled by code or machine learning. The only current exception to this is that most of these devices can be under the control of a human teleoperator. In such cases, a PMR that is controlled by a human can be expected to inherit the reasoning capability of its human controller; still, it is the human that is reasoning.

There can be times when the descriptive language used in this ISO 4448 series appears to grant PMRs a degree of agency. They have no agency. Any agency that can be inferred is with fleet operators and teleoperators.

In all cases, a PMR has no “social rights,” any more than does a bicycle, although there are number of circumstances in which a PMR can potentially have the “right-of-way,” just as a bicycle with its rider often does. There have been regulations passed in several countries that require a PMR to follow pedestrian rules or for a motor vehicle operator to treat a PMR in a roadway intersection as though it is a pedestrian. These regulations are describing the behaviour of a PMR or how it is to be treated in a traffic circumstance. They do not confer any social rights, as has on occasion been erroneously interpreted in mass media.

It is also critical that the utility and capability of PMRs does not overshadow the social rights and well-being of vulnerable workers. It is frequently stated that robots are needed to address labour shortages. The ISO 4448 series is neutral in such issues, although its drafters recognize that automation has job impacts. It is not the drafters’ place to argue whether new jobs, other jobs, or better jobs will become available, but the drafters do recognize that there will likely be labour impacts.

Intelligent transport systems — Public-area Mobile Robots (PMR) — Part 1: Overview of paradigm

1 Scope

This document provides an overview of the ground-based automated mobility systems deployment paradigm, which covers such curb sides and pathways 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 or remote operation of such vehicles. This includes vehicles and devices that move people as well as goods within proximate distances of human bystanders.

Note: Aerial (flying) drones are not part of the scope.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TS 14812 *Intelligent transport systems — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TS 14812 and the following apply.

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

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

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

3.1
ambulatory
relating to or adapted for walking
Note to entry: Implies having and traveling on legs in the case of PMRs.

3.2
block-face
one side of a city block. The segment of a street and sidewalk between two consecutive intersections. The area that pedestrians or vehicles traverse along one side of the block.

Note to entry: The length of the block face is the distance between two consecutive cross-streets.

3.3
bystander
a human within a proximate distance of a PMR that is any of uninvolved, inattentive, unprotected, or untrained regarding the task of a PMR or other automated vehicle.

3.4
curb
edge where a raised footway, road shoulder, or road median, meets an unraised street, carriageway or other roadway

3.5
delivery robot
robotic vehicle used to deliver goods, food and other items, often for "last-mile" applications

Note to entry: While the words 'drone' is correctly used to describe a wheeled robot, this document uses the term 'robot' and the specific acronym PMR

3.6
dockless scooter
rental e-scooter that does not require returning to a docking station to terminate the rental

3.7
loadPlan
An electronic message provided to a road vehicle to schedule a time and place for a pick up or drop off

3.8
micromobility
first mile or last mile forms of transport

Note to entry: Including e-scooters, bicycles, skateboards and pedestrian devices.

3.9
pathway
infrastructure designed to permit the movement of various combinations of active transportation users and PMRs within the same space, including outdoor footways, cycleways, crosswalks, road shoulders, trails and indoor passageways, corridors, or hallways

3.10
public-area mobile robot
PMR
wheeled or legged (ambulatory) ground-based device that is designed to travel along public, shared, active transportation pathways without the use of visible human assistance or physical guides

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

Note 2 to entry: While the term "PMR" excludes devices with visible human assistance, a PMR can be teleoperated by a human.

Note 3 to entry: While the term "PMR" excludes devices with visible human assistance, PMRs can carry humans as passengers (e.g., an automated wheelchair).

Note 4 to entry: While the term "PMR" excludes devices with visible human assistance, PMRs can be electronically tethered to follow a human.

3.11
robotaxi
vehicle with an automated driving system (ADS) that is configured to perform the entire dynamic driving task (DDT) throughout its operational design domain (ODD) for the purpose of a for-hire passenger service.

Note to entry: This is a form of ADS-DV (Automated Driving System – Dedicated Vehicle) defined in SAE J3016-202104

EXAMPLE: Remotely monitored automated taxi.

3.12
tripPlan
An electronic message provided to a PMR with a schedule, map and rules for a PMR trip

3.13
teleoperator
human with oversight of and some potential to navigate, guide, or direct a remote vehicle, sometimes including lateral and longitudinal control of that vehicle

4 Abbreviated terms

ADS	automated driving system
ATS	automatic traffic signals
C-ITS	cooperative intelligent transport systems
DDT	dynamic driving task
ICT	information and communications technology
JDR	journey data recorder
ODD	operational design domain
PMR	public-area mobile robot
PUDO	pickup and drop off
VRU	vulnerable road user

5 Purpose and justification

5.1 General

Automated road vehicles for passenger and goods transport can be expected to comply with existing motor vehicle road use and parking rules. However, automated devices used on footways and other active-transportation pathways for delivery, maintenance, surveillance or similar tasks would often be subject to newly established, local regulations — if any.

Detailed regulations for such PMRs do not yet exist for many cities and regions, because there is generally insufficient traffic management experience with the intention, deployment, and behaviour of PMRs.

In addition, these two types of robots — automated road vehicles and PMRs — converge at crosswalks and road intersections which are also used by pedestrians and other users of active transportation devices. A similar observation regarding other users applies to those types of PMRs that are designed for use on cycleways and roadways. Concurrent use of such these infrastructures by both types of robotic systems will create unique spatial conflicts, implying that the rules for each will commingle possibly leading to unintended consequences.

The need for standardisation is five-fold:

1. Safety and conflict-avoidance
2. Planning
3. Commercial
4. Operations and management
5. Legal, liability and insurance

5.2 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 navigating, waiting, or performing tasks in public spaces, including loading and unloading, cleaning, monitoring, delivering and 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. Such conflicts are already very common and cumbersome at many curbs and on many sidewalks. Increasing numbers of such vehicles and devices can be expected to operate without on-board or proximate human operators, and without the lane- or path-markings such as those that guide on-street vehicles. It is necessary for machines that operate at curbs, on sidewalks, in building corridors and sometimes combinations of these, to 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 agreed terminology and structure.

5.3 Planning

Projects to re-format and reorganize streets, curbs, or sidewalks, or to design indoor pedestrian spaces, can imply the building and shaping of such spaces to be workable for vehicles and devices whose operating characteristics are potentially different, or differently constrained, than those of vehicles and devices under direct human operation. Such planning activities need guidelines requiring common terminologies, taxonomies, categorizations, rules, and architectures. They will also need detailed metrics and design parameter descriptions.

5.4 Commercial

Some curbs, sidewalks and other pedestrianized spaces can be used more frequently than others by automated commercial vehicles (taxis, shuttles, trucks, public-area mobile robots, etc.) each with a variety of task capabilities. These vehicles would be loading and unloading passengers and goods and executing service tasks. The use of machines and devices without 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 waiting-place reservation systems operating in near real-time. The design of such reservation systems requires agreed terminologies, taxonomies, categories and rules.

5.5 Operations and management

Curbs, 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 on foot or with the help of vehicles and devices, automated or not, expect to be able to arrive and depart in a timely manner without finding their 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, standardization is required.

5.6 Legal, liability and insurance

Public spaces can be shared by many classes of mobile users including local residents, vendors, visitors, shoppers, workers, whether able-bodied or otherwise. Any physical conflict involving an automated device or vehicle that causes bodily harm, financial loss, or other harm or perceived harm can be subject to legal action. Hence a common understanding and description for these spaces, and the interactions, data sensors and data recording therein, is necessary to determine liability for legal and insurance purposes. This common understanding and description require standardized terminologies, taxonomies, categorizations and rules.

6 Parts outline

6.1 General

Key topics for standardization of deployment for PMRs are as follows:

1. definitions and data;
2. behaviours;
3. safety;
4. municipal readiness;
5. personal assistance.

Within the context of automated road vehicles and PMRs as covered by the ISO 4448 series, these components need to be addressed in terms of deployment matters related to loading and unloading within public, pedestrianized spaces (e.g. at the curb), or throughout their entire management and activity spectrum within public, pedestrianized spaces (e.g. on sidewalks, pathways, bike lanes or within public buildings).

6.2 Definitions and data

6.2.1 Data definitions and general concepts

Data definitions include units, defaults, and ranges where appropriate. Consistency throughout informs deployment discipline and improves the potential for integration among systems and across jurisdictions.

6.2.2 Security, privacy, testing & data: threat, vulnerability, & risk profiles

Specific points for standardization describe:

1. communications and cybersecurity issues that are necessary for secure and assured connectivity, location, determination, teleoperation, IoT, recovery, and enforcement override;
2. the maximum privacy issues and guidelines for PMRs;
3. testing guidelines for PMRs, and
4. data capture, use, retention and sharing guidelines for PMRs operating in public spaces.

NOTE: Privacy, data retention and use are determined by the local jurisdiction.

6.3 Behaviours

6.3.1 Loading and unloading of goods and passengers at the curb

A key point for standardization is a body of orchestration procedures to manage loading or unloading of passengers and goods. This could apply to any publicly accessible loading location(s) for applicable vehicles. When developed for the context of automated vehicles, such procedures could also be used by human-operated vehicles. Orchestration procedures could manage the endpoints of a trip with an electronic document called a LoadPlan that describes multiple features about hypothetical points “A” and “B”, related to queueing for use of a spot at point A or point B for a loading or unloading activity.

It would be important to incorporate procedures and rules for the case of vehicles constrained to the curbside or other designated loading area to load and unload PMRs that move goods or passengers along public pathways that do not admit larger vehicles (for example transferring from a truck or van into a smaller vehicle such as a PMR). This aspect could integrate with PMR orchestration messages called TripPlans.

Other important elements would include methods and metrics to determine whether a curb on a block-face is suitable to a particular type or intensity of use of automated vehicles or devices.

6.3.2 Public-area mobile robot access on human pathways

An important aspect for standardization includes establishing methods to manage PMR congestion by describing capabilities for trip reservation and queueing for public-area mobile robots in public spaces (footway, cycleway, roadway, and crosswalk). PMR orchestration could be provided by methods such as:

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

NOTE: Method 2 provides more traffic control and a finer degree of management by monetization (use charging) than method 1.

6.3.3 Public-area mobile robot behaviour on human pathways

It is especially important to describe “rules of the road” for PMRs on public pathways or in public spaces. This can include the full range of behaviours related to sharing space with humans, pets, other robots, and infrastructure, and can be described as a standard, enforceable traffic code for the sidewalk. This aspect of the ISO 4448 series could become very important for municipal regulation and enforcement protocols which would often be locally determined.

6.3.4 Public-area mobile robot-to-human communication signals

PMRs share public space with bystanders, including those with vision or hearing challenges, hence it will be important to describe standard sound, light, haptic, and gestural (motional) displays for social communication between PMRs and bystanders. Its key purposes can include:

1. clarity regarding a robot’s intentions when near bystanders; and
2. socializing the robot’s presence.

6.4 Safety

6.4.1 Safety and reliability for public-area mobile robots

There is a need to address multiple physical, mechatronic, and operating safety aspects of PMRs. This includes sensors, effectors, fire & chemical, hazardous goods – and more. These could be organized into three categories, as follows:

1. location safety, as impacted by a surrounding context;
2. device safety, as impacted by the device safety design; and
3. safety for proximate humans, as impacted by the disposition and behaviour of proximate humans.

6.4.2 Journey planning sufficiency for public-area mobile robots

An important safety capability is the definition of a reliable field of perception including range and maximum blind spot extent for journey planning competency. This can focus on the planning range between the full trip (path planning or a PMR macro plan) and the immediate next decisions (trajectory planning or a PMR micro plan). This intermediate range, a meso plan, would ensure that a PMR can perceive well in advance any pending barrier(s) to the execution of its macro plan in order to avoid:

1. being trapped by navigating too deeply into unexpected circumstances, or
2. exhibiting undesired, unexpected, or alarming behaviour in the presence of bystanders.

6.4.3 Journey data recorder (JDR) for public-area mobile robots

To be able to understand, track and enforce PMR behavior in public spaces, it will be important to describe journey data recorder (JDR) functions for PMRs. Such functions can include:

1. measurement of shyDistance compliance (immediate spatial clearance);
2. comparison of shyDistance compliance among fleet operators;
3. social compliance for license renewal;
4. a tool for investigating complaints;
5. a record for event reconstruction;
6. a tool for measuring congestion regarding the granting of TripPlans; and
7. a method for testing software.

6.5 Municipal readiness

6.5.1 Suitability of pathway infrastructure for public-area mobile robots

It will be critical to describe methods and metrics to determine whether a footway, cycleway, roadway or crosswalk is suitable to a particular type or intensity of PMR use.

Note: this could provide a critical opportunity to ensure that PMR methods and metrics match or exceed current disability accessibility guidelines that apply to any infrastructure shared by PMRs, wheelchair users, and other vulnerable road users.

6.5.2 Environmental worthiness of public-area mobile robots

It will be important to describe definitions and metrics to determine extreme weather and other environmental conditions that impact PMR operation safety. This can be scaled to PMR capability so that a fleet operator or managing authority can determine which classes or types of PMRs are permitted to operate in particular environmental circumstances.

6.5.3 Post-crash procedures for public-area mobile robots

It will be valuable to have clear, consistent methods for PMR crash clean-up, description and reporting. Such methods can be very important for municipal oversight and enforcement, subsequent licensing renewals, as well as immediate safety for bystanders.

6.5.4 Mapping maintenance for public-area mobile robots

It is critical to describe map parameters such as map resolution, update frequency, and error tolerances required for PMR TripZones or TripPlans. It will be equally critical to have consistent guidelines to keep such maps up-to-date.

Note: There is a parallel and independent need for similar maps to enable way-finding for many members of the disability community. This implies opportunities for collaboration, map-sharing and map crowdsourcing, in which users from both accessibility and robotics communities provide a steady stream of information that can contribute to timely map updates shared by both communities.

6.6 Personal Assistants

6.6.1 Personal assistant robots for human transport

There is a need for standards to address personal passenger robots such as automated wheelchairs or people-movers for use in public facilities such as airports, hospitals, malls, museums, entertainment parks, etc.

6.6.2 Personal assistant robots for tasks and goods movement

There is a need for standards to encompass e-tethered robots, such as:

1. personal “follow-me” PMRs transporting loads; and
2. maintenance robots used in “follow me” operation.

7 Context

7.1 Automated vehicles

7.1.1 Automated motor vehicles at the curb

Vehicles equipped with automated driving systems (ADS) are able to load and unload passengers and goods without a human driver present. Such vehicles are popularly referred to as "driverless vehicles," and are generally both automated and connected. The integration of automation and connectivity allows these vehicles to accept route instructions and navigate accordingly while responding to other vehicles.

Passenger cars and goods-transport vehicles are increasingly becoming connected, while progress has been slower than anticipated. While the automated taxi is being piloted in a few carefully managed and constrained areas, since 2019 this technology has also advanced more slowly than had been promised during the years prior. Furthermore, the fully automated (SAE Level 5) vehicle will almost certainly be delayed even longer — possibly never reaching the full capability frequently promised prior to 2018.

The reasons for this are clear. Rapid developments in sensors and software have enabled the ‘dream’ of automated service vehicles to be realisable in respect of their mechanical instantiation, but the barriers to deployment of automated passenger vehicles in a high-volume, high-speed, multi-agent road system lie as much or more in the traffic management and fleet operator behaviour than in the servo-mechanical manipulation of the vehicle. The speed and impact forces at 50 km/h or 100 km/h, of a mass exceeding one ton, usually has life threatening consequences that have to be safely and reliably managed before automated vehicles, such as robotic taxis and delivery vans, become commonplace.

Nonetheless, it is almost certain that significant numbers of ADS-equipped vehicles in constrained ODDs (SAE Level 4) will operate in growing deployments and will require coordinated and wide-area PUDO (pick up or drop off) management.

7.1.2 Automated devices (PMRs) on pedestrian infrastructure

While the promised, large-scale arrival of automated passenger vehicles has been considerably delayed, the introduction of PMRs for numerous public-area services are still advancing.

For several reasons there are fewer and far less dangerous deployment, cost, safety, and regulatory challenges to be overcome for PMR deployment relative to the automated road vehicle. (Differences in size, speed, sophistication, and teleoperation are important ones.) Additionally, the accelerators promoting the development of delivery robots are more accessible to startup innovators, investors, retailers, and other participants. In sum, there are many fewer safety and entry barriers.

Concerns for road-congestion, traffic safety, and global-warming underscore the benefit of using small, clean, quiet, electric robots in place of sedans and delivery vans, in appropriate ODDs. The rapid increase in e-commerce and its demand for rapid, cheap delivery is another growth driver, while growing labour shortages are a driving factor in some countries.

PMRs are already engaged in indoor maintenance activities such as mopping and sweeping facilities including airports or shopping malls and in outdoor surveillance and package delivery. They are expected to soon engage in sweeping, de-icing, snow removal, measurement, monitoring, repositioning dockless scooters for recharging, and similar services. They will likely arrive in some cities at a larger scale and sooner than will ADS-equipped vehicles. Without deployment standards these will be difficult to govern.

As fleet sizes increase, these devices will likely impact other vulnerable users of active transportation infrastructure. Even if perfectly engineered, the introduction of machines that share active transportation space with pedestrians and cyclists will impact traffic safety.

It can be argued that maintenance robots to keep sidewalks clear of ice, or to monitor such spaces for safety issues from potholes and cracks or vandalism-related damage can offer a counter balance, but it is unquestionably necessary to pay attention to deployment rules that can minimize inconvenience and risk to vulnerable users. In other words, device safety is only part of the equation; deployment rules and their enforcement are equally and perhaps even more critical.

As of 2023, worldwide there are a several hundred companies—mostly start-ups—engaged in developing small, teleoperated and sometimes partially automated devices for operation on city walkways and cycleways. Thousands of small retailers and many tens of delivery operators are using 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 PMRs long before being expected to govern robotic cars and trucks.

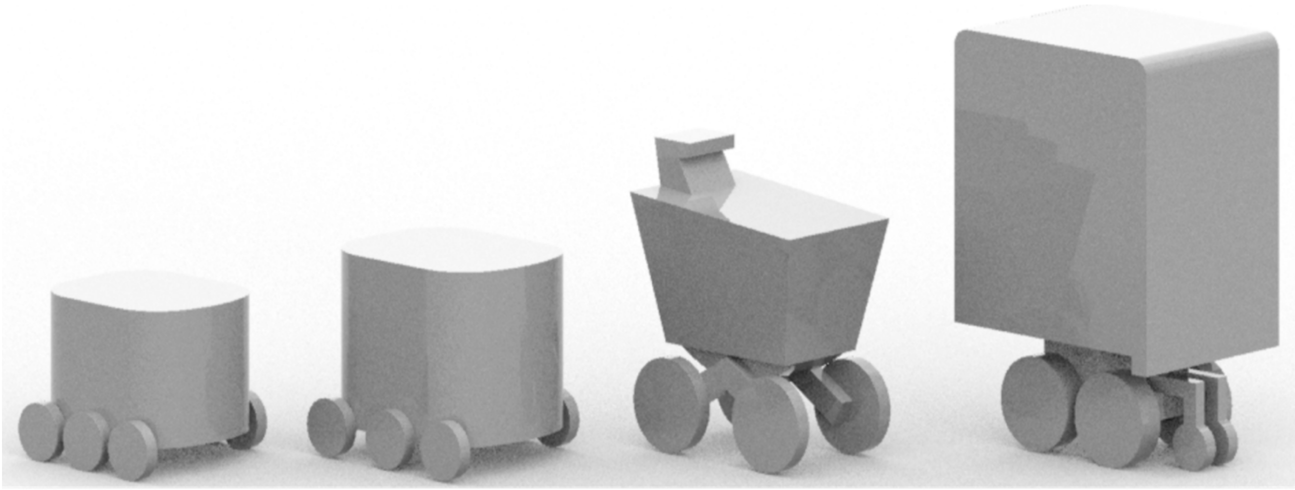

Figure 1: Example PMR forms for small-package delivery.
(Image, courtesy Urban Robotics Foundation)

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As a specific case, personal delivery devices (sidewalk delivery robots, **Figure 1**) are generally 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 are among early examples of these PMR devices, some of which have been discontinued. There are already several hundred related designs in trials or deployment, and it is not possible to predict their final design outcomes. Such PMRs and their successors—including legged robots—are expected to increasingly frequent active transportation pathways. As they become more capable, their adoption could become more pervasive.

It is critical to address characteristics and behaviours of PMRs in pedestrianized spaces, in addition to the concern for PUDO for road vehicles (7.1.1). As well, the intersection between orchestration for PUDO at the curb and for PMRs entering and exiting larger goods vehicles (sometimes referred to as motherships) will also be important to address.

7.2 The evolution of the sidewalk and accelerators for PMRs to operate there

7.2.1 General

In this clause several factors are outlined which impact the evolution of PMRs.

7.2.2 History

The curb is the edge where a raised footway such as a sidewalk, a road shoulder, or a road median meets a street or other roadway.

Sidewalks are a relatively modern development that have evolved as cities have developed and have been populated by an ever-expanding mixture of pedestrians and, more recently, faster-moving vehicles.

As cities grew larger, with larger populations, and ever more and ever faster vehicle movements, sidewalks have become the norm. They are built into many urban plans and in a variety of widths and forms.

Some parts of a curb can be reserved for loading zones or bus stops and parts of a sidewalk can be a reserved loading area or can house a bus shelter. Street furniture (signs, lamp posts etc.) are more usually 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 jurisdictions these are constrained to the roadway). The remaining walkway space is interrupted by driveways, fire hydrants, bus shelters, garbage bins, trees, benches, and posts to lock bicycles. In many cities, cars, both legally and illegally, park on or straddle sidewalk space. Most road space for vehicles is generally much more expansive, carefully structured and better managed compared to footway space intended for pedestrians.

The mid-20th century description of the curb and sidewalk, while still dominant in many communities, is sometimes giving way to a much greater variety and more managed usage of sidewalks such as conformance to accessibility guidelines, ride-hail pick-up and drop-off, segregated cycle or micromobility lanes, ecommerce delivery, bicycle or micromobility docks, charging stations, and al fresco dining.

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

There is currently a growing trend toward the reduction of road traffic in ever more and ever larger urban centres. Any community seeking to reduce private motor vehicle traffic, would also seek to reduce the use of cars and trucks for commercial deliveries. To the degree that people still require deliveries, the use of smaller, quieter, cleaner PMRs for this purpose would likely increase demand for these devices, as well as demand for wider infrastructure for active transportation, accessibility, and PMR safety.

7.2.3 Safety

One reason PMRs, especially those used for delivery, will potentially become pervasive before ADS-equipped motor vehicles is that the safety barrier for PMRs is 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 kg fully loaded. The travel speed of these smaller PMRs is usually constrained to a walking pace—four to six k/h. Small and slow, they can stop quickly. In the event a PMR fails to avoid a collision with a stationary object or pedestrian, harm would be less as the impact momentum of such devices is low. However, while the harm to a pedestrian struck by a robot would generally be far less than the harm to that same pedestrian struck by an automobile, the risk remains, especially for children and elderly who can more often be using the sidewalk than the crosswalk, which greatly increases their relative exposure time to a collision.

Another unintended consequence for consideration is a potential increase in pedestrian collisions due to an increase in PMR traffic. Well-managed, and well-operated PMRs are expected to cause very many fewer pedestrian collisions relative to current experience with human driven automobiles or bicycles.

However, this outcome is not guaranteed and systems of certification, traffic management, behavioural enforcement, and liability would still be required.

Larger delivery PMRs—half the size and weight of a passenger sedan and perhaps travelling at 40 km/h—present greater safety challenges from a momentum perspective within a pedestrian environment and can be confined to bicycle or micromobility routes and roadway shoulders except for very low speed operation in the final metres to delivery. Still, this needs to be carefully considered because safety on busy or poorly conditioned infrastructure would be negatively impacted by the addition of PMR traffic.

Safety challenges will depend on the environment in which PMRs are deployed. These challenges are not merely about the size and speed of the PMRs. Safety is more likely to be impacted by the size and speed differential between PMRs and the other users and vehicles sharing the same space. For example, if confined to a road, pedestrian safety challenges can potentially be reduced since there is a lack of vulnerable users in comparison to a footpath.

In spite of a reduced safety concern per distance travelled, the sheer variety of PMRs presents challenges for protecting pedestrians and cyclists. Regulations will need to account for a wide range of safety considerations. Smaller PMRs can be banned from the roadway except when crossing at intersections, larger PMRs can be banned from sidewalks, and heavier maintenance PMRs such as snow ploughs to be used on pedestrian footpaths can be constrained in terms of times of day or by requiring proximate human oversight.

There are also certain unique areas of concern such as three-way interactions among pedestrians, motor vehicles and PMRs within intersections. For example, a PMR within a crosswalk could be blocked by a motor vehicle making a legal right turn on red. The PMR could steer out of the crosswalk into the traffic lane to pass in front or behind the intruding vehicle, wait in the crosswalk until the vehicle completes its turn, or return to the original ramp — all of which are risky and undesirable solutions.

To counter-balance that, one safety advantage that automated PMRs have over e-scooters and bicycles is that they are designed not to hit anything. E-scooters and bicycles rely on the judgement and attention of their riders, and human operators of any vehicle are known to take risks (such as at traffic intersections or with speed) to gain a minor time advantage. Note that the human teleoperator of a non-automated PMR can also exhibit inattention or judgement failures, but such an operator, whose job depends more on preventing a crash or complaint than being a few minutes early for a delivery, will likely take fewer risks.

Nonetheless, if any PMR collides with a human, especially a child, a senior, or a person with mobility challenges such as collision can still cause serious harm depending on the weights and crash dynamics involved. Such a crash would on average be less harmful than a crash between a full-sized motor vehicle and a pedestrian, but no PMR crash can be considered safe.

One exception to consider is that if a PMR surprises an automobile driver (in the same way as would an animal running into the street from behind a parked vehicle), it could trigger that vehicle driver to suddenly swerve, precipitating a possibly fatal crash even if the PMR itself is not struck. In summary, moving goods delivery activities from the roadway to the sidewalk can make the roadway safer, but it is unlikely to make the footway, crosswalk, and cycleway safer.

7.2.4 Cost

Currently, most PMR forms — whether used for last mile delivery, maintenance tasks like sweeping or spraying, or patrolling an area perimeter, etc. — are less costly to develop, deploy, and operate than are automated passenger vehicles, which demand far greater effort and investment.

This low cost-barrier has enabled many start-ups to establish mobile robotic service companies. Some of these companies provide services using PMRs developed by others, while some have developed innovative devices. In a further distinction, some develop, manufacture, and operate highly automated devices, while others rely predominantly or entirely on teleoperation to respond to the sharp rise in e-commerce triggered by the COVID-19 pandemic, which itself exacerbated problems of cost and labour availability. Taken together, this equates to a large number of companies, devices, operating variations, and a pending traffic management problem that requires standardisation and systems for the deployment and governance of this new form of traffic.

7.3 The challenges

7.3.1 General

In this clause several factors are discussed to sensitize the reader to many special challenges of PMRs. This will help users of this document better understand the intention of many of the suggested elements that the remainder of the ISO 4448 series should focus on.

7.3.2 Infrastructure

PMRs and robotaxis each face complex infrastructural barriers; some of these are related, such as at road crossings. Because pedestrian pathways are often less rigorously structured or managed than are most roadways, infrastructure often present more complex barriers for PMRs to negotiate.

PMRs will have to negotiate obstructions such as human legs, barking dogs, baby strollers, planter boxes, tree roots, people waiting at the bus stop, uneven pavement, curb edges, ramps, and crosswalks — a more disorderly environment than the highly regulated city streets where robotaxis will operate.

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 footways, 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 can constitute a high barrier for operating PMRs in these spaces given conditions such as:

1. Garbage bins standing on the pathway
2. Vehicles parked on the pathway
3. Construction materials stored on the pathway
4. Furniture or mattresses left on the pathway
5. Tree limbs fallen on the pathway
6. Shrubbery overgrowing the pathway
7. A sidewalk that abruptly ends (incomplete pathway)
8. Severely damaged or potholed pavement

In many of these cases, a PMR would have to request a new route or be able to navigate around these barriers, for which legs might offer an advantage.

Depending on community preferences for active transportation and on the generosity of neighbourhood infrastructure for walking or cycling, a local population can exhibit a limited tolerance for sharing active infrastructure with PMRs. Even if constrained to using road shoulders or a "mothership" (see clause 11) approach in the case of delivery, there often remains an expectation of using or crossing pedestrian infrastructure.

For constraints of infrastructure configurations and access permissions, early designs (see **Figure 1**) represent only a partial solution to robotic deliveries. There are many aspects of navigating footways, using stairs, doors, elevators and locker systems that confound these early designs. There are already many instances of pre-commercial PMRs that are ambulatory and have graspers (legs and arms).

If PMR technology is to be generally and widely deployed, eventually many PMRs will use legs rather than wheels. One instance of a ground-based robot, the quadrupedal robot, is a legged robot with motion reminiscent of a dog.

Whether bipedal or quadrupedal, a legged PMR that is able to self-navigate in ODDs that include instances of pathway barriers and obstacles such as listed above could be superior to wheeled and tracked robots because of their ability to operate in many more terrain conditions in the same manner as would a human or animal. This makes traversing curbs, moving around barriers on narrow passages, or mounting stairs more achievable, and having such PMRs better equipped to manage being impacted, kicked or shoved. Many demonstrations of such ambulatory terrestrial robots are visible on the web, but are likely to need further development before becoming widely viable.

7.3.3 Revisions of existing regulations for PMR use on public infrastructure

The operating assumption for many jurisdictions is that the use of PMRs on public infrastructure is often prohibited in the absence of specific regulations. Hence, it can be expected that many jurisdictions will require new or altered regulations to permit the use of PMRs.

Among national governments to have added clauses to their road traffic regulations are Estonia, Finland, Japan, and South Korea. Several U.S. States have passed related legislation. A few jurisdictions have banned PMRs, presumably temporarily, as they await guidance from a superior level of government. These include the Canadian cities of Toronto and Ottawa which did so at the end of 2021.

One of the complexities of this regulatory work is that the governance of pedestrian spaces (such as sidewalks) is typically a municipal matter, while the governance of road traffic and vehicle safety is directed at a higher level—either provincial, state, or national. It is in the overlap, i.e., crosswalks and sometimes bicycle lanes, that direction from senior levels of government may be required. Examining the subject national legislation from the countries and states mentioned above makes this clear.

Regulatory elements can be required to address the following:

1. Pedestrian and cyclist safety and rights-of-way
2. Requirements for infrastructure dimensions (related to accessibility regulations)
3. PMR speeds, dimensions, weights (maximums and minimums)
4. Equipment such as brakes, lights, speakers, mics, reflectors, signage (decals)
5. Device identification and its visibility for enforcement
6. Areas and hours of operation, especially avoiding certain zones such as schools
7. PMR behaviour regarding accessibility (e.g. distance-keeping, blocking ramps or entrance ways)
8. Audible signals emanating from a PMR such as their loudness and meaning
9. Requirements to alert other users of PMR presence (sounds, lights, flags)
10. Requirements to recognize and respond to sounds such as emergency vehicle sirens
11. Enforcement and penalties
12. Liability and insurance

7.3.4 Greater variety of mobility types, and configurations

As described above, curb and sidewalk space in many towns and cities are under increasing pressure for access from a growing variety of users, innovations, devices, businesses, and services.

Over the past decade, digitalization of mobility and commerce has brought rapid growth in new forms of taxi-class operations, such as loading and unloading passengers at the curbside, and a dramatic rise in goods delivery from e-commerce systems, accelerated by society's response to the pandemic.

In some cases, 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 often adds bike and micromobility lanes at the curb, as well as scooter and bicycle storage systems on or beside the footway.

The onset of the COVID-19 pandemic created rapid and unexpected demands for these sidewalk and curb spaces to accommodate social distancing (e.g., 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 extend temporarily beyond the curb and into cycling and parking lanes.

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

7.3.5 Greater demand for orchestration in pedestrianized mobility space.

The near future is expected to see growing demand for the delivery of passengers and goods to the curb — soon using automated vehicles and local delivery of goods via PMRs. Indeed, such systems are already in successful operation in numerous cities and campuses.

This will not only lead to increasing traffic volume requiring highly digitalized management, but also a change in the nature of the interaction of these vehicles and their mobility systems with each other, with the curb, with payment systems, with active human mobility, and with existing manual vehicles and devices.

It is logical that such digitalized management systems will use communication and security systems compatible with those used for cooperative ITS (C-ITS). Indeed, there is strong logic to use similar architecture and communications means since loading and unloading passengers and goods interacts with curbside robotic systems. PMRs will need to cross roads therefore needing to be aware of approaching robotic 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 stress — their inadequacy and shortcomings made evident by the pandemic.

Neither current rules nor their temporarily modified versions will sufficiently support the anticipated automated systems. Cities will need new operating guidelines as automated taxis and PMRs arrive at curbs an on footways to 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 needs to be achieved safely, mixed with human-operated vehicles, without inconveniencing active transportation or pedestrian traffic, and with regard for universal design.

7.3.6 Growing access demands on pedestrianized space

Today, pedestrians use the sidewalk in a variety of ways. For those walking to a destination or to make a delivery, the sidewalk is a path*.* For those who are 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 of PMRs to the human pathway implies a purely path-oriented use, except for departure and arrival terminus points. Functionally and navigationally, this is comparable to a pedestrian in a wheelchair using the sidewalk as a pure travel path. (See 9.2)

PMRs that navigate human pathways will almost certainly be required to consistently recognise and accommodate others using these as a place.

Wheeled PMRs have some characteristics similar to a wheelchair. They can easily travel faster or slower than the average human pedestrian; they confront issues of climbing over uneven, damaged, steep, sloped, or potholed pavement and ramps to sidewalks; they often have difficulty managing a step of significant height and generally cannot negotiate multiple steps; and they cannot easily step aside or streamline their body width by turning sideways while walking as can most ambulatory humans.

7.3.7 Growing mismatch between infrastructure configuration and user capabilities

There are many circumstances for which it is difficult for a wheelchair or PMR to climb a curb or a gradient, or use narrow passages that would not permit a robot and a wheelchair to pass each other. This is due to three factors:

1. The predominance of car-oriented environments, such as in most suburbs that have a car population. These tend to crowd out sidewalks making them narrower than ideal for the introduction of PMRs. This also tends to distort the design of footways and cycleways such as when there is insufficient traffic space, especially at intersections, quite often elements of active-transportation infrastructure are curtailed first, meaning active transportation users can find themselves cramped for space. PMRs will compete for this same space.

2. The default assumption of ambulatory humans in the design of active transportation space automatically puts wheeled PMRs at the same disadvantages that such design puts the wheelchair user.

3. The design assumption, in the case of a wheelchair and an ambulatory pedestrian passing each other, is that the pedestrian will walk around or step aside for the wheelchair or if not, the wheelchair user will be inconvenienced for only a short period of time. If the use of PMRs were to grow considerably, this assumption would be challenged.

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

7.3.8 Regulatory or infrastructural bias — pedestrian vs PMR

As a machine, it can be expected that the PMR can be regulated to have fewer spatial rights and diminished rights-of-way compared to a pedestrian or cyclist. This is distinct from the fact that some jurisdictions require a PMR to use a road crossing using the same rules as a apply for pedestrians and require that automobiles at an intersection treat a PMR already in the intersection using the same rules as apply for a pedestrian within the intersection. These are traffic regulations and generally do not confer social rights on a PMR.

Conversely, as a working machine, a PMR could play an important economic role, or perform a critical task for someone who has protected social rights. Perhaps certain types of PMRs can be provided with specific rights such as boarding a public transportation vehicle or entering a building that would not otherwise be permitted, similar to the permissions currently granted for helper animals.

A wheeled PMR might be unable to pass certain barriers or obstacles that an able-bodied human can; it might be subject to vandalism or mischief in ways that are different or more frequent than those confronting a wheelchair user; and it can have a very much lower height profile compared to a wheelchair user, making it less visible to pedestrians or motor vehicle drivers unless specially marked or equipped with flags, lights, or motion alarms.

While a PMR will be a connected vehicle for teleoperation purposes, having no onboard or accompanying human to provide or receive social signals, could make it socially mute, relying entirely on information from other connected devices, and the skill and patience of its teleoperator. Conversely, it could be programmed to send and receive social or directional signals and to exhibit more patience than the average human.

Partially automated PMRs can be teleoperated, but the ability of a teleoperator to engage in social signalling might be severely limited. It will be important to close this gap order for pedestrians to become extremely comfortable with PMRs.

7.3.9 The problem of compute resources for PMR automation

Remote (teleoperator) oversight for PMRs will likely be required by regulation long into the imaginable future. It would be desirable for a PMR to always be able to automate any navigation situation except the most extreme edge cases. The simple reason for this is to increase the ratio of concurrent PMR devices under observation per teleoperator to maximize fleet operator profit.

Automated cars and trucks currently carry and power sufficient local compute resources to handle all but a diminishing numbers of extreme edge cases. This is not to say that robotic cars and trucks will eventually solve all edge cases. Rather, it is to say that current robotic vehicles appear to handle very much more within their ODDs, both relatively and absolutely, than PMRs appear to handle within theirs.

While the size and energy requirements for this amount of compute intensity decreases continually, this is still not something that a very much smaller PMR can afford to carry and deploy in the mid-2020s. While this might improve in the next few years, contemporary PMR systems are compute-starved relative to what would be needed to operate without (or with very little) teleoperator intervention. In other words, the combination of very complex unstructured navigation environments coupled with compute resource constraints can lead to mediocre performance, slow response times, and more frequent remote interventions.

Fortunately for PMR fleet operators these problems can be absorbed by human teleoperators that can intervene as often as is necessary to address navigation and other problems. Because there are no human passengers to alarm and no risk to bystanders, this solution acts as a perfect, but expensive, bridge to the time in which PMR capabilities will match those gradually being achieved by robotic automobiles.

One of the biggest differences between robotic taxis and PMRs is that teleoperation (except for pure oversight and emergency recovery) is almost entirely unacceptable for passenger transportation, but completely acceptable—and essentially invisible—for small goods last-mile transport and a myriad of other maintenance and security tasks.

In sum, the current state of PMR technology is nascent and its operation within infrastructure shared with pedestrians needs careful consideration, especially as the number and variety of PMRs expands.

8 Operating principles for PMRs

8.1 Contrasting types of infrastructure

8.1.1 General

For operations in a shared, human-social environment, operating and deployment standards need to provide general rules for PMRs on multiple types of pathways used by active transportation users of all abilities.

8.1.2 Contrasting pathway and curb

The core matters of scheduling and pairing automated vehicles with places to access are similar for both curb and sidewalk. However, in the case of pedestrian pathways, place (block-face or footway) is very different from the curb where place implies a space for loading and unloading.

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

Depending on the prevailing view of the governance of public space such as Communal Public Square, Regulated and Orderly Public Square, or State-Owned Property (see Reference [5], and 9.1), such pedestrian actions can be protected or curtailed. It will be desirable for any standard to be agnostic to any particular governance style or theory.

Certain PMRs, especially maintenance PMRs such as sweepers or snowploughs, can be constrained for use at places or times when few or no pedestrians are present.

8.1.3 Contrasting cycleways and footway

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

First, PMRs might need to travel at the speed of cycle lane traffic flow in order to minimize disruption to other users. Second, PMRs often need to overtake stationary or slow-moving cycle users. Depending on the nature of the cycle lane and the disruption, this can require the PMR to temporarily stop, travel in a lane going in the opposite direction or move onto the sidewalk. Third, PMRs will need a method for dealing with pedestrians who cross the cycle lane, such as when jaywalking or accessing a parked car. Depending on the behaviour of the pedestrian that is crossing the path of the PMR, the PMR can stop or slow down and alert the pedestrians of its presence (similar to a cyclist ringing its bell). Such behaviour would likely be less acceptable on a footway.

8.2 Behavioural factors

For the behavioural aspects for PMRs, there are many important factors, listed in Table 1 to consider within the context of the ISO 4888 series.

Table 1: Factors that can influence the acceptance and workability of PMRs

Alarm or harm	It will not be acceptable for PMRs to harm or alarm humans or animals. It is possible that a PMR could behave defensively using sound, light, or evasive movement in the event it is threatened; hence a PMR could emit sound(s) to indicate concern or alarm. NOTE: Within this context, the term “concern” is intended as a low alarm circumstance, wherein a PMR (or its teleoperator) determines that it is potentially close to being endangered. For example, being touched by a bystander could be considered precursor to a harmful act, but it would be unacceptable for a PMR to exhibit aggressive alarm behaviour each time a pedestrian comes closer than a PMR’s programmed shyDistance.
Apparent	Many pedestrians could be made uncomfortable or alarmed if a PMR approached quickly from behind or seemed to appear suddenly because they are small or quiet. It will be important that other pathway users are not surprised or alarmed by a proximate PMR. Hence, it will be important for PMRs to be visible, audible or both to all users on the pathway, including those with visual or auditory impairment(s) as well as to avoid mishaps with distracted pedestrians.
Congestion	PMR area occupancy (device count) could be controlled within a block-face to avoid crowding pedestrians. It is possible to standardize an orchestration system to prevent this.
Forthcoming	It will be important for PMRs to capture and secure information required for oversight and event post-mortems according to requirements set by the relevant licensing authority. It will be equally important for the relevant authority to describe that information prior to licensing and deployment of PMRs.
Intrusive infrastructure	PMRs can be guided by localized infrastructure, high-resolution mapping, and other data or technologies. It is possible to describe standard constraints on physical infrastructure such that it does not negatively affect the use of this shared space by making it more cluttered, riskier, more confusing, or less accessible.
Legible	Some pedestrians could be confused or be caused to stumble if a PMR made a sudden turn directly in front of them, crossed a person’s path with too-little notice, or passed too closely. It is important for PMRs to signal and behave in ways that are consistent and understandable to proximate humans.
Loitering	Sometimes a PMR may need to wait for a task to complete or a new instruction for a new destination. It is possible to standardize the use of public spaces by a PMR that is waiting so that it will minimize obstruction other users.
Non-conflicting pathways	PMR fleet operators will tend to prefer routes that optimize travel time. It is possible to have standard methods that allow transportation authorities to control infrastructure use while respecting other demands on the same infrastructure.
Non-conflicting travel rules	It matters how a PMR uses a footway in order to avoid pedestrians or minimize conflicts with them. It is possible to standardize whether to travel on the edge of the sidewalk that avoids building doors, travel clockwise or counter-clockwise, pass only when necessary, travel single-file, or sometimes use cycle lanes.

Pedestrian free flow	It will be important that PMR usage rules such as navigation manoeuvres, stopping rules, and waiting-area rules do not to compromise pedestrian flow and access. It is possible to standardize how PMRs should: • wait on curb cuts and at intersections • enter and use road crossings • request right of way • withdraw from a location and request an alternate route
Physical hazards	PMR configurations and deployments could create physical hazards for bystanders. These could be caused by physical elements such as size, weight, speed, and protruding parts, or by algorithmic elements such as shy distances or trip planning guidelines created or deployed according to parameters set by the responsible authority.
Privacy	PMRs and robotic motor vehicles should not diminish the privacy of people using or residing near the pathways they use. This implies a need for standardized constraints on the recording, use, and retention of data.
Rights-of way for PMRs	There are circumstances for which a PMR should be able to demand right-of-way over another PMR or human. It is possible to standardize methods for a PMR be used to halt or seize another PMR. A PMR that is deployed (on-duty) in an active fire, medical or police emergency, or one deployed to transport a human in an evacuation should be able to demand (and be granted) priority over humans or other PMRs.
Rights-of-way for humans	PMRs and robotic motor vehicles are expected to grant right-of-way to proximate humans. Such rules, if executed without exception, could cause a PMR to become immobilized for an extended period in a crowded circumstance, so such rules can either be tempered or PMRs could be denied access to areas that have a high risk of such circumstances.
Security	PMRs and automated vehicles should not diminish the security of humans or other machines on or near the pathways they use. This includes both cyber and physical security. PMRs that are compromised, such as a suspected or reported security risk, abandoned, crashed, failed, in a proscribed area, on fire, etc., could be made subject to seizure, inspection, disablement, or being impounded or destroyed, as appropriate by local enforcement systems.
Shy distance and social distance	PMRs and robotic motor vehicles can be expected to respect cultural and contextual interpersonal distances normally observed by humans walking or standing in a public place, known as shy distance. This could be extended to a local social distance if PMRs are identified as a disease vector and shy distance is less than social distance.
Signals	It will be important for PMRs to signal their presence, priority, and properties to other machines. This can enable rights-of-way decisions and can help differentiate automated (unaccompanied) mobility devices from human operated devices, humans, and non-mobility entities.
Sounds	PMRs are able to make sounds. It is possible to standardize PMR minimum and maximum sound levels relative to the range of human hearing capabilities and ambient noise levels. Exceptions could be defined for emergency service PMRs.

9 Governance principles for PMRs

9.1 General

Reference [5] outlines three views of public space that might guide a regulator of PMRs:

1. Communal Public Square,
2. Regulated and Orderly Public Square, or
3. State-Owned Property.

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

The principle of the ISO 4888 series is to remain agnostic to such legal theory. Rather its goal will be to ensure necessary and sufficient data and procedures so that respective socio-legal preferences can be supported in any country, state, or city by way of constructions that allow legislators to adapt the series to their governance needs and be able to communicate relevant rules to roboticists, operators of automated devices, and their users (e.g., logistics, maintenance, or security companies). Correspondingly, makers and operators of PMRs can anticipate and comply with the resulting rules.

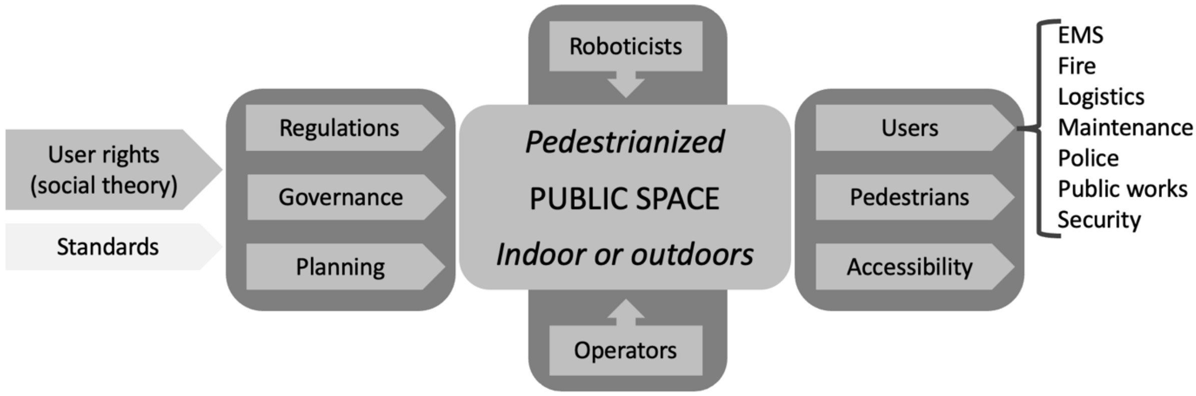

Figure 2: Social rights and standards influence planning and governance which, in turn, influences how public spaces are managed and the operation of machines in those spaces benefit users and pedestrians.

During navigation, it is necessary for a clear space in the direction of travel to be open in order for a PMR to proceed. The proximate, realtime issue depends on the size and comfort of that clear space, and the behaviour of a PMR within that space. It is necessary to ensure that human users sharing that space are not inconvenienced, endangered, or harmed in terms of access, safety, or reasonable enjoyment of the use of that 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 entering, develop into a circumstance that inconveniences or delays pedestrians or adds to pedestrian congestion potentially made worse because of the presence of the PMR(s). These circumstances are dynamic.

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, the product of millions of years of evolution, is unlikely to improve, but within the foreseeable future PMR mobility skills will almost certainly improve. The risk is that PMRs will eventually exhibit more nimble, quicker, and capable mobility than humans. In unregulated, congested circumstances, this could become deleterious to human access in these spaces. Standards needs to be continuously protective of human access as this technology can eventually outperform current human capabilities.

Several instances of U.S. state legislation that have been enacted since 2017 indicate that PMRs (short-sightedly identified as "personal delivery devices" in these legislative documents) are always required to give way to pedestrians. This behavioural constraint is necessary but insufficient in the case of the use of greedy spatial algorithms.

For this reason, it will become critical to standardize data and procedures to control the ingress of PMRs to a given area so that their occupancy (count within a block face) at any given time can be controlled. This would reduce, but not obviate, the effect of greedy navigation algorithms.

Related to this, it is possible for a PMR that is required to 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 this is likely not possible on every occasion. This is another reason to consider occupancy counts on block-faces according to sidewalk configurations and times of day so as to minimize the likelihood of such events.

As PMRs become more capable, they will potentially acquire, through machine learning or other techniques, more foresight to further reduce the probability of being trapped. One of the intentions of the ISO 4448 series is to provide ways to minimize the likelihood of this outcome.

9.2 Similarities between PMRs and wheeled, human assistive devices

This subclause 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 that seeks alignment with existing accessibility standards for users of wheelchairs and assistive scooters would meet with greater social acceptance. Such goal-congruent alignment provides opportunities to address sidewalk design and configuration to intentionally benefit accessibility goals while standardizing PMR access and flow.

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 (curb 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 can have several constraints similar to those of a wheelchair.

As a machine, the PMR can be expected to have diminished rights-of-way compared to a pedestrian, cyclist, or other human user. Conversely, as a working machine it can be performing an important public service or safety role, or it can be performing a service critical to a human with specific mobility needs. Some specially marked PMRs could potentially inherit specific rights in the way that a service dog inherits certain rights-of-way from the human it is helping. A PMR might be unable to cross certain path elements that an able-bodied human can traverse, it can be subject to vandalism or mischief in ways that are different or more frequent than those confronting a wheelchair user, and it can have a 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 automated machine, the PMR can potentially have no onboard human to provide or receive social signals. It can be programmed to send and receive social or directional signals and to exhibit more patience than does the average human. As partially automated machines, some can be teleoperated, but the ability of a teleoperator to engage in social signalling will potentially be limited. An example of this would be teleoperated micro-mobility devices such as self-standing scooters being guided back to a docking station.

Nearly all PMRs in current commercial service employ wheels while a few use tracks and even fewer use legs (ambulatory). Legged robots have multiple advantages on uneven, steep or damaged terrain, steps, etc. (see 7.3.2) They are also more complex and currently more expensive on average than wheeled robots.

10 Environmental and social considerations

10.1 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 footways, cycleways and crosswalks. will be sufficiently resilient to environmental forces such as temperature, precipitation, wind, or blowing sand so as to be not to be disabled, set off course, blown into traffic or other obstacles, or become airborne and hence hazardous.

These descriptors would be employed by the appropriate authority 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 can potentially be expected to withstand stronger wind gusts; hence some machines could be rated at higher resiliency ratings, so that the guidance during particular environmental conditions would be nuanced by such technical specifications. Either way, this is a multidimensional issue.

These will be interpreted according to contexts. For example, an authority that licenses, operates, or insures PMRs might need to define criteria for operating in high winds so that a PMR is not blown off course, into traffic, pedestrians, or shop 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). Hence the challenge in using such standards will be to set out descriptions for safe operating conditions for cities to manage constrained-use guidelines and to gauge liability for insurance purposes. This will impact the operational design domains of both manufactures and operators.

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 between 25 kg and 100 kg, the nature of safety parameters differs among PMRs as well as from that of a passenger automobile or truck that might weigh one or two orders of magnitude more. That needs to be detailed, and any orchestration system would need to communicate those details.

In summary, while standards can describe terms, definitions, ranges, limits, and procedures, it is usually not appropriate for them to set specific operating values or liability for PMRs. Any subsequent authority or system controller would use standard definitions, procedures, and protocols in conjunction with the values and rules from appropriate permitting or insuring entities. Such common definitions can also inform the language used to ascertain those liability issues and to consider know how to apportion liability (insurance subrogation).

10.2 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." From Reference [6].

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 usually rely on peripheral vision and grant inconsequential amounts of attention to the task or they send and read facial, gestural or body signals that facilitate uneventful passage. These 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 currently not available to PMRs.

This subclause considers a potential understanding gap between pedestrians and PMRs in proximity to each other. It is recognized that some pedestrians have sight or hearing impairments or are not ambulatory or if ambulatory, are frail or insufficiently nimble to respond quickly to the approach of a PMR, perhaps causing alarm or confusion for such pedestrians.

PMR behaviours can be described as a critical (necessary and sufficient) subset to be deployed in PMRs when used in public spaces shared with uninvolved and untrained human pedestrians. Such behaviours can be described so that auditory and visual signals are mutually reinforcing and that hearing or sight impaired pedestrians each receive identical-meaning signals as do unimpaired pedestrians.

A small number of socially-effective signals using paired sound and light signals can be standardized. In all cases where a vehicle movement (“body language”) signal has a redundant audio or light signal., they can always be displayed together for consistent understanding by all proximate pedestrians. This would not address pedestrians who are both blind and deaf, nor would it address pedestrians who are severely cognitively challenged.

The number of signals can be set to a critical minimum to achieve universality and ease of learning. Such signals can be designed to communicate either or both navigational intentions or requests as well as sociality. Public acceptance of PMRs is a critical aspect of a set of such common signals. Such signals work best if designed and used consistently by all PMRs, analogous to the common organization, interpretation and use of automatic traffic signals (ATS), brake lights and turn-signals for motor vehicles.

11 Use Cases

These are several current scenarios of use cases—some tried, others potential. These are illustrated in Table 2. None are advocated or opposed. The unintended consequences of some of these scenarios are often unexplored, poorly understood and potentially challenging for cities.

Table 2: Selection of use cases for PMRs

Advertising	PMRs — usually on another task — have already been deployed to carry advertising messages.
Construction site materials delivery	There are examples of robots that have been ruggedized to move materials within construction environments. In cases where construction borders pedestrianized areas, these become PMRs by definition. The behaviour of these PMRs takes on extra safety dimensions to account for potentially distracted bystanders.
Delivery of food and refreshment to realtime locations	A delivery PMR could deliver food or other items to a person at any location reachable by that PMR. There is no need for a fixed address. For example, a person sitting in a park could receive a delivery.
Delivery service, al fresco food	PMRs could be deployed to fill food deliveries within a public open air food court with multiple food companies sharing delivery services.
Delivery, packages from “motherships”	Delivery robots can be integrated with larger trucks, often referred to as “motherships," utilizing a combination of automation, and human collaboration to streamline the delivery process. A delivery van would be loaded at a shipper or distribution center. This van (mothership) would act as a mobile hub for multiple PMRs (delivery robots in this case). One or more PMRs are transported within the mothership to a location proximate to the final delivery. At the delivery area, the mothership parks in a suitable area based on factors optimizing parking permissions, proximity to receiver and accessibility considerations. PMRs are released from the mothership with or without human assistance, then proceed via footways and crosswalks to the final delivery location. After delivery, the robot returns to the mothership to load new packages, recharge, or await further instructions.
EV charging	PMRs have been deployed for mobile, on-demand EV charging within a car park.
Garbage assistants	PMRs can be designed to assist with tasks like moving garbage bins to a central location or picking up fallen bins on the sidewalk. This is a complicated task, so progress is slow.
Inspection services	A PMR can be configured to inspect or monitor an area or pathway for infrastructure conditions, safety infractions or both. It is possible for such a device to gather data about the condition of assets such as traffic signage along the pathway taken. Such a PMR can be equipped with legs to inspect other public areas such as a public park that are less accessible to a wheeled vehicle.
Maintenance, street or area cleaning	A maintenance PMR can be configured to clean streets and public park areas of litter and animal faeces. Some can be equipped to clean a soiled site with antiseptic spray once cleared. An alternative to an automated robot set to do such tasks is a “follow me” robot that follows a worker that might be collecting garbage, or effecting

	small repairs such that the robot is carrying waste or tools as the worker moves to complete their task.
Maintenance, washing, vacuuming services	There are already several PMRs for mopping or sweeping floors in public areas, spraying pathways with cleaners and disinfectants, removing gum from the pavement, picking up cigarette butts, etc. Ideas such as washing windows at street level have been considered.
Maintenance, winter	PMRs are being designed to plough or blow snow, spray de-icer on pathways and outdoor car parks.
Personal services	There have been demonstrations of a PMR being used as an assistant to a blind pedestrian, performing a task of a service dog. There have been instances of a PMR shown walking a dog, which while technically feasible, this could be socially unacceptable for several reasons. It is technically feasible (although possibly risky) to have personally-owned PMRs that can run nearby errands for urban dwellers such as shopping or dry cleaning. A follow-me robot, while not strictly automated at a distance, can follow its owner or user at 1-2m carrying items on behalf of its owner. An example would be helping seniors with shopping. Another example is a follow-me suitcase for luggage. It is also the case that a follow-me robot might offer a degree of physical protection or health monitoring for the human to which it is electronically tethered.

Bibliography

[1] ISO/TS 5206-1 *Intelligent transport systems — Parking — Part 1: Core data model*

[2] ISO/TS 14812:2022 *Intelligent transport systems — Vocabulary*

[3] SAE J3016-202104 *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*

[4] TEMPLETON, B. Self-Driving Cars Are In Trouble Over Pick-Up/Drop-Off. They Can Fix It. Even At the Superbowl. 2023-02-09 https://www.forbes.com/sites/bradtempleton/2023/02/09/self-driving-cars-are-in-trouble-over-pick-updrop-off---they-can-fix-it--even-at-the-superbowl/

[5] THOMASEN, K. "Robots, Regulation, and the Changing Nature of Public Spaces" (2020) 51:2 Ottawa L Rev 275.

[6] WOLFINGER, N.H. Passing Moments: Some Social Dynamics of Pedestrian Interaction. Journal of Contemporary Ethnography, Vol. 24, No. 3, October 1995 323-340

