Urban Robotics Foundation

Executive Guide to PMRs

What you need to know about Public-area Mobile Robots

2024 Edition

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www.urbanroboticsfoundation.org

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Executive Summary

The leadership of any **government** (regional and/or municipal) and the executive management of any public facility such as **airports**, **hospitals, shopping malls, and parks**, will confront acquisition and deployment decisions regarding work- and support-systems that are becoming increasingly automated, and that claim ever growing numbers of applications.

Many of you already have.

Here, in this series of documents, we are focused on **mobile robotic systems**, in particular with devices, machines, or vehicles that move among pedestrians, citizens, visitors, passengers, patients, or patrons.

These devices may be providing a service (e.g. maintenance or security) within a facility or outdoor space, or they may be performing delivery tasks, using sidewalks, pathways and other pedestrian routes, and possibly crossing roads, bridges, etc.

We call these devices, ***public-area mobile robots***, or **PMRs**. What is unique about PMRs is that those people among whom they are moving are generally uninvolved, unprotected, untrained, and frequently inattentive with regard to the task or activity being performed by the robot.

Nonetheless, matters of public or user acceptance, bystander safety, the perceived "behaviour" of these devices, whether people appreciate or fear them, and certain liability issues will become matters of concern to executives and their management teams.

This Executive Guide:

- summarizes the definition and current market circumstances for these devices;
- outlines the opportunities and challenges of engaging with PMR technology;
- briefly outlines the implications of delaying or advancing any decisions to begin testing PMRs;
- describes a way for you to access and process a body of deployment standards meant to help confirm and guide your deployment decisions; and
- briefly outlines the leadership you will be required to establish when the time comes, while outlining the standards and guidance available to that leadership team when they are ready for their next steps.

Please **reach out** to us if you have any questions.
https://www.urbanroboticsfoundation.org/contact

Executive Director's Message

Welcome to the **2024 Executive Guide to Public-area mobile robots (PMRs),** published by the Urban Robotics Foundation. This is Part One of a new series of publications that make up URF's Guides to Public-area mobile robots.

Bern Grush
Executive Director

Mobility Innovation and Open Standards

In 2019, I was appointed by the International Standards Organization (ISO) as the global lead for drafting what is now called *ISO DTS 4448: Intelligent Transport Systems - Public-area mobile robots*. With over 30 years of experience writing national and international standards on a range of topics including parking, road pricing and autonomous vehicles, I am passionate about transportation and mobility innovation. It is clear that creating global, open standards and helping leaders understand how to integrate those standards into their decision-making will expedite successful deployment of these vehicles and devices.

Leadership is Risky

We are in a time of change—some would say disorder. Much is remarkable and exciting; and much is alarming and uncertain. A major force that drives this turmoil is polarization and one place we see its impact most emphatically is in engineered intelligence—remarkable for its potential but alarming because so few understand its workings or its outcomes. Two of these technologies are the juggernauts of ***automated vehicles*** *and* ***artificial intelligence as applied to mobility*****.**

Someone seeking to address a labour shortage or reduce motor vehicle traffic has reasons to want to deploy PMRs while someone confronted daily with physical accessibility issues has reasons to fear them *unless these same devices can enhance the accessibility experience of that person.*

It does not matter whether one seeks labour-saving convenience, safety, return on investment, a cleaner environment, cheaper delivery, or any of many other beneficial promises of this technology. What does matter is that, on net, cities and public facility operators need to see value, while no person is left worse off. And that is a tall order, indeed.

It is a very real possibility that unintended consequences from all this effort could turn out badly. We have never before put machines that move freely among unprotected, untrained humans without proximate human oversight and direct, mechanical control. Although there is always remote oversight this oversight is not apparent to pedestrians, cyclists, and motorists. A lack of understanding of this can lead to complaints or worse.

There is little in the tradecraft of complete streets that tells us the design rules that fit such a mobility case. This will be a very critical gap to close during the early years of the deployment of PMRs.

About the Urban Robotics Foundation

Given the stakes outlined on the previous page, the Urban Robotics Foundation (URF) was created in 2021 as a non-profit organization to bring together stakeholders from around the world who are interested in the opportunities and challenges presented by public-area mobile robots (PMRs) and to help shape the related international standards.

URF'S goal is to build a global network of people focused on learning how PMRs can contribute to improved livability in urban ecosystems.

The purpose of the Urban Robotics Foundation is to create pathways to **readiness for PMRs with a focus on accessibility**. We do this in four pivotal ways:

1. Publishing a series of Guides to PMRs
2. Conducting workshops (virtual & in-person)
3. Providing vendor-independent advisory services
4. Leading the project to draft the ISO DTS 4448 deployment standard for PMRs

The early years for this technology will bring lessons; we will need to learn from those. Risks can be mitigated with careful testing through pilots and trials from which lessons can be shared.

The Urban Robotics Foundation is here to help. **We invite you to join us!**
www.urbanroboticsfoundation.org

Robots Among Us

"Sidewalk delivery robots, once only a sci-fi reality, are getting more attention these days because of their potential to revolutionize ground-based delivery and serve as a "last-mile" solution that takes the human out of the loop. The robots simply navigate to your address while using cameras to avoid accidents and locking features to prevent theft.

"These robots claim that they can make it easier to do contact-free deliveries, empowering restaurants and consumers to save money, and even reduce greenhouse gas (GHG) emissions, traffic congestion, and parking problem on the streets. Could these robots even improve quality of life by safe and cost-effective delivery of food, medicine, and other small packages to individuals with no access to cars?"

From: Serena Alexander (2022) Robots Among Us: An Analysis of Community Perspectives and Reactions toward Sidewalk Delivery Robots in the City of San José. (Mineta Transportation Institute) *https://transweb.sjsu.edu/sites/default/files/2203-Alexander-Perspective-Sidewalk-Delivery-Robots.pdf*

What are Public-area mobile robots?

Robots are designed in a near infinite array of sizes and purposes. Most are used in factory environments. Until recently, these devices were generally affixed and often caged in a specific work location. One early exception is a small consumer robot to vacuum floors in homes.

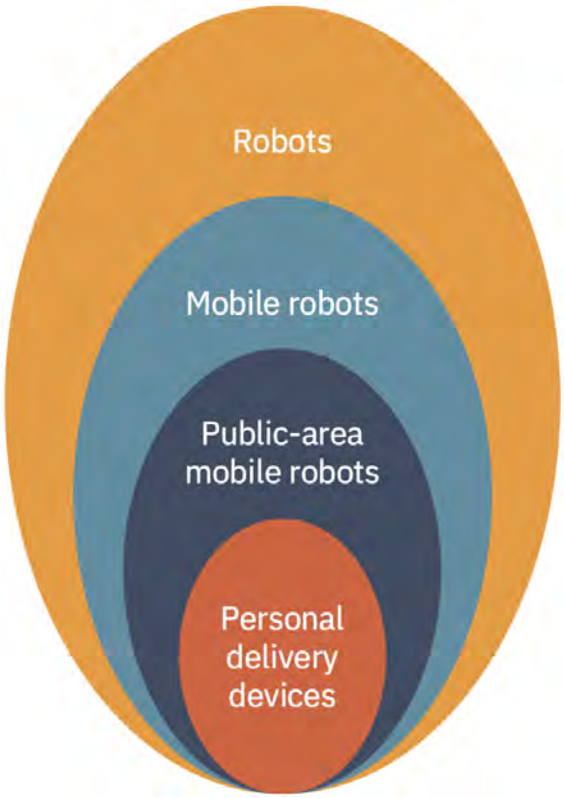

Figure 1: *Defining Public-area mobile robots*

Over the past decade, **mobile robots** have become more capable. Mostly wheeled, they have graduated from factory and warehouse to more complex jobs in mines and on farms. They are often referred to as: industrial mobile robots (IMRs) or automated mobile robots (AMRs).

Mobile robots are now moving into more complex and dynamic spaces and use-cases, mixing among human bystanders. **Public-area mobile robots (PMRs)** perform a variety of tasks including maintenance, logistics, and security. In addition to using any number of wheels and with or without self-balancing ability, PMRs are also deployed using legs or tracks.

Currently, the **most popular type of PMR** is the **delivery robot** or **'PDD' (Personal Delivery Device**). They are most often used for "last-mile" food delivery, but new use-cases are constantly being tested and deployed in many locations.

While the story of mobile robots is several decades old, the focus of the Urban Robotics Foundation is the more recent appearance of small mobile robots in public spaces shared with non-involved pedestrians (‘bystanders’).

The International Organization for Standardization (ISO) defines a Public-area mobile robot (PMR) as: "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" *(ISO draft technical standard 4448-1)*.

PMRs can be teleoperated, but the key distinguishing feature is that there is no human operator on board or accompanying the device. PMRs can be used to carry humans as passengers (e.g., a wheelchair or assistive scooter robot) and they can be electronically tethered to follow or lead a human.

PMRs are deployed among 'bystanders' who may be inattentive, untrained, non-involved, and unprotected compared to trained personnel working and collaborating with robots in factories or warehouses.

Use Cases

PMRs can be used to:

- clean (mop, sweep, de-litter)
- deliver (last-mile, food, retail goods, medication, equipment)
- maintain (mow, de-ice, remove snow)
- manage (parking citations, tour guide)
- monitor (patrol, protect, secure, inspect)
- move people (travellers, patients, shoppers)
- and more...

Where permitted, PMRs can operate in public spaces such as city sidewalks, college campuses, pathways, hospitals, parks, zoos, airports, and malls. They can be used both indoors and/or outdoors. Crossing streets and bike paths present some of the most complex interactions.

Figure 2: Example form factors of PMRs; Ottobot delivery robot (Ottonomy.io), Saltnex (Capra Robotics), Wheelchair robot (Cyberworks Robotics)

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Market Developments

Overall, the global mobile robot market is expected to grow in value from USD 20.3 billion in 2023 to USD 40.6 billion by 2028 at a compound annual growth rate (CAGR) of 14.9% (Source: MarketsandMarkets, July 2023).

If we focus *only on the last-mile delivery segment* of the market, the CAGR for PDDs is estimated to exceed 25% from 2023 to 2032, driven by advancements in robotics technology and the entry of new players. (Source: Global Market Insights April 2023)

Does our history with e-scooters portend a direction for PMRs?

All of us are aware of the numerous positive and negative outcomes of recent mobility innovations such as ride hailing, e-scooters, and e-bikes. Many of the promised outcomes were framed in comparison to then-current contexts — “ride-hailing is better than using taxis”, “e-scooters reduce automotive congestion,” and “e-bikes reduce automotive ownership.”

Often, negative outcomes get serious notice only after deployment is underway. That is generally because these outcomes only become socially observed and politically charged when innovations begin to scale: “ride hailing takes riders from the transit system,” “e-scooters are lying on the pavement everywhere,” and “e-bikes are being driven on the sidewalk!” Negative outcomes tend to displace the positive outcomes, at least in the press.

On the next page, Figure 3 shows the current state of regulation and, by implication, municipal readiness, for e-kickscooters in a large sample of worldwide cities. According to "Scooter Race," a 2023 report published by McKinsey, e-scooters are banned in cities accounting for 30% of the sample population, unregulated in 32% of the sample, and regulated in 39% (either by tender (10%) or open with no player-limit (29%)).

It is clear that PMRs are very different from e-scooters. E-scooters move people and are controlled by human riders who may or may not follow rules or be thoughtful about alarming or inconveniencing bystanders. PMRs move goods, execute maintenance and security tasks, and are controlled by a fleet operator using software and/or with employees who are teleoperators.

Those differences aside, a major similarity is that both device types share space with active transportation users, whether pedestrians or cyclists and both cross roadways thereby interacting with motorized traffic. It is here that the similarities are important even though solutions are very different.

Banning PMRs will result in lost opportunities and services, especially for aging and mobility challenged populations. As well, any municipality that maintains a complete ban would miss future opportunities to reduce logistics traffic in urban neighborhoods.

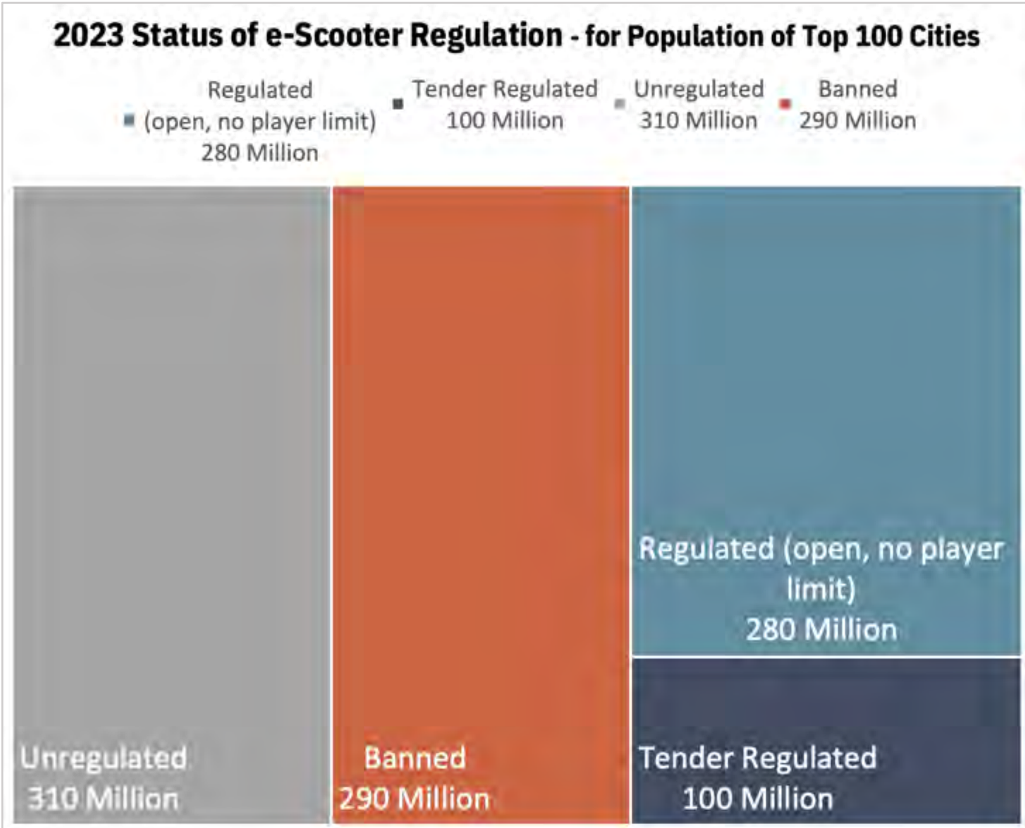

Figure 3: 2023 Status of e-Scooter Regulation Globally. Data source: https://www.mckinsey.com/featured-insights/sustainable-inclusive-growth/chart-of-the-day/scooter-race

Unregulated PMRs may result in many negative outcomes, such as unexpected or competitive behaviours at road crossings, inability to control congestion, or insufficient ability for a municipality to convey traffic rules or real-time road information.

We provide a more in-depth assessment of the risks and benefits of regulating or banning PMRs in URF's **2024 Discovery Guide to PMRs.**

What is the Cost of Taking a 'Wait and See' Approach?

According to a 2020 report **The Future of the Last-Mile Ecosystem**, published by the World Economic Forum, "There has never been a time of greater change for the 'last mile'. Consumers order more things online, expecting more control and faster deliveries. ... Inner cities are struggling with traffic congestion and air pollution due to the increasing number of delivery vehicles, their emissions and second-lane parking... These developments are not surprising, but they are challenging because they are not linear. Rather, they are interwoven in complex ways that reinforce their speed and magnitude. This poses new questions to last-mile ecosystem players: ... Which disruptive technologies and delivery chain innovations should be prioritized over others? Which regulatory city interventions offer maximum impact?"

Figure 4 shows a forecast increase of 36% in the number of delivery vehicles from 2019 to 2030, an increase of 6 Mt of CO_2 and a 21% increase in the average commute time for a representative city among the Top 100 cities globally in a base case scenario.

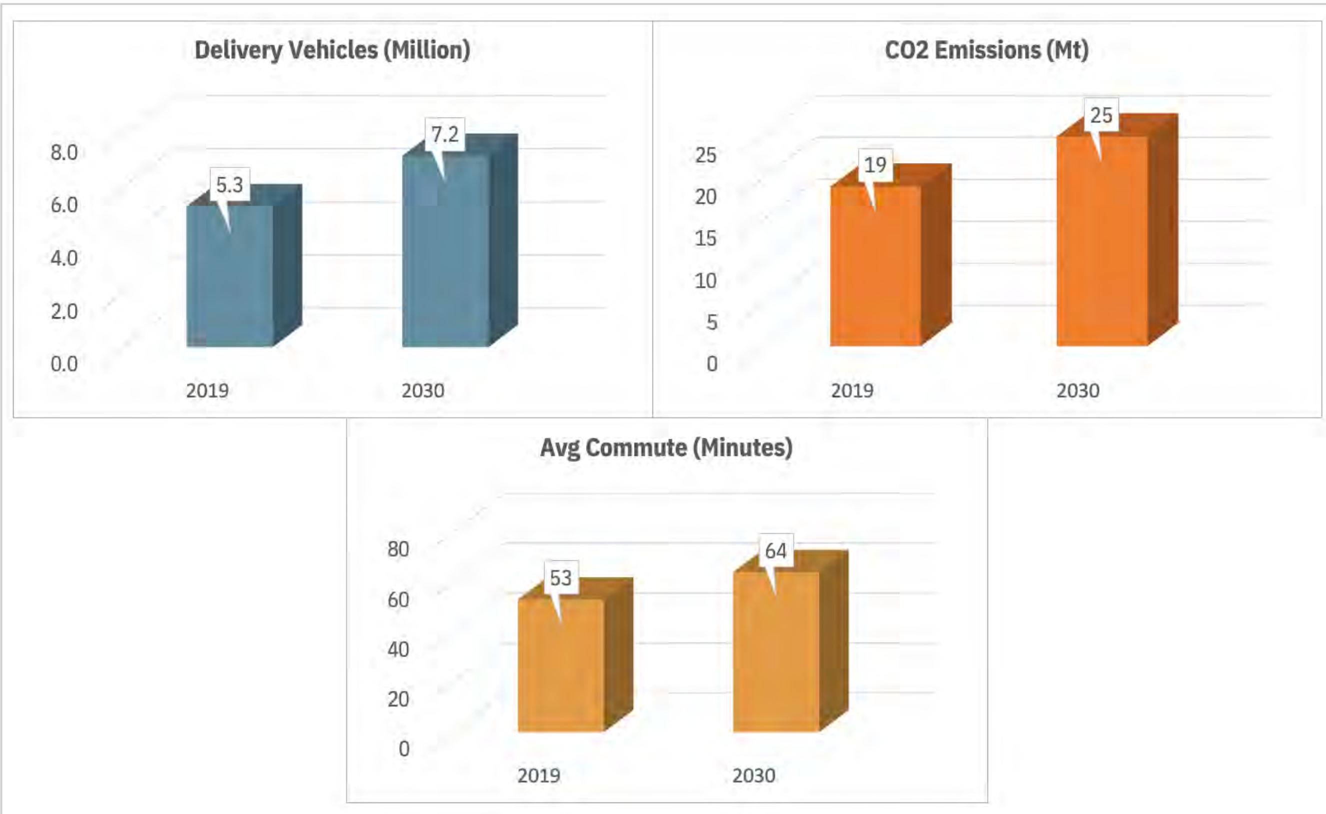

Figure 4: Forecast impact of taking a 'wait and see' approach (The Future of the Last Mile Ecosystem) Source: https://www3.weforum.org/docs/WEF_Future_of_the_last_mile_ecosystem.pdf

The WEF recommendations are aligned with the approach we take at the Urban Robotics Foundation:

"In terms of next steps, we encourage private and public players to **team up and accelerate the roll-out of pilots** on the suggested interventions. Also, we believe there is tremendous value in **building discussion networks or consortiums** for cities to exchange the most effective methodologies, discuss challenges and liaise with private sector players. Besides, we believe that **robust, harmonized regulations** – e.g., for autonomous driving and inner-city e-mobility – would help automotive OEMs and logistics players to better allocate R&D investment and accelerate the adoption of sustainable supply-chain technologies. Lastly, the **use of data and advanced analytics is a vital enabler** for interventions such as effective load-pooling and real-time traffic control. Also, **joint data standards and effective data sharing** can bring tremendous benefits to all ecosystem players.

Opportunities

Public-area mobile robots — robots operating near human bystanders in public spaces — present substantial opportunities while also posing significant challenges in terms of complex interactions with active humans sharing those spaces.

Depending on how they are deployed, PMRs offer opportunities distributed among key stakeholders including: municipal governments and urban planners, logistics operators, facility operators, accessibility advocates, environmental policy makers, and the general public as shown in Table 1**.**

Table 1: Example opportunities of PMR deployment by stakeholder group

Stakeholders	Opportunities
Municipal Governments & Urban Planners	Improve services to underserved areas, data-driven insights, public safety, sanitation, space efficiency, and infrastructure management
Logistics Operators	Greater modal flexibility, reduced costs, remote access, service scalability, and alleviation of labour shortages
Facility Operators	Address traveler and patient mobility, facility sanitation, area security, and alleviation of labour shortages
Accessibility Advocates	Universal accessibility, collaboration with active transport stakeholders, and commercial pressure for ADA compliance
Environmental Advocates	Energy efficiency, CO_2 reduction, reduced congestion at loading/parking spaces implies reduced emissions, noise, and idling
Public	Improved livability, enhanced services, reduced traffic, safer neighbourhoods, and more active transportation options

The ***necessity*** for deploying PMRs is being underscored by labour shortages which, in turn, are driven by aging populations in many countries. Even re-shoring has labour impacts that ripple through the logistics chain. The protest of "*robots will take our jobs*," is being out-shouted by concerns of *"we need robots to support the decline in available labour".*

The combination of de-globalization and falling fertility demands more agile mechanization to support consumption. In other words, in many populations the cry of "*we need jobs to maintain our standard of living*" is being replaced by *"we need robots in order to maintain our standard of living."*

Accessibility

If system planning, bylaws, service provisions, and infrastructure planning each make **accessibility a first priority**, the realization of these opportunities can be enormous and shared by all stakeholders.

Putting accessibility first means our deployments will engender the greatest degree of acceptance, community value, and safety. If accessibility in its broadest sense is not a critical, primary design filter, it is unlikely that PMRs will achieve more than a small fraction of their potential.

Our history of sharing urban space with the automobile, a flawed design history, illustrates the outcome of putting the machine and its purposes first.

Drivers of Change

The ***existence*** of PMRs is made possible by recent advances in sensors, software, tiny motors, and mechatronics that were initially developed for factories, farms, mines, and warehouses.

The ***popularity*** of PMRs has been accelerated by robots used for delivery, surveillance, and sanitation in response to COVID.

The ***adoption*** of PMRs is made easier by early legislation in several countries such as Estonia, Japan, Finland, and South Korea, as well as in more than 20 US states.

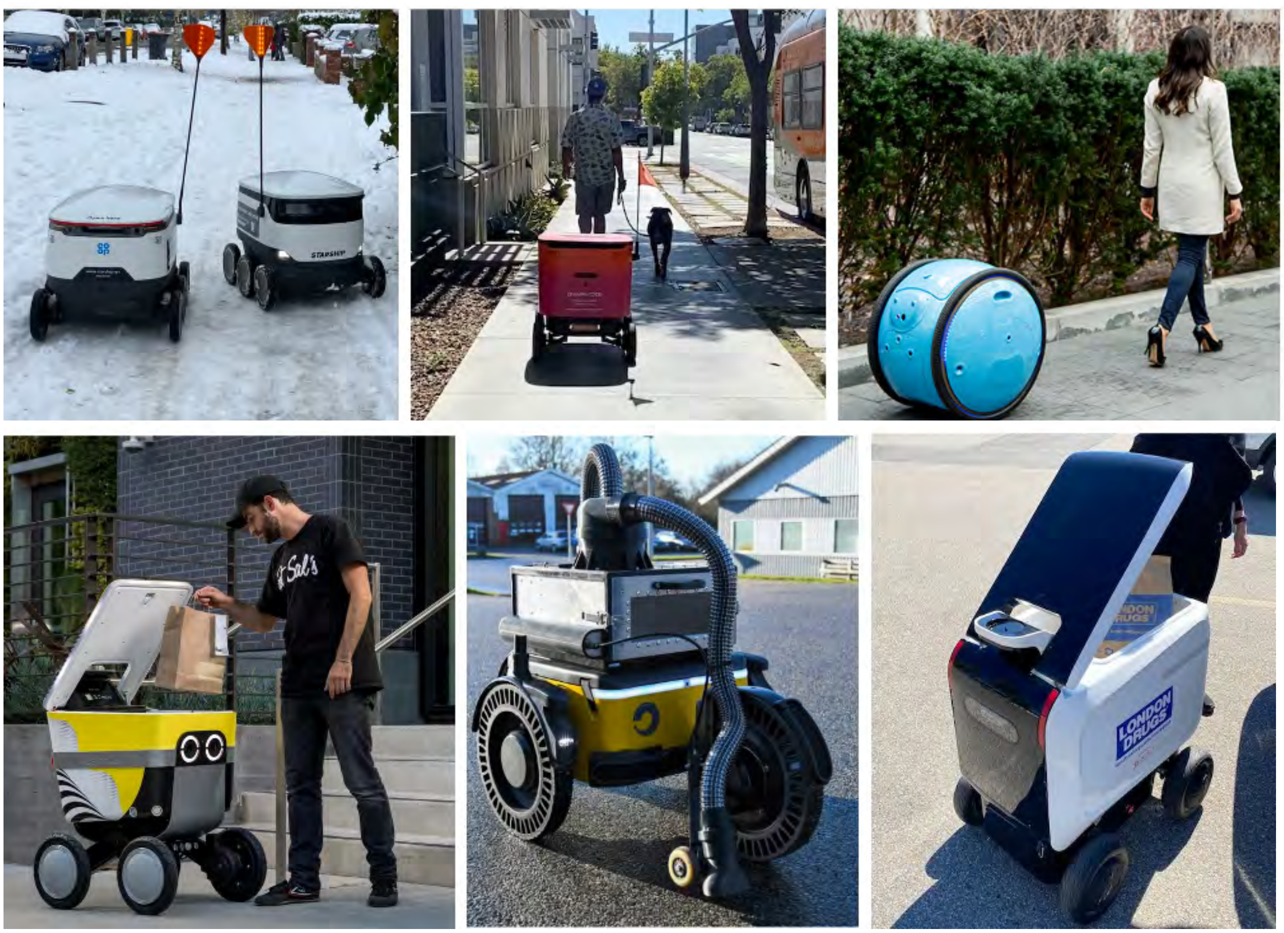

Figure 5: Examples of PMRs: Starship robots on snowy path, Coco Delivery, Piaggio (Gita) follow-me robot, Serve Robotics food delivery, Capra Robotics (Butty), Real Life Robotics (Bubs).

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Challenges

PMR challenges are likely to weigh heaviest on municipal governments. Consider that municipalities carry responsibility for accessibility and active transportation issues as well as for vibrant commercial zones, and safe, well-maintained environments.

Table 2 shows examples of challenges that are relevant for the same stakeholder groups identified in Table 1. It is well-known that every opportunity can also present challenges. The good news is that challenges are not show-stoppers. In all cases, challenges are matters that can be overcome by investment, bylaws, effort, agreements, collaboration, planning, research, and dialogue.

Table 2: Example challenges for PMR deployment by stakeholder group

Stakeholders	Challenges
Municipal Governments & Urban Planners	Infrastructure readiness, safety concerns, regulatory frameworks, liability management, equitable service availability, keeping regulations up-to-date, cyber security, data privacy, and traffic orchestration
Logistics Operators	Public acceptance, map maintenance, changing regulations, operational scalability, interoperability and standardization, traffic orchestration, and technical limitations
Facility Operators	Safety, insurance, customer comfort, and increased complexity at command centres [orchestration]
Accessibility Advocates	Pedestrian crowding, protection and promotion of accessibility rights, and balancing needs of all active transport users
Environmental Advocates	Recycling of PMRs and their batteries and sidewalk congestion
Public	Communications, public acceptance, and understanding how to engage with PMR technology

Challenges weigh heavily on municipal governments even if higher levels of governments set guidelines thereby alleviating at least some decision-making pressure. For example, safety concerns, could be absorbed into certification programs based on various related safety standards set by higher levels of government.

Creating Open Standards

The International Organization for Standardization (**ISO**) is an independent, non-governmental organization with a membership of 169 national standards bodies. Through its members, the ISO brings together experts to share knowledge and develop voluntary, consensus-based, market relevant, international standards that support innovation and provide solutions to global challenges.

URF's Executive Director, Bern Grush, is the global project lead for drafting the ISO standard for the parameters and procedures for PMR behaviour and deployment — *ISO/TC204/WG19 DTS4448 — Public-area mobile robots*.

There are sixteen parts to draft ISO-4448, organized into four major themes as listed in Table 3.

Table 3: Structure of Draft Technical Standard ISO-4448

Theme	Parts
Definitions and profiles	1. Overview of paradigm 2. Data definitions and general concepts 3. Security, privacy, testing & data: Threat, vulnerability and risk profiles
Machine behaviours	4. Loading & unloading of goods and passengers 5. Access on human pathways 6. Journey planning sufficiency 7. Behaviour on human pathways 8. Robot-to-human communication signals 9. Journey data recorder
Operational context	10. Suitability of pathway infrastructure 11. Environmental worthiness 12. Post-crash procedures 13. Mapping maintenance
Personal & safety	14. Personal assistant robots for tasks and goods 15. Personal assistant robots for human transport 16. Safety and reliability

At URF, we believe the biggest barriers to successful PMR deployment are related to municipal readiness and public acceptance (or lack thereof). Once a new standard is published by the ISO, it can take years for stakeholders to fully understand how to implement the standards and even longer for the benefits to be fully realized across the industry and among the public.

By publishing the first edition of these guidebooks in advance of the release of ISO-4448 (anticipated in stages during 2024-2026), URF wants to help maximize the promised benefits of these technologies and help expedite public dialogue and acceptance. Through sharing best practices, case studies and research findings, and through conducting workshops and providing advisory services to support deployment teams, we can help improve the chances of successful deployment while minimizing any unintended consequences during pilot testing and early deployment phases.

Governance and Readiness

Figure 6: Deployment Pillars are key elements at each "maturity stage" of the PMR deployment process.

If PMRs are to operate at scale in public, pedestrian spaces, then there are several governance concerns that should be consistently understood and addressed. Transparency demands that pedestrians and cyclists, users of sidewalks, people of all ages and abilities are able to understand and support the rules that guide these machines. Ultimately, it is essential that these robots behave in similar ways across operators and from one city or town to the next.

Makers of these devices and operators of their fleets must understand what is expected of robotic equipment if they are to succeed in these spaces. And local governments will need a template from which to govern their streets, intersections, police, and insurers in regard to safety, traffic, and tort.

Deployment Pillars

PMR deployment impacts a number of areas of municipal responsibility. We have grouped these areas into six " **Deployment Pillars**":

Readiness: Careful planning is needed for trials, limited deployments, and eventual larger-scale, multi-fleet, mixed logistics and maintenance operations. This is a critical endeavor that should include:

- Consulting with community stakeholders to understand the priority use-cases
- Selecting suitable communities for trials
- Determining changes needed to bylaws; setting up frameworks for licensing and permits
- Understanding required infrastructure investments
- Analyzing data, reporting, and planning for subsequent deployments

Behavior: Establishing a common baseline of behavior for PMRs is crucial. This includes how they interact with pedestrians, signal their intentions, and ensure safety for all — including those with disabilities. ISO-4448 offers a framework for these behaviors, which can be adapted to your community's needs.

Orchestration: There are systems for air traffic control and traffic signals and rules of the road for motor vehicles. However, human pathways such as sidewalks lack formal orchestration systems. Currently, pedestrians move freely, engaging in various and arbitrary activities. ISO-4448 offers a framework to integrate robots into these spaces minimizing negative impacts for pedestrians and for traffic at road crossings.

Certification: As PMRs become increasingly autonomous, governments need assurance they are safe, identifiable, cyber-secure, and controllable. Certification, whether self-, agency, or third-party certification will be essential for operation in pedestrian spaces.

Enforcement: Fleet operators will be highly motivated to ensure their PMRs are safe and programmed to follow all agreed rules. Still things can go wrong — a robot might fail mid-road-crossing. There may be rare circumstances in which a robot is controlled for malicious purposes. In all cases, it must be legally and safely possible for the jurisdictional government or agency of that government to halt, commandeer, seize, or impound a robot. An obvious example of this might be that city personnel battling a fire is permitted to block or physically remove a robot.

Monetization: To ensure orderly operation, managing PMR traffic will be akin to overseeing ships, planes, and cars. Monetization, likely overseen by a city or regional government, will be needed to fairly allocate and recover the costs for orchestration, certification, and enforcement.

Deployment Pillars will evolve as PMRs diversify and diffuse. These devices will become increasingly ambulatory and capable in other ways as they continue to be integrated into the operational fabric of our cities and public facilities.

The Leadership You Will Need

The advent of pedestrian-scaled robots coupled with automated passenger transport in our cities promises a transformative wave of change in the coming decades. This shift will surpass the combined impact of the automobile's introduction at the end of the 19th century and all mobility innovations since 2005. Beyond automation and technology, we must also consider how these systems influence accessibility, crime, efficiency, jobs, safety, and various other aspects of urban life.

Safety, for instance, extends to crosswalks, cybersecurity, winter maintenance, crime reduction through patrolling robots, and the well-being of pedestrians with disabilities. Robotics will permeate nearly every facet of urban planning and life itself. Consequently, cities and public facilities require leadership that encompasses accessibility, equity, political, and social dimensions for urban success — far beyond “just technology.”

In a smaller municipality or public facility, a majority of these concerns might be the purview of a single department (e.g., Public Works), whereas in larger cities, they might impact many different departments. Each city will organize its approach to suit, and cities will likely need to change their approach several times over the next decades.

Standards-mediated Leadership

The ISO 4448 draft standard for PMRs is intended and designed for **Governance and Deployment** leadership. It will be critical to your jurisdiction or facility, and to any superior level of government that has relevant authority in your jurisdiction or facility, to have access to standards and deployment models for PMRs. While there are multiple layers of consideration, your leadership will primarily focus on the governance and deployment layer at the top of Table 4 while remaining aware of the issues implied in the lower four levels.

Table 4: A view of system layers for Public-area mobile robots

	Layer	Areas of Concern (examples):			
5	Governance & Deployment (ISO DTS 4448)	Acceptance Accessibility Communications Crash Reporting Enforcement	Insurance Liability Location safety Orchestration Personal Assistant	Personal Transport Pickup/drop-off Regulation/Bylaws Rules of the road	Seizure Traffic Management Vandalism Waiting space
4	Robot Tasks/ Use-cases	Cleaning Delivery	Measuring Monitoring	Salting Security	etc.
3	Robot Operations	Charging Insurance	IoT Orchestration	Pound (for Seizure) Signals	etc.
2	Operational Design Domain	Infrastructure	Mapping		etc.
1	Machines	Ground-based	Ambulatory	Tracks	Wheels

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Your Next Steps

As you begin (or continue) your journey to deploying mobility innovations such as PMRs, we are pleased to offer additional publications, webinars, workshops and vendor-independent advisory services to support you. This Executive Guide to PMRs is Part 1 of our guidebook series. URF's Discovery and Project Guides (Parts 2 & 3 respectively) will be available for purchase on our website as they are published. *https://www.urbanroboticsfoundation.org/guidebooks*

URF Discovery Guide to PMRs: Opportunities and Challenges with Public-area mobile robots

The **URF Discovery Guide to PMRs** provides further exploration of the use cases for PMRs with examples from around the world. It offers details and examples of the range of opportunities, challenges, benefits and risk mitigation strategies to consider when deploying mobility innovations such as PMRs. The Discovery Guide can be considered a prerequisite to fielding questions from city council to municipal staff—or questions to city council from accessibility advocates. A prospective PMR project manager would read this before advising a municipal development team, voting for project budgets, or deciding priorities for a pilot. Technology companies would read this to gain insights on how their products and services could better align with needs and opportunities within urban ecosystems.

Target Audience: Municipal/Regional governments, transportation planners, engineering consultants, robot designers, fleet operators, system integrators.

Purpose: Inspire readers with examples and a summary of the issues faced by stakeholders across the spectrum of PMR use cases while sparing them the project details necessary for execution.

URF Project Guide to PMRs: Best practices while preparing for Public-area mobile robots

The **URF Project Guide to PMR Deployment** is intended for project teams who are ready to dig into the details of how to move forward once a pilot project is being considered or has been identified. It can be purchased in its entirety or in separate modules which will be used as workshop handouts for team training (virtual or in-person). The Project Guide is organized into thirty chapters based on a detailed review of the six **Deployment Pillars** (Figure 6) evolving through five defined maturity stages analogous to a Capability Maturity Model for technology deployment. Our Project Guide takes the reader through progressive steps from discovery to expansion and optimization at scale, for each pillar. Each chapter offers suggested checklists and recommendations for each stage and pillar.

Target Audience: Smart City project teams, attendees of URF workshops and training sessions, fleet operators, system integrators.

Purpose: Provide a detailed guide through all steps and deployment issues with informative (rather than normative) connections to ISO DTS 4448 throughout.

Acknowledgements

Thank you to our supporters, members and sponsors who make our work possible.

If you are not already a member, we invite you to join the Urban Robotics Foundation to become more engaged with our community. Member benefits include strategic networking for setting up pilot projects and sharing of key learnings/best practices, early access to review and help shape the ISO draft standard, and the opportunity for discounts on products and services provided by URF and our affiliate partners/organizations.

Thank you for your interest in preparing for the deployment of public-area mobile robots and for reading our Executive Guide to PMRs. Please visit **www.urbanroboticsfoundation.org** for more information on URF membership, and/or to inquire about our other publications, webinars, workshops, and advisory services.

Bern Grush, Executive Director, URF and **Lee St. James** (she/her), Managing Director, URF

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Appendix A: Use Cases

CLEAN

Mobile robots can be used to disinfect, filter air, sweep, vacuum, and wash corridors and passageways in the public areas of facilities such as airports, hospitals, office buildings, shopping malls and train stations. Similarly, mobile robots can perform related tasks on sidewalks, within parking lots, along curbs and road shoulders or any public footway with a suitable layout and surface for cleaning activities such as removing leaves and litter.

When cleaning tasks are performed in public spaces while members of the public are traversing the same space, such robots would be considered "PMRs" and would be subject to the governance and deployment guidelines that are part of ISO DTS 4448. Additional care must be afforded to bystanders who are not involved in the operation or purpose of the robots. The presence of non-involved bystanders almost always implies liability for the facility operator or the municipality that is hosting such PMRs.

Cleaning PMRs generally operate by following a pre-planned route with remote monitoring or may be teleoperated or a combination of the two. None are fully autonomous, since they all require oversight, even if not teleoperated. As PMR technology for cleaning continues to advance, these robots may become increasingly versatile among bystanders and capable of handling a wider range of tasks to meet the evolving needs of public works and public facilities. This will become especially important for countries and industries experiencing labour shortages.

A recent article in Supermarket News* shows an example of a PMR that roams the shopping aisles of grocery stores scanning for spills and other hazards while searching for inventory items that are misplaced or need re-stocking. It does not actually clean; however, it can send notifications when it detects a spill or other hazard. *https://www.supermarketnews.com/technology/stop-shop-upgrades-marty-robot-300-plus-locations

DELIVER

PMRs for last-mile delivery have advantages…

- **Access**: can operate in places that do not permit cars and trucks
- **Clean**: when electric and replace car trips, they reduce pollution / emissions
- **Efficient**: smaller, quieter, lower cost method to move small packages short distances
- **Managed**: they can be orchestrated, route-constrained, recorded, scheduled, and watched
- **Multitask**: can handle safety, environmental, and asset monitoring tasks while delivering
- **Scalable**: integrate with e-bike delivery for a full solution and to backstop labour shortages
- **Traffic and parking**: reduce automotive use for local shopping trips / deliveries

…and disadvantages…

- **Handoff limitation**: usually requires receiver to be present and to come to the machine
- **Limited capacity**: often make single-address deliveries, then return to start
- **Navigational hurdles**: sidewalk conditions, weather, stairs, doors, elevators
- **Operations**: fleet operator and staff to oversee, teleoperate, maintain
- **Public fears**: jobs, disability community
- **Vandalism**: anger, theft, pranks

Delivery is and will remain a key application for PMR technology. Nonetheless, more innovation and cost reduction are needed for things such as navigating difficult footway passages, stairs, doors, elevators and heavy weather. Equally important are secure locker systems to address the handoff problem. Together, these matters constrain the operating domain and business case for last mile delivery.

A "quick run to the store" is one of the key values of having a private vehicle stored at your home. Addressing local consumer delivery far more fulsomely than has been done so far would help erode the need to own a private vehicle. Neighbourhoods that are provided with robotic delivery services would become *candidates* for low car use communities and possibly even lower car ownership which would also help relieve demands on infrastructure (such as for curbside parking), providing more room for both micromobility and PMR use.

MAINTAIN

Some aspects of property maintenance are seasonal. So is specialized robotic assistance.

Summer maintenance includes robotic assistance in landscaping in public parks, gardens, and green spaces. While robots for trimming and weeding are on the horizon, mowing lawns is the most popular summer maintenance application, and has been in use on public properties for a few years.

Advancements in this technology provide mowers capable of handling expansive public areas. Low-noise, emission-free, and autonomous these are being used across universities, city parks, and sports facilities. There are several advantages:

- Quiet operation means they can work inconspicuously, even during nighttime hours, minimizing disruptions to nearby residents
- During wet weather, tractor and ride-on mowers can cause more harm than good; the lower weight of robotic mowers means far less damage
- Lawns are healthier if cut more often but with shorter clippings
- Electric robotic lawnmowers produce no emissions during operation. Traditional ICE lawnmowers produce up to four times the emission pollution of an ICE car

Robotic mowers require fleet management for setup and remote monitoring. If they operate around bystanders (such as picnickers, dog walkers or golfers), then they are PMRs and the ISO DTS 4448 series would apply for deployment.

Winter maintenance includes snow removal and de-icing. Snow plowing, brushing or blowing robots need to be heavy enough to support the momentum to move snow but small enough to operate on walkways. This has been difficult to achieve, to date. There are instances of much larger robotic snowplows for airport runways but they only operate near trained personnel, hence are not PMRs.)

There are also robotic devices for spraying brine or similar liquids for walkway de-icing. Similar to other winter maintenance robots these would either be set up for fixed routes with human monitoring or teleoperated.

In addition to the various cleaning activities listed earlier, robotics for **all-season maintenance** include various prototypes for **trash removal** such as devices to move garbage bins to and from the curb, collect trash from bystanders, and gather bins for easier collection. This is an example of an application for which there are many ideas with fledgeling attempts at solutions. What is needed more than anything is a requirements specification from a city without which we will likely have only products searching for market. This is an area where a city with a clear requirement could work with a government grant and a local university team to solve a valuable problem.

Another promising device was recently designed for **road surface repair.** According to a January 2024 article in Creative Media news*, this is device is currently being demonstrated and marketed to repair road surfaces by filling potholes, repairing cracks, and applying surface treatments to improve safety and prolong infrastructure lifespan. *https://creativemedia.news/uncategorized/pothole-robot-detects-and-fills-using-ai-70-faster/

MANAGE

Mobile robots are being fitted to support numerous management tasks:

Crowd control. According to Konrad Szocik and Rakhat Abylkasymova from the Department of Social Sciences, University of Information Technology and Management in Rzeszow, Poland: "*progress in [robotics] is unavoidable. … [we] discuss arguments which favor the use of police robots, in particular crowd control robots … while we have some ethical issues associated with crowd control robots, in general, the benefits are higher than the possible risks.*"

While URF is not qualified to advise regarding ethics, many cases of using robots to assist in police work have already occurred and with some controversy in several cities and in multiple countries. This is something that every city should be aware of.

Emergency response. Numerous robots are being developed to help with emergencies such as natural disasters and fires and to provide search and rescue support, damage assessment in hazardous or hard to reach places, and supply delivery. Such robots have already saved lives. These may or may not be PMRs, depending on how and where there deployed, nonetheless they join other robots in the urban arsenal.

Many of these robots are hardened because of their military pedigree. Something to keep in mind is that cities will inherit much value from military robotics just as we inherited GPS and the Internet from what was originally military innovation.

EV battery charging. A PMR, with a large battery, can move to a parked EV and discharge its battery into the EV. This allows charging of any EV within the lot without installing fixed charging stations. There are several companies from several countries providing these. They may soon become part of critical parking infrastructure.

Info bots. PMRs can be used to guide visitors or tourists in city or amusement park such as a zoo. This can enhance visitor experience, improve their ability to locate points of interest and provide other valuable information for their visit. Communication can be interactive, multilingual, promotional, or educational. Such PMRs can collect data on patterns, preferences, and surveys to help planners, tourist agencies, and businesses while enhancing visitor engagement and satisfaction.

MONITOR

PMRs can monitor public spaces both for infrastructure status and security issues.

Asset inventory and inspection. Robots can be equipped for inspection during sidewalk traversal, collecting data on pavement conditions and assets such as benches, newspaper boxes, signage, street lights, transit shelters, trash cans, etc. Such robots could support one human operator in completing several times more inspections in the same work period. A city that adds inspection sensors and processing to existing delivery robots could gather inspection data as deliveries were being made, thereby lowering inspection costs still further. The orchestration systems that will be required when there are large numbers of robots could have algorithms to ensure all streets are regularly inspected.

Security. If you operate a public facility such as an airport, hospital, mall, park, or school, how do you currently monitor the safety and security of both property and the people on your site? If you are a decision maker in a public works department or on a police services board, what challenges do you have with safety, surveillance, and security patrols?

Security PMRs could help facility operations, city staff and police officers by deterring vandalism, preventing crime, and expediting emergency responses.

Outdoor security and inspection. Security robots have an early history of working among trained personnel and on private property, but they have recently been deployed in projects to keep perimeters safer They are increasingly being piloted on school properties.

For public safety at special events, robots can assist police on safety patrols providing additional deterrence. They can serve as force multipliers with onboard cameras and sensors providing higher levels of situational awareness that enable faster and more effective responses.

Using a human security guard to observe and report is growing increasingly ineffective in the face of recent technical advances. Today, PMR sensors can easily surpass human sensing; robots can be networked to instantly share data creating a highly effective observation and collection platform. It is possible to obtain verifiable, unambiguous data without resorting to manual data logging.

Indoor mobile robot use is growing in place of fixed security cameras. There are now systems that use doors and elevators, as well as AI and sensors to detect anomalies such as unidentified people, unexpected motions or sounds, open doors, leaks, spills, hazardous gases, overflowing trash cans, unattended devices, suspicious packages, dirty whiteboards, medical emergencies, etc.

Given growing concerns for both safety and labour shortages, security companies worldwide look to deploy robots for patrols. To meet this demand, rapid advances are being made to innovate and fabricate mobile security robotics. As these operate increasingly within public areas, they will be classified as PMRs.

MOVE PEOPLE

PMRs that move hospital patients or air travellers with mobility challenges are unique for having human passengers. If a robotic wheelchair or person-mover pod is automated to take its passenger on a programmed route, for example from a ticket gate to a certain departure gate, or within a hospital from their room to the x-ray department, this classifies as a PMR due to the potential presence of other non-involved bystanders while the robot is en route to its destination.

Such devices are becoming critical as populations age — especially with respect to accessibility in large public spaces. Factors driving mobility assistance requests in airports include disability, long walking distances, help with bags, and wayfinding difficulties. And requests are growing. The demand for mobility assistance is heightened in countries with aging populations, extending beyond air travel to hospitals, museums, and shopping malls.

Airports

The most common special service request at air terminals, a WCHR request, involves assisting the passenger from the ticket gate to the departure gate due to an inability to walk long distances. If such a passenger can get into and out of such a device, climb stairs, and move inside the aircraft cabin, a robotic wheelchair can handle all the rest. Demand for such assistance is growing dramatically. Even faster than the growth in air passengers.

URF

Owing to an aging population and sedentary lifestyles, an increasing number of people are challenged to walk long distances in places like airports and shopping centers. Borrowing innovations from other applications, robotic wheelchairs offer impactful solutions to the growing demand for occasional and place-specific mobility assistance.

URF estimates a strong a growing demand for this type of PMR service from the air-travel industry alone – perhaps 61 million requests in 2024 and growing: https://www.urbanroboticsfoundation.org/post/pmr-use-case-robotic-wheelchairs-improve-accessibility-in-airports-hospitals-more

This means that many airlines will be faced with labour shortages, and passengers who need such assistance may be delayed, or be less likely to travel. This observation of growing demand is underscored in a recent article describing strong growth in senior travel: https://www.airport-technology.com/comment/senior-travellers-are-back-and-airports-need-to-be-ready-for-them/

Hospitals

There have been hospital trials designed to move patients through a multi-stage diagnostic process. One pilot ensured hospital staff always knew where a patient is, and the patient easily finds their way to the next station—a form of workflow.

Autonomous wheelchairs for hospitals and other public spaces must have a critically low error rate. To address this, innovations use redundant landmarks on walls and ceilings to back up what can be mapped on the floors which may be transient. As navigation error rates plummet, so do teleoperation costs - thus providing safe, reliable, and cost-effective systems for ageing populations and those with mobility challenges.

Robotic Wheelchairs are in a unique category

Robotic wheelchairs are of particular value in maximizing the social impact and acceptability of public-area mobile robots. Socially, autonomous wheelchairs are more naturally inclusive than the popular delivery robot, which may sometimes experience lower acceptance among the disability community. Robotic wheelchairs experience little or no social pushback compared to some other forms of PMR.

The need for wheelchair robots is virtually unquestionable, especially in airport, hospitals and large public facility environments. The distance that must be travelled in such locations can be taxing for a senior or a disabled user. Equally important, when a user is experiencing a facility for the first time, the challenge of navigation can be reduced by using an automated wheelchair loaded with a pre-planned route.

Taken together, the social value of robotic wheelchairs may be as high or higher than the social value of any other form of PMR. What this implies is that anyone experiencing the benefits of these robots would be more inclined to see them as accessible and robotic wheelchairs will contribute to the social acceptability of the entire PMR category.