INFO BRIEF

Sharing Spaces with Robots: The Basics of Personal Delivery Devices

Pedestrian and Bicycle Information Center
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Innovations in autonomous technologies are making it possible for companies to introduce robotic vehicles into an increasing number of new environments. This is true for sidewalks and bike lanes in several states, where personal delivery devices (PDDs) are permitted to operate and deliver goods. This Pedestrian and Bicycle Information Center (PBIC) Information Brief clarifies terms and definitions for PDDs, describes their physical and operational characteristics, and provides an overview of key policy and research areas affecting their deployment with an emphasis on pedestrians and bicyclists (see Cregger et al., 2020, for a review of PDDs and other network impacts). This brief is intended for transportation professionals and communities where PDDs are being considered, tested, or deployed.

What is a Personal Delivery Device?

A PDD can be defined as *a device designed to transport cargo using automated driving technology capable of operating with or without human supervision*. Other terms include Sidewalk Delivery Robot, Delivery Robot, and Sidewalk Robot. In the context of this Info Brief, the definition refers to emerging technologies intended primarily to transport cargo in spaces normally occupied by pedestrians and bicyclists, such as sidewalks, crosswalks, and bike lanes. They are not permitted to carry passengers and, according to most states, they do not meet the definition of "motor vehicles" because they do not travel primarily on public streets, roads, and highways (49 U.S. Code § 30102; AAMVA, 2021). They also do not have a driver on board and are not subject to the same regulations as other vehicles. Autonomous vehicles that operate on roadways with other traffic, like the Nuro R2, are not considered PDDs and must meet Federal safety guidelines or be granted an exemption petition from the National Highway Traffic Safety Administration (NHTSA). See **Table 1** for visual examples.

PDDs are a category of robotic vehicle designed to deliver goods such as groceries and take-out to customers within a predetermined service area without direct contact with a delivery person. Typically, secured cargo can be only accessed by the recipient or the sender through a mobile app or delivery code (Paddeu et al., 2019). The compact size of the devices and driverless operation makes them an option for delivering supplies to medical workers and meals to patients in quarantine or to people with limited mobility (Transportation Research Board, 2020).

How and where do PDDs work?

PDDs are designed to operate in the public realm using portions of existing infrastructure that are shared with other users, including pedestrians, drivers, transit operators, bicyclists, delivery drivers, and motorcyclists. This distinguishes PDDs from other automated devices, such as autonomous robots working in warehouses, which operate in controlled environments with trained employees who are familiar with robot interactions. PDDs are currently not developed, operated, nor regulated by any one group or governing body. They exist in a rapidly changing regulatory and technological landscape and take on many different operational and physical forms. Although there is no standardized classification system for PDDs, they can be grouped by several operational and physical characteristics (e.g., Cregger et al, 2020). Each of these characteristics may have implications for safety, efficiency, and appropriateness of the interaction between PDDs and their operating environment.

Operational Domain

PDDs operate in spaces normally occupied by pedestrians and bicyclists (see **Figure 1**). This includes sidewalks, crosswalks, and bike lanes. PDDs designed to operate in bike lanes may also be permitted to travel along the road shoulder or edge of the roadway when marked bike lanes are not present. Because local populations and infrastructure characteristics can vary by location, technology developers and local communities will need to carefully consider how PDDs might affect

Table 1. Examples of PDD test platforms. (images via Dimensions.com, unless otherwise specified)

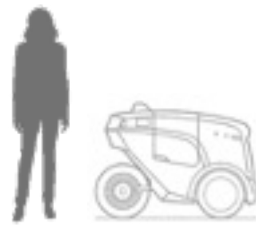
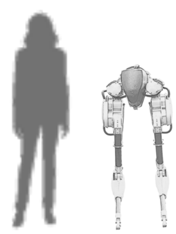
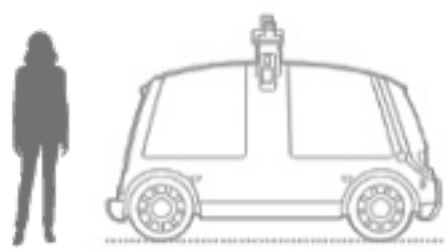
PDD Examples	Size Comparison
☑ **Small, wheeled, slow-moving sidewalk robot** A wheeled delivery robot that is less than 4 ft tall and weighs less than 100 lbs unloaded, that operates on sidewalks at pedestrian speeds (~1 to 3.5 mph) with or without an operator. This describes the majority of PDDs in use. *e.g., Amazon Scout, Starship Delivery Robot*	
☑ **Fast-moving robot that operates in bike lanes** A wheeled delivery robot capable of traveling at higher speeds than a pedestrian (~10 to 20 mph), which may behave more like a bicycle (e.g., travelling on the roadway in bike lanes). *e.g., Refraction REV-1, TeleRetail Pulse 1*	
☑ **Larger, heavier sidewalk robot** A larger, heavier delivery robot (taller than 4 ft and more than 100 lbs) that operates on sidewalks at pedestrian speeds (less than 10 mph) and can carry larger and heavier loads than smaller sidewalk robots. *e.g., FedEx Roxo*	
☑ **Robot without wheels** A delivery robot that uses non-wheeled locomotion (e.g., legs) and operates on sidewalks at pedestrian speeds. *e.g., Ford Digit*	
☒ **Autonomous delivery/retail vehicle** A large roving kiosk or mobile store that operates in roadways as a vehicle. This is not a PDD. *e.g., Nuro R2, Robomart*	

Figure 1. Personal delivery devices are designed to operate in spaces utilized by a diverse population of pedestrians and bicyclists.

people who rely on a variety of mobility options. This includes:

- Predicting how people and PDDs will navigate together along sidewalks of varying widths with different objects that reduce the amount of walking and rolling space (e.g., trees, posts, signs, mailboxes, etc.);
- Ensuring pedestrians and cyclists can safely and effectively transition between the road and sidewalk without having to accommodate or yield to a PDD;
- Equitably accommodating the diverse groups who rely on sidewalks, crosswalks, and bike lanes.

Operational Characteristics and Example Use Cases

A PDD's intended use can influence its physical characteristics (e.g., size, capacity, level of autonomy) and determine the device's travel behavior and patterns. For example, PDDs designed for localized food delivery are small and travel on sidewalks in a fixed area, such as a college campus, to deliver orders to customers on-demand. This localized delivery model requires a sufficient customer base with well-maintained pedestrian infrastructure to be effective. PDDs that travel longer distances or carry larger payloads are faster and larger than those that only need to carry local orders.

Another emerging use case for autonomous home delivery requires two specialized machines: a large on-road carrier vehicle (similar to a delivery van) and small PDDs that ride in the carrier until they are deployed within a closer delivery range to deposit packages at customers' doorsteps. This type of home delivery may be viable in urban or suburban areas because the carrier vehicles can travel longer distances than the small PDDs. The PDDs themselves must have the ability to unload the cargo for deliveries where the recipient is not required to be present.

The use case also determines the form of human interaction. For example, in most deliveries, the recipient meets the PDD and enters a security key to access the cargo compartment. In other cases, PDDs deliver packages to secured locations to be picked up in the future. A PDD will also need to interact with other automated devices or people at the beginning of the journey for loading.

With any delivery, there is a high likelihood of PDDs encountering pedestrians and other sidewalk users, and eventually other PDDs, with increasing probability in more dense urban environments. For PDDs that require humans to retrieve their cargo, decisions will eventually need to be made best practices for waiting and queuing in public space if multiple devices are present. Similarly, developers must determine how PDDs will cooperate with other sidewalk or bike lane users and people in intersections, street crossings, and in the transition zones between them, such as curb ramps.

Navigational Characteristics

The technology required by PDDs is analogous to the automated driving systems used in automated and autonomous vehicles (AVs). Combinations of cameras, lidar, ultrasonics, and radar are used for sensing objects in the environment, and inertial measurement units (IMU) and global positioning systems are used for navigation. Some feature dynamic routing that allows the PDDs to choose the shortest routes to their destinations based on real-time operating conditions (Paddeu et al., 2019). The capabilities of the automated driving systems that control PDDs continue to evolve and will vary by manufacturer. Their abilities to detect, recognize, and respond to different objects on and off the roadway are key technical considerations that are being observed and addressed during testing. Until they can safely and effectively operate autonomously, they will require supervision. Because these devices do not have human drivers or handlers monitoring them in person, they are often supervised remotely through a live video stream. This allows remote operators to assume control and operate the PDD remotely if the automated driving systems cannot resolve a novel navigation challenge.

Physical Characteristics

Size, weight, and payload. Most sidewalk PDDs are compact, measuring between 2 to 3 1/2 feet tall and approximately 2 feet wide. Unloaded, most weigh around 50 to 200 pounds and carry payloads ranging from 20 to 100 pounds. For comparison, most electric kick scooters weigh less than 50 pounds, electric bicycles less than 100 pounds, mopeds between 200 and 250 pounds, and personal mobility scooters between 200 and 400 pounds (Sandt, 2019). However, the size of the PDD varies by developer and can be restricted by local regulation. For example, FedEx's Roxo is nearly five feet tall, and the faster moving REV-1, which travels in bicycle lanes at 15 mph, can carry up to 280 pounds.

Speed and terrain coverage. PDD operating speeds depend on context and are not synonymous with top speed. While the maximum speeds of different sidewalk PDDs range from 1.5 mph to 15 mph, most operate at pedestrian speeds (i.e., 1.5 to 3.5 mph). If a PDD operates on multiple facility types, like the REV-1 that can use sidewalks or bike lanes, the device can change speeds to match the other users in its operating environment.

The majority of sidewalk delivery robots use wheels to move around, but some companies are experimenting with legged delivery robots. Legs have the advantage of being able to cover varying terrain, such as stairs, but they tend to be slower than their wheeled counterparts (Cregger et al., 2020). Because of their locomotion abilities and limitations, legged robots are capable of delivering to a customer's doorstep when deployed from a larger, wheeled carrier vehicle that transports them to and from their destinations. However, some wheeled robots may soon be able to perform similar tasks using special movable wheels to climb stairs and overcome other terrain challenges associated with traditional wheeled devices.

State regulation of PDDs

PDD operations are currently not subject to motor vehicle codes. Therefore, oversight may vary from one state to another. Because they are not intended to operate exclusively on roads, they are not regulated by state departments of transportation and do not necessarily require registration. Legislation of PDDs is established at the state level, and regulation and enforcement is generally left to municipalities, with local law enforcement addressing violations on a case-by-case basis. State laws typically overlap in a few common topics:

Physical and operational limits

PDD Speed and weight are generally limited by state laws. In most states, speed is limited to around 10 miles per hour on sidewalks and 20 miles per hour on streets. In some exceptional cases, speed is limited to lower than 10 miles per hour on sidewalks to levels closer to adult walking speeds. PDD operators can also choose to operate at speeds lower than the maximums set by the states (e.g., Table 1). PDDs that operate on roadways do so in a manner analogous to bicycles, operating in bike lanes or close to the shoulder when bike lanes are not available. Weight is regulated by setting maximum amounts on the weight of the PDD, which can vary between 80 and 1,000 pounds. In several states, the weight limit does not include the weight of the payload; therefore, the total weight of the PDD may be considerably higher. A small number of states also regulate dimensions, keeping the dimensions of the PDD to about 32 inches wide and 40 inches long. Setting caps on weight and dimensions can limit the impact in the event of a collision, but also aligns the physical characteristics with those of other vehicles that are regulated by local departments of transportation.

Areas of operation

State laws broadly indicate that PDDs operate on sidewalks and crosswalks, generally restricting them to locations designed for pedestrians. Accounting for variations in infrastructure, some states allow PDDs to operate in roadways in the absence of sidewalks. In these cases, PDDs are expected to operate close to the shoulder. Most PDDs are permitted to operate at higher speeds in streets (e.g., 20 miles per hour instead of 10), but most states restrict their operation to bike lanes and shoulders on roads where the speed limit is 35 miles per hour or less. States vary in their approach to operations on trails and shared use paths, with some states allowing passage by PDDs and others barring their use.

Human oversight

Definitions of PDDs generally indicate that they are intended to operate “with or without” active control or monitoring by a human operator. There is an expectation that a human operator will be available to intervene and assume active control if the PDD encounters a situation it is not able to navigate; however, states vary in the level of active human oversight. Some states require a human present and available to provide immediate intervention, while others require continuous active monitoring or control from a remote location.

Right of way

PDDs are expected to comply with traffic control devices and signals, including those intended for pedestrians. In most cases, they are not permitted to interfere with pedestrians or other traffic and are expected to yield the right of way to all other road users. In some locations, regulations grant them the rights and duties of pedestrians.

Other characteristics

There are some characteristics that are consistent across deployments. All PDDs are expected to have a clear label indicating the name of the operator (i.e., the company), the operator’s contact information, and a unique identifier for the PDD. All operators are expected to maintain at least $100,000 in insurance to cover damages. All PDDs are also required to have a functioning braking system. Very few states allow PDDs to transport hazardous materials (e.g., ammunition). Those that do are required to follow any applicable federal regulations such as the Hazardous Materials Transportation Act (49 U.S.C. § 5101 et seq.).

Examples of state bills regulating PDDs:

H.B. 2422, (AZ, 2018)	H.B. 49, (OH, 2017)
S.B. 20-092, (CO, 2020)	S.B. 1199, (PA 2020)
H.B. 1027, (FL, 2017)	S.B. 969, (TX, 2020)
H.B. 204, (ID, 2017)	H.B. 277, (UT, 2020)
S.B. 874, (MD, 2020)	S.B. 758, (VA, 2020)
S.B. 0892, (MI, 2020)	H.B. 1325, (WA, 2020)
H.B. 2290, (MO, 2020)	S.B. 148, (WI, 2017)
S.B. 739, (NC, 2020)	

PDD Research and Policy Considerations

PDDs share many functional characteristics with *automated guided vehicles* (AGV), the automated vehicles used for moving goods and materials in factories and warehouses. These devices operate with high degrees of accuracy in structured settings where the staff receives training and instruction on their behaviors and uses. AGV design is also addressed by American National Standards Institute (ANSI) and International Organization for Standardization (ISO) guidelines, which sets specific safety standards for slowing and stopping in the presence of hazards and the design of bumpers to stop the vehicles when other sensors fail. In contrast to industrial settings, sidewalks and roadways are much less structured, road users do not receive training on interacting with automated vehicles, and there are no specific standards governing the designs. While standards are under development (e.g., ISO TR4448), PDD deployments are ongoing.

The characteristics of pedestrian environments can vary across several dimensions, including sidewalk width, physical condition, and level of use, all of which can affect PDD operations. While PDDs are not supposed to "unreasonably interfere" with pedestrians, the sidewalk is a complex environment that will undoubtedly introduce conflicts. For example, some damaged sidewalks will create impassible sections for some small-wheeled PDDs, which will require them to temporarily occupy and block passable portions needed by pedestrians. In most states, PDDs assume the rights and responsibilities of pedestrians, while not necessarily sharing their cognitive and physical skills. Some tasks that many pedestrians would take for granted, such as pressing a walk button at a crosswalk, would prove challenging or limit the operational domain of a small, wheeled transport. PDDs will also stop on sidewalks during loading and unloading, and, as complex mechanical devices, may experience technical failures and become incapacitated. In a busy location with multiple deliveries and large numbers of pedestrians, multiple PDDs waiting for customers in a delivery queue could block pedestrians and create congestion.

All of these examples are amplified when PDDs operate around people with disabilities (see **Figure 2**). For example, wheelchair users require a corridor at least three feet wide for passage. They also need four feet of lateral space plus additional room to maneuver; therefore, with PDDs allowed to share and potentially block sidewalk space, communities will need to consider ways to expand and ensure passable spaces (six to eight feet wide) and access points such as doorways and curb cuts. Most state regulations require lighting visible at hundreds of feet, but auditory warnings are absent from most current legislation. This has considerable safety implications for interactions with blind pedestrians. PDD interaction experiences from deaf-blind pedestrians and pedestrians in wheelchairs highlight alarming scenarios for people with disabilities that may not be experienced by everyone but demand attention (Girma, 2020; Ackerman, 2019). Prioritizing the needs of people with disabilities, engaging a diverse range of road users, and considering principles of universal design principles can help mitigate the risks and harms that PDDs may pose.

Finally, researchers and policymakers should actively work to address the existing systemic biases in automated device development and operation that perpetuate race and gender inequities and "ablism" biases in technology

Figure 2. PDDs will also need to accommodate people with disabilities.

performance. The complex artificial intelligence algorithms that autonomous systems rely on for detecting, recognizing, and differentiating between objects and people require the systems to learn from extensive training datasets. If those datasets are not sufficiently comprehensive or do not include enough data from the intended operational environment, the systems can fail in unexpected ways. Previous examples of limited algorithmic training or testing have led to facial recognition programs and pedestrian detection systems struggle to recognize darker-skinned people and women (Buolamwini, 2017; Howard and Borenstein, 2018). When computer vision algorithms are trained using majority White datasets, they may struggle to recognize faces in a more diverse operational environment. Similar issues have been reported for voice recognition programs that are worse at understanding women's voices than men's (Howard and Borenstein, 2018). If perpetuated, the biases that result from utilizing test data from populations that do not represent the community where the algorithms will operate could not only make it harder for some groups to use PDD services, but could also lead to systemic negative outcomes such as wrongful identification or failing to yield to Black pedestrians, women, children, or other underrepresented groups in the development and testing processes. Policymakers and technology developers should also consider how the historical and ongoing harms of surveillance and policing in communities of color may influence public trust in and desire for PDDs on shared streets, especially when data use, ownership, and privacy practices are not transparent. It will be critical to maintain open communication and to carefully consider the needs, perspectives, and concerns of communities for future PDD deployments. This includes the ability for PDDs to recognize and respond appropriately at a local level, which may vary from one community to another.

Conclusion

While developers are testing more deployments in more states in the wake of new legislation, several challenges exist and the real impacts of PDDs will remain unknown until they are deployed in large numbers. Early deployments appear to operate in settings with high quality physical infrastructure and limited operational ranges, like university campuses. While many states require lights on PDDs, many locations opt to only operate during daylight hours. PDD mobility remains well-behind human mobility in terms of being able to negotiate curbs, thresholds, stairs, and damaged and cluttered walkways; as well as the ability to safely interact with other users of the walkway space. Like automated vehicles, broad deployment of PDDs depends on regulatory decisions, public trust and acceptance, and technology readiness. This document offers a basic exploration of these considerations with the aim of cultivating a shared understanding of the technology, while centering the need for safe and equitable mobility for those expected to interact with these devices.

References

Ackerman, E. (2019, November 19). My fight with a sidewalk robot. CityLab. https://www.bloomberg.com/news/articles/2019-11-19/why-tech-needs-more-designers-with-disabilities

American Association of Motor Vehicle Administrators (AAMVA). (2021). Automated Delivery Vehicles and Devices Whitepaper. American Association of Motor Vehicle Administrators. Arlington, VA. https://www.aamva.org/automateddeliveryvehiclesanddeviceswhitepaper-may2021/

American National Standards Institute (ANSI). (2019). Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles (ANSI/ITSDF B56.5-2019).

The Algorithmic Justice League. (2020). The Algorithmic Justice League's 101 Overview. Ajl.org https://global-uploads.webflow.com/5e027ca188c99e3515b404b7/5e332b739c247f30b4888385_AJL%20101%20Final%20_1.22.20.pdf

Buolamwini, J. (2017). Gender shades: intersectional phenotypic and demographic evaluation of face datasets and gender classifiers. [Master's thesis, Massachusetts Institute of Technology] Dspace@MIT.

Cregger, J., Machek, E. Behan, M., Epstein, A., Lennertz, T., Shaw, J., & Dopart, K. (2020). Emerging Automated Urban Freight Delivery Concepts: State of the Practice Scan. U.S. Department of Transportation Volpe National Transportation Systems Center. DOT-VNTSC-FHWA-21-01.

Girma, H. (2020, August 11). The robots occupying our sidewalks. TechCrunch. https://techcrunch.com/2020/08/11/the-robots-occupying-our-sidewalks/

Howard, A., & Borenstein, J. (2018). The ugly truth about ourselves and our robot creations: The problem of bias and social inequity. Science and Engineering Ethics, 24(5), 1521-1536. doi: http://dx.doi.org.libproxy.lib.unc.edu/10.1007/s11948-017-9975-2

Jennings, D. & Figliozzi, M. (2019). Study of Sidewalk Autonomous Delivery Robots and Their Potential Impacts on Freight Efficiency and Travel. Transportation Research Record. 2673(6).

Paddeu, D., Calvert, T., Clark, B., & Parkhurst, G. (2019). New Technology and Automation in Freight Transport and Handling Systems. https://uwe-repository.worktribe.com/output/851875/new-technology-and-automation-in-freight-transport-and-handling-systems

Sandt, L. (October 2019). The basics of micromobility and related motorized devices for personal transport. Pedestrian and Bicycle Information Center: Chapel Hill, NC.

Transportation Research Board. (2020). Preparing for Automated Vehicles and Shared Mobility State-of-the-Research Topical Paper #6: Potential for Impacts of Highly Automated Vehicles and Shared Mobility on Movement of Goods and People. NCHRP Project 20-113F. https://www.nationalacademies.org/our-work/forum-on-preparing-for-automated-vehicles-and-shared-mobility-services

State Legislation

H.B. 2422, 53rd Legislature, 2nd Reg. Sess. (AZ, 2018). https://www.azleg.gov/legtext/53leg/2r/bills/hb2422h.pdf

S.B. 20-092, 72nd General Assembly, 2nd Reg. Sess. (CO, 2020). http://leg.colorado.gov/sites/default/files/documents/2020A/bills/2020a_092_01.pdf

C.S./H.B. 1027, 2017 Legislature. (FL, 2017). https://www.flsenate.gov/Session/Bill/2017/1027/BillText/er/PDF

H.B. 204, 64th Legislature, 1st Reg. Sess. (ID, 2017). https://legislature.idaho.gov/wp-content/uploads/sessioninfo/2017/legislation/H0204.pdf

S.B. 874, 2020 Reg. Sess. (MD, 2020). http://mgaleg.maryland.gov/2020RS/bills/sb/sb0874f.pdf

S.B. 0892, 2020 Legislature. (MI, 2020). legislature.mi.gov/documents/2019-2020/billengrossed/Senate/pdf/2020-SEBS-0892.pdf

H.B. 2290, 100th General Assembly, 2nd Reg. Sess. (MO, 2020). https://www.house.mo.gov/billtracking/bills201/sumpdf/HB2290C.pdf

S.B. 739, 2019-2020 Session. (NC, 2020). https://www.ncleg.gov/Sessions/2019/Bills/Senate/PDF/S739v5.pdf

H.B. 49, 132nd General Assembly, Reg. Sess. (OH, 2017). https://www.legislature.ohio.gov/download?key=7376&format=pdf

S.B. 1199, 2019-2020 Reg. Sess. (PA 2020). https://www.legis.state.pa.us/CFDOCS/Legis/PN/Public/btCheck.cfm?txtType=PDF&sessYr=2019&sessInd=0&billBody=S&billTyp=B&billNbr=1199&pn=2042

S.B. 969, 86th Legislature. (TX, 2020). https://capitol.texas.gov/tlodocs/86R/billtext/pdf/SB00969I.pdf

H.B. 277, 2020 Gen. Sess. (UT, 2020). https://le.utah.gov/~2020/bills/hbillenr/HB0277.pdf

S.B. 758, 2020 Session. (VA, 2020). https://lis.virginia.gov/cgi-bin/legp604.exe?201+ful+CHAP1269+pdf

H.B. 1325, 66th Legislature, 2019 Reg. Sess. (WA, 2020). http://lawfilesext.leg.wa.gov/biennium/2019-20/Pdf/Bills/House%20Passed%20Legislature/1325-S.PL.pdf?q=20210512210221

S.B. 148, 2017 Reg. Sess. (WI, 2017). https://docs.legis.wisconsin.gov/2017/related/proposals/sb148

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