Personal Delivery Robots: How Will Cities Manage Multiple, Automated, Logistics Fleets in Pedestrian Spaces?

Bern Grush
Urban Robotics Foundation, Toronto, Canada

Synonyms

Personal delivery robots are sometimes called: personal delivery devices; Sidewalk robots; Delivery robots; Delivery bots; Sidewalk drones; Micro utility devices

Introduction

The company currently leading the last-mile logistics market with small, personal robotic deliveries claims to have made 1.5 million deliveries as of May 2021, with one-third of this number achieved in the first 5 months of 2021. This same company claims to "make more than 80,000 road crossings every day" (Edwards 2021).

This latter number should give pause to any city transportation planner. A claimed achievement of 500,000 deliveries over 5 months, implies an average of 3310 trips per day, 80,000 daily crossings imply 24 crossings per trip. Assuming 12 crossings each way on a round trip, this means the average trip would be a bit under a mile – certainly a reasonable distance for such service. What is troubling is the potential for pedestrian, cycling, and automobile interactions at those crossings should these 80,000 daily crossings swell to several billion per day, worldwide, in a few years. See Fig. 1.

As of 2021, the worldwide volume of such deliveries made by all providers will likely be at least double the numbers claimed by the single, lead provider. When express delivery companies combine this technology with micro-warehousing and local lock boxes – all technologies in various stages of development and deployment and with very few remaining *technical* barriers – the daily number of trips and their related street crossings could potentially rival the number of pedestrians and bikes at these crossings in locations of greatest demand. This would be especially true in cities with less-active and more auto-oriented populations, where the relative, local numbers of such robots could easily exceed pedestrian volumes.

As will be developed in this entry, robotic services in public spaces, especially last-mile delivery, promise enormous benefits for our cities and its citizens if deployed in ways that are clean, safe, and comfortable (see Table 1). They could also pose a challenge to urban livability if left unmanaged as we did street parking for most of the twentieth century, and which most cities still manage so poorly.

R. Brears (ed.), *The Palgrave Encyclopedia of Urban and Regional Futures*,
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The promise made for last mile delivery (and similarly for other services) by sidewalk robots is that they would replace larger vehicles such as congestion-causing stepvans from express-delivery companies or would avoid "mov[ing] a 2-pound burrito in a 2-ton car" (serverobotics.com). Most would agree that small, quiet, slow, electric delivery devices would be more desirable than internal combustion step vans, but a shift from goods movement on the roadway to goods movement on the pedestrian footway portends new implications that are yet fully understood.

This entry will attempt to address that.

Robots Operating in Public Spaces

There are several aspects to consider when planning or regulating commercial and service robots operating in public places. These range from technology, social and urban impacts, through traffic and safety impacts, as well as standards and monetization issues. This entry section provides a cursory overview.

Table 1 lists the design principles developed by Transport for London for pedestrian networks comprising publicly accessible footways and other public spaces where people are permitted to walk (Transport for London 2020). The principles listed in this table were developed for the full spectrum of pedestrian circumstances, without consideration of the introduction of robotic devices sharing these spaces. Nonetheless such planning principles, where they exist, would directly impact future regulations regarding delivery robots operating in these spaces.

Technology Capability

The fundamental design purpose of a robot is to perform a defined task effectively. To that end, robotics is an engineering discipline – at its core, mechatronics, but inclusive of many others including industrial, human factors, and artificial intelligence. Matters of user safety as well as time and cost efficiency are of first order in applications such as factory, agriculture, warehousing, and mining. In those well-understood environments, proximate humans are usually working in collaboration with, or are trained to be wary and respectful of, robotic operations. In this entry, however, we are focused on robots to be deployed in public spaces at a considerable, non-line-of-sight distance from responsible human oversight while surrounded by noninvolved humans (sometimes referred to as "incidentally co-present persons" (InCoPs).

The proximity of noninvolved humans, such as nearby or passing pedestrians, adds a considerable level of complexity to the core system issues of human safety, operating time, and cost efficiency. Consider also that some pedestrians may be vulnerable due to age, ability, health, or distraction, while others might engage in mischief or vandalism.

Add to this challenge the fact that robots operating in public spaces are inclined to be on sidewalks, pathways, laneways, parking lots or bike lanes almost all of which have discontinuities, gradients, curbs, and narrow passages, as well as fixed and transient obstacles. These spaces assume ambulatory, flexible, meandering, erratic human users at speeds between 0 and 8 kph.

Hence, the physical design of a robot to plough snow, pick litter, or transport a meal will be sized and shaped to its task and its intelligence design configured to navigate the pathways it is expected to encounter.

To address the intelligence challenge, robotics designers approach this with similar technologies and solutions as are being applied to the problem of the autonomous vehicle. Hence, these machines variously use multiple cameras, LIDAR, HD-maps, AI software, and teleoperators. A key design goal for any of these robotics designers is to determine the sensor and software configuration sufficient to maximize the ratio of robots to teleoperator. At this writing, the leading practitioners can operate two or three robots per human teleoperator, depending on pathway conditions.

Using the SAE scale (SAE International 2021), current robots operating in public space, delivering groceries or food, for example, are operating at Level 2 (one teleoperator fully attentive to one robot) or Level 3 (one teleoperator attending to a small number of robots that need only occasional

Personal Delivery Robots: How Will Cities Manage Multiple, Automated, Logistics Fleets in Pedestrian Spaces?, Fig. 1 A robot (pink, center) crossing a busy intersection in Toronto in 2021. (Image courtesy tinymile.ai)

Personal Delivery Robots: How Will Cities Manage Multiple, Automated, Logistics Fleets in Pedestrian Spaces?, Table 1 An example set of planning and design principles. (Transport for London 2020)

Safe	The public realm should be safe to use at all times of day and for people to feel safe to spend time in
Inclusive	All walking environments should adhere to the principles of inclusive design by ensuring that they are accessible to, and useable by, as many people as reasonably possible without the need for special adaptation or specialized design
Comfortable	Designated walking areas should allow unhindered movement for pedestrians by providing sufficient space
Direct	Facilities should be positioned to provide convenient links between major walking trip attractors
Legible	Features should be consistent and easy to understand for all pedestrians to know intuitively how to navigate within a space
Connected	Walking networks should have a high density of route options to suit pedestrians needs
Attractive	Walking environments should be inviting for pedestrians to pass through or spend time in

interventions). The design goal is to achieve Level 4 (multiple teleoperators share-managing large fleets that are 5, 10, 20, times more numerous than the human operator collective). In such highly automated fleets, each robot would seldom demand attention; hence a very high level of fleet automation is required to match such a high level of robot operation.

Level 3 capability is already achievable in some, limited public spaces, and these machines are beginning to alleviate last-mile delivery issues in those selected environments. To become a sustainable industry – i.e., to become pervasive – such environments must be made more numerous and be managed to maintain a profitable ratio of robots per operator.

A key motivating factor for this segment of the robotics industry is that the current costs of last mile delivery are very high. The COVID pandemic exaggerated the impact of e-commerce, food, and grocery delivery and has promoted both supply and demand for final-mile delivery (Grush 2021a). In 2020–2021, supply has meant the expansion of gig delivery operators as well as accelerated innovation and investment by companies such as Amazon and FedEx, and numerous startups such as Starship and Serve Robotics (a recent Uber spin-off).

The fact that Level 3 sidewalk robotics is within reach, means profitable delivery operations are also within reach from the machine-sidewalk-teleoperator perspective. But that is still insufficient for a workable (governable) robotic delivery system to operate at scale in an urban, public environment. Remember, also, deliveries are only one of the many potential tasks such machines will be able to perform in these same public spaces.

With this logic, the greatest design challenge we face is the safe, societally acceptable operation of multi-operator, mixed-purposed, variably scheduled fleets of robots in a partially managed or often poorly managed, urban spatial environment.

After considering some social, urban, and traffic matters in the remainder of this section, the second section of this entry will outline a proposed solution to this challenge ▶ "A System to Manage Sidewalk Robots".

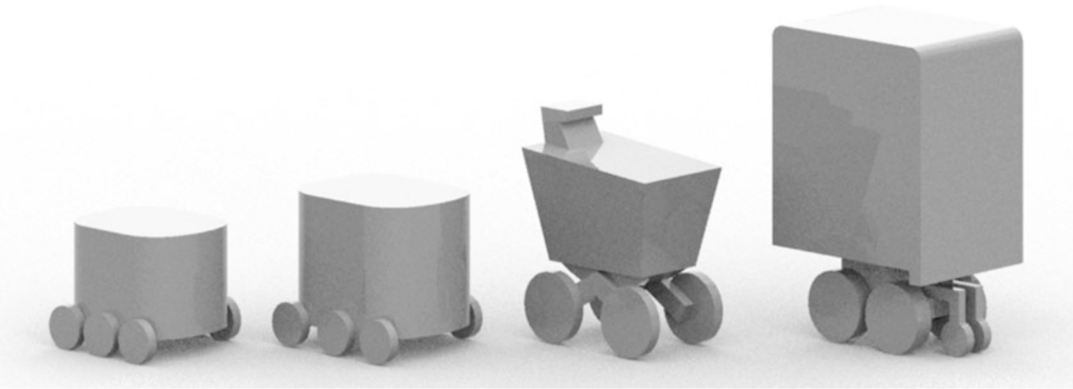
Social Impacts

Sidewalk robots (Fig. 2) arrive for us at a complex juncture. After well over a century of the influence of the automobile in determining how humans are regulated and channeled to walk in constrained public spaces that are spatially and speed dominated by lethal machines, we are just beginning to claw back space for cycling and vulnerable road users. The needs of the latter have been largely, discounted until recently. Municipalities have begun to take seriously competing demands for scarce sidewalk real estate, but aging infrastructure poses challenges and complexity when designing to accommodate these smaller vehicles. We are also just beginning to add micro-mobility forms at scale, to design a (very) few "complete streets," and to promote metrics such as "walkability" or concepts such as the "15-minute city." At the same time that urban areas and populations grow, the average size and personal ownership ratios of motorized vehicles is at least sustained and, in aggregate, continues to grow, even if peaking among some populations. Urban space demanded by automobiles is not abating.

Add to that the social distancing demands of COVID-19 and our cities have become effectively denser with mobile humans, devices, and machines. One example is the increased incursion of bicycles and micromobility devices sharing sidewalks and multiuse trails in many cities. I have experienced this personally numerous times in both Toronto and Montreal.

We must ask ourselves: "Have sidewalk robots arrived at the best possible time, or at the worst possible time?" The answer, of course, is that it is up to us. If we are to welcome these robots into our pedestrian and active-transportation spaces, then how will relative accessibility for all existing parties including these new devices be delineated and ensured (Clamann and Bryson 2021) (Grush 2021b)?

Jeremy Hsu describes both the upsides and downsides of sidewalk robots. On the upside, he quotes from a study: "By moving the last leg of deliveries from the road to the sidewalk, cities could reduce congestion and eliminate the parking



Personal Delivery Robots: How Will Cities Manage Multiple, Automated, Logistics Fleets in Pedestrian Spaces?, Fig. 2 These are four of many tens of delivery robots in small-scale commercial or trial use today. They range 68-–91 cm (length), 53–71 cm (width), 55–147 cm (height, without flag), 33–136 kg (gross weight). and 5–24 km/h (max speed) (Dimensions). Larger and faster delivery robots are planned for roadway use. Ambulatory (legged) robots are being developed to handle stairs. Innovation is only just beginning. (Illustration commissioned by the author.)

problem entirely." And on the downside, he asserts: "When the pavement gets more crowded, even robots rolling along at walking speeds will face challenges which will get worse in US cities with narrow sidewalks." He concludes: "Given these obstacles, sidewalk delivery robots are not necessarily destined to win the future" (Hsu 2019).

While it is unnecessary to take a fixed position on any of these matters, there will clearly be cities that will see small, well-behaved robots as a way to promote the fortunes of local retail devastated by box-stores, ecommerce and the pandemic, to encourage small, quiet, slow, electric deliveries as a way to reduce automotive travel for short-haul shopping (Grush 2021c), or to cope with rising congestion from e-commerce and food deliveries.

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

It should also not be surprising if pedestrian, accessibility, cycling, and/or labor advocates demand limits on the use of such systems. The next decade will see much social discourse about the deployment of these technologies. It will become a goal of urban planners and municipal managers to govern the deployment of such technology somewhere between the extreme approaches of outright banning or complete laissez-faire. Paraphrasing Alanna Coombes:

> *To thrive we need community, business and political agreement on who has what rights at the kerb, footway and crossing. In turn, these rights need to be turned into clearly defined priorities that meet the needs of citizens, including those traditionally excluded, and businesses. Public space as we are contemplating for robotic traffic must be inclusive and protective of community and artistic expression and livability. These vital public spaces – like the city centers in which they exist – need to adapt to the needs of current and future generations, addressing their economic, social, community needs and their wellbeing.* (Coombes and Grush 2022)

Urban Planning

Closely related to these social issues is urban planning – an instrument that can be used to further social progress, especially its civil aspects. In the same way that active transportation and micro-mobility modalities, as well as livability and climate have become central concerns for planners over the past decade or more, the sustainability issues of urban freight and especially e-commerce and food delivery have grown in volume and urgency.

For any municipality wishing to deploy robots for a public or commercial purpose, it will be necessary to confirm that the sidewalks, pathways, and crosswalks to be used can accommodate those robots without violating applicable accessibility guidelines. For example, a sidewalk would need to be wide enough to permit a pedestrian in an accessible mobility device or aided by a service dog to pass a delivery device at most locations on the pathway. As well, if there were places such that a robot must stand aside for a wheelchair to pass, then sufficient waiting space is needed for such robots, and that remaining narrow passages need to be very short to minimize robot-pedestrian standoffs. Further complicating accessibility challenges is the proliferation of pet friendly establishments. Will robots be able to distinguish between a pet and a service animal? For example, if an algorithm depends on the ability of a human to act in a specified manner when a robot is approaching, how will that algorithm need to consider pedestrians with sight loss that may not be able to see an approaching robot and act accordingly – or at least not be alarmed or confused? Micromobility operators have begun to seriously consider adopting acoustic vehicle alerting systems similar to those required of electric/hybrid cars but little standardization exists with regard to such alerting systems.

Many other matters such as maximum in-line or cross gradients and surface conditions are important. Many of these are already incorporated in draft standards under development (Grush 2021b). One critical goal is to ensure that all urban pathways and trails intended for robot use be sufficiently specified, organized, and maintained to meet applicable accessibility guidelines, *even while supporting the intended robot traffic volumes*. This latter point implies the planner has some way to know or control the dynamic volume of robotic traffic, which is one of the intentions of the above referenced standard.

Ideally, the innovators of these devices and the deployers of the expected fleets would engage in meaningful dialogue with other road, bicycle, and sidewalk users, but too little such dialogue has thus far taken place. That may be understandable from the innovators' perspective partly because they are still determining what is feasible to innovate, but it may also be partly due to the sense that it is often easier to apologize later rather than ask now. That would be especially true if a new industry were able to accrue sufficient demand to act as a defensive buffer, later.

Regardless of one's urban-moral stance in this, the advocacy opportunity for pedestrians, vulnerable road users, cyclists, micro-mobility, and all other active transportation users is to press for attention now. The opportunity is to collaborate with those logistics companies that will deploy robotics to lobby for coherent urban spaces and approaches for active and small-device mobility corridors. The basis of this collaboration would be municipal monetization of robotic commerce to fund, manage, and maintain such pathways and corridors sufficient to both accessibility requirements and commercial needs. This would imply universal design at an appropriate scale.

In the zero-sum game currently being played out between motor vehicle and active modes, the sidewalk robot has properties of both. Several of the US State Senate bills that authorize a class of sidewalk robots called personal delivery devices define these robots as pedestrians in terms of the rules they must follow and the rights of way that motor vehicles must grant them in turn. At the same time, they are a special "pedestrian" class that must always grant rights-of-way to human pedestrians (Grush 2020) (Kingson 2021). This arrangement may not be suitable in the future case of sidewalk robots deployed for fire, police, or- Emergency medical services (e.g., ambulance) work.

In any city where robotic goods delivery scales dramatically, the urban mobility space that is now split between motor vehicles and active modes may need to be repartitioned. How we currently segregate space among pedestrians, cyclists, street parking, transit lanes, and moving motor vehicles has grown increasingly fragmented, and in some places bordering on the irrational. The unintended consequence of shifting last-mile goods delivery from curbside stepvans onto sidewalk robots may be to force the re-rationalization of urban mobility space.

The most critical matter planners must face is the conundrum between the possible, the probable, and the preferable. Should planners find ways to accommodate sidewalk robots, or should they take advantage of the potential of sidewalk robots, and other forms of vehicle automation, to build the city they prefer?

Traffic Management

Even if mobility spaces that mix robotic service modes and active-mobility modes were optimally designed, we cannot avoid consideration of traffic management within those spaces. As well, we do not yet have a full and common traffic code that guides all these mobility forms to cohabit and cooperate on these pedestrian pathways and crosswalks. Standards for many of these issues are being developed. One will be mentioned in section "A System to Manage Sidewalk Robots" of this entry.

One of the most important matters will be sidewalk congestion wherein a large number of robots among pedestrians may become unworkable and frustrate pedestrian passage.

Urban planners can take a lesson from the last half-century in recalling the unfortunate but often necessary behavior of goods delivery vehicles in their parking behaviors as they frequently blocked traffic through lanes and more recently bicycle lanes for lack of loading and unloading infrastructure proximate to the delivery point.

As an industry, express delivery has often had little choice but to rely on infractions, citations, and traffic court as a "part of doing business" in larger cities. In this unwitting traffic management agreement, motor traffic, cyclists, and shipment receivers bear these costs. Wherever goods movement will be relocated to the sidewalk, any time that these vehicles cannot be accommodated within the existing space, the delivery operator will necessarily resort to some scheme to complete its delivery.

Urban transportation managers have been able to survive the problem of courier parking in our cities for several decades by relying on double parking, citations, and traffic court. Any other solution was deemed to incur more trouble, more complexity, and even higher costs.

If sidewalk robots are deployed at scale, such a violation-citation-payment approach would become even more unworkable.

The key point here is that an adherence to universal design principles is insufficient to manage a volume of robots that would overwhelm pedestrian traffic, unless there were independent lanes for robots – itself an unaffordable solution except in very few cases. Physical urban planning alone cannot eliminate this issue; such traffic requires dynamic, digitalized control.

Roadway traffic management incorporates universal patterns: traffic signs, signals, circles, speeds, parking areas, protocols, enforcement, citations, etc. Details may differ in each jurisdiction, and some at each intersection. Traffic management rules, or "robot orchestration" will differ slightly at each location, as well, and all of the signs and signals will be communicated via digital maps in real time. This will provide the opportunity needed for both congestion control and monetization (Grush and Coombes 2022).

A System to Manage Sidewalk Robots

Section "Robots Operating in Public Spaces" of this entry briefly highlights some of the technical, social, urban, and traffic management issues relevant to the large-scale introduction of mobile, human-scale robots for a variety of service purposes – especially final-mile delivery services – on public sidewalks, bike lanes, footpaths, and crosswalks.

To manage multiple automated fleets of mobile robots in pedestrian spaces, we will break the problem into four loosely connected layers: Regulatory, Orchestration, Fleet, and Machine.

The top, regulatory layer is provided by local, regional, and/or state and national regulations. These would be designed for local purposes and demands, and could be expressed in digital form using standard data definitions and procedural elements of ISO/DTS 4448 (Grush 2021b).

In this section of the entry, we are concerned with the second layer, designed for the digital orchestration of regional robot traffic. We assume that the two lower, digital layers for fleet and machine management preexist the orchestration layer. All three of these layers are in the "connected vehicle" domain.

Problem Definition

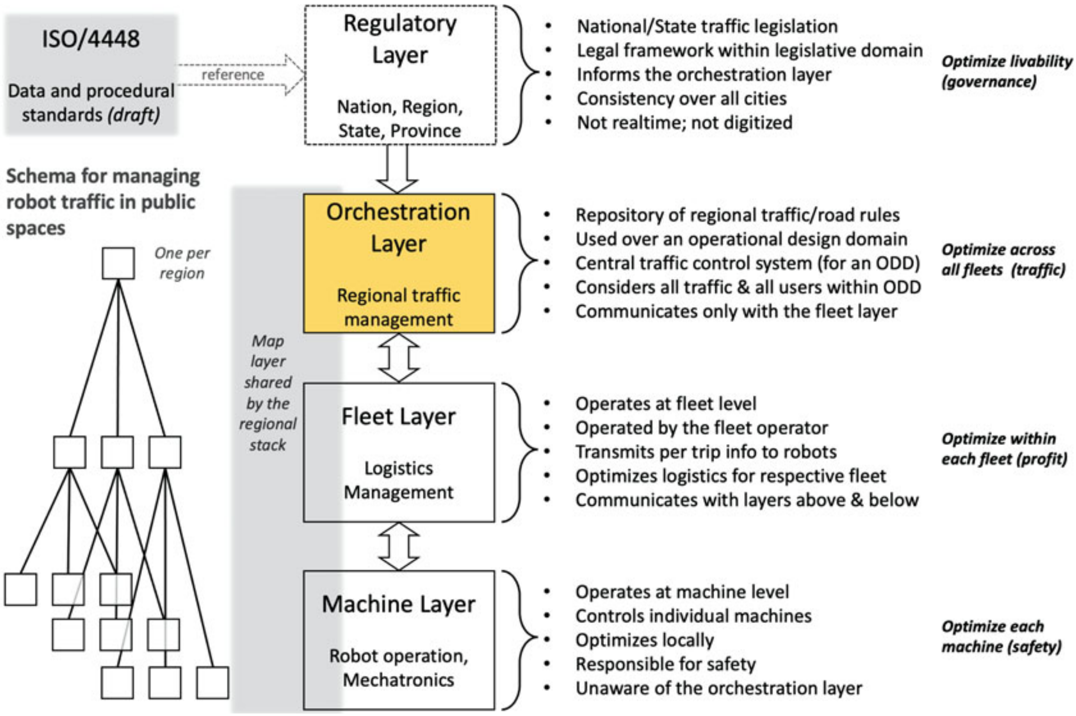
A high-level problem statement for orchestrating multiple, concurrent fleets of robots would be:

Orchestrate the flow of an arbitrary number of robots from an arbitrary number of fleets of robots that comprise an arbitrary number of machines assigned independent tasks, with independent schedule constraints, within a mapped "operational design domain" including dynamically changing traffic volume constraints.

(a) Each fleet of robots has an independent operator with an independent fleet-operating system (fleet layer)
(b) Robots in each fleet navigate safely and collaboratively among any proximate robot, human, or obstacle (machine layer)
(c) Data at the orchestration layer can only be communicated to or from the fleet layer
(d) The orchestration layer cannot communicate with any robot
(e) Latency between layers is effectively zero from a traffic management perspective. This means that any instruction or constraint from the orchestration layer can reach a robot by way of its respective fleet layer within 2 or 3 s.

Digital Management Layers

Figure 3 illustrates these four key system layers. As stated, we are focused only on the orchestration layer. This layer is the robot traffic control system that a region or municipality may employ to govern usage, manage congestion, and monetize public infrastructure for commercial usage in



Personal Delivery Robots: How Will Cities Manage Multiple, Automated, Logistics Fleets in Pedestrian Spaces?, Fig. 3 In this schema for managing robot traffic in public spaces, there are four loosely connected layers. The Machine, Fleet, and Orchestration layers would be fully digitalized and operate in the "connected vehicle" domain

what are usually pedestrianized operating design domains. The same system structure could be used to manage loading and unloading goods and passengers from robotic vehicles at the curb.

The fleet layer in Fig. 3 is populated by fleet managers, each of which comprises software representing the business of a single entity, say an express delivery company or a de-icing fleet. This system is agnostic in regard to how elements of the fleet layer assign work to its robots, how many fleet managers are active, or how many active robots a fleet manager has deployed.

The machine layer (Fig. 3, bottom) is only populated by robots, and may represent multiple machine models, perform multiple task types, be made by multiple manufacturers, and utilize multiple software platforms. Coordinating each sub-fleet within whatever constraints are passed down from the orchestration layer is the problem of the respective fleet operator and is assumed to be handled by software that is arranged to manage that communication. The orchestration layer never communicates with the machine layer. This simplifies system management and helps to keep private the business of the fleet operator. This entry is not concerned with this layer, or the one above it.

The Orchestration Layer

The orchestration layer (Fig. 3) is a fleet-independent, ground traffic control system that addresses several local (regional) matters especially gross positioning related to traffic distribution. This is distinct from micro-navigation matters critical at the machine layer or logistics and task optimization matters at the fleet layer. The central essence of the orchestration layer is an intelligent, dynamic, constraint-aware routing engine. It also manages real-time information distribution regarding local (block-face) rules some of which may change dynamically. These rules may also include user fees.

The only potential override by the orchestration layer would be the assignment of a route for traffic distribution reasons that might not be the route that the fleet layer for the respective operator would have derived. However, because the orchestration layer is enabled to use pricing to manage congestion, a fleet operator could have multiple route choices, including its own time-optimized, distance-optimized, or charge-optimized choice(s).

The orchestration layer is also concerned with parameterizing robot behaviors related to positional and shy-distancing management, as well as deferential, social behaviors regarding proximate humans, vulnerable road users, pets, businesses, and other machines.

The purpose of the orchestration layer is to maximize:

- Accessibility for all users, especially pedestrians, including vulnerable road users
- Traffic flow (congestion, rights-of way)
- Acceptance of robots in pedestrian spaces (human comfort, robot social behaviors)
- Efficiency in regard to the use of infrastructure within the relevant ODD
- Fleet operator awareness of local conditions for the intended trip

  and to minimize:
- Pedestrian confusion, alarm, or frustration
- Spatial conflicts and or congestion
- Unexpected navigation or access barriers for the fleet operator

This layer is generally unconcerned with robot task-related information. Exceptions to this would be in regard to carriers of hazardous goods, robots executing emergency-related tasks, and certain public works tasks such as snowplowing or litter-picking. A traffic authority would likely wish to manage certain types of task features for such cases.

The data exchanged between the orchestration and fleet layers comprises a few dozen elements such as:

- Trip data: Origin, destination, time, actual max speed, etc.
- Robot data: Size, weight, max speed set, equipment capabilities, registration number, etc.
- Trip contract: Several elements indicating agreement to several spatial and pathway travel rules, human-robot communications, and expected conditions regarding surface conditions and weather resiliency, and more.

To summarize, the orchestration layer is concerned about social, urban, livability, infrastructural, and congestion matters. Since these matters are locally structured, their preferred solutions should be locally (regionally) determined. Hence, any fleet operator focused on completing robotic tasks effectively and safely need only receive route permissions and machine behavior cues from the orchestration layer and may remain otherwise unaware of local expectations or infrastructure since all required instruction including real-time changes would be communicated from the orchestration layer.

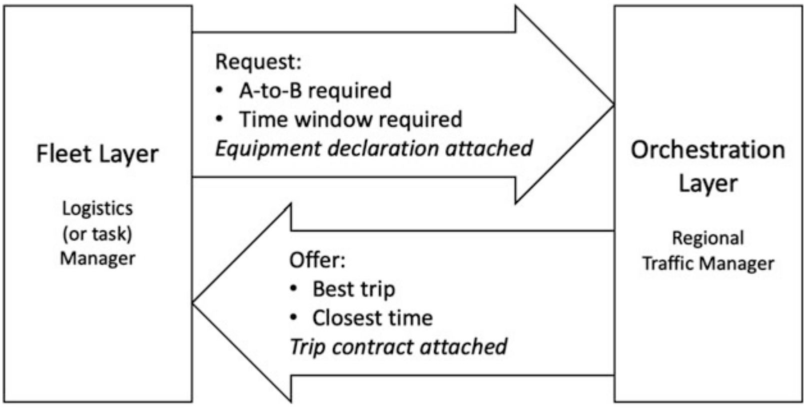
Hence, the differences between a robot getting from A-to-B in Kolkata and getting from A-to-B in Berlin, would be absorbed in, and communicated from, their respective orchestration layers. This permits robot operating systems and fleet management systems to be relatively unconcerned with these local differences, focusing rather on universal design matters that allow them to operate in any desired location.

Orchestration Process Overview

The communication process (Fig. 4) between a regional orchestration layer and any fleet layer operating in that region would consist of several messages concluding in a “trip contract.”

The contents of a trip contract include several dozen elements (depending on the number of path segments in the trip. In addition to an agreed pathway and time window, these include:

- Information such as “narrowest passage” or “steepest gradient” on each path segment



Personal Delivery Robots: How Will Cities Manage Multiple, Automated, Logistics Fleets in Pedestrian Spaces?, Fig. 4 A standardized set of messages are required to negotiate a trip contract between a fleet operator and the regional authority managing the ODD. This simplified figure shows only the fundamental concept of a trip request for a declared device (equipment), and an offer of a trip contract (Grush 2021b)

- Instructions such as "use the right (or left) side" of a crosswalk for each crosswalk between path segments
- Constraints such as maximum speeds or weight per segment and crosswalk
- Equipment provisions such as lights, flags, sounds, etc.
- Financial data such as the user fee per segment on this contract

Draft definitions for the data intended for use in such trip contracts are included in a draft technical standard (ISO/DTS 4448) (Draft technical standard (DTS) 2022). All ISO/DTS 4448 data elements are provided with a default to guide orchestration level set-up. Any element could be set to suit the needs of a local authority.

Many elements are local map-associated parameters (such as max speed, max weight, travel left, travel clockwise) that would be determined, stored, and exchanged within mapping regimes suitable to the local governing authority, and converted to the standard trip contract format.

Many elements are variable over geography, such as maximum cross gradient, or maximum pathway roughness. Other elements may change dynamically, even in real time, depending on local capabilities. These might be user fees affected by congestion or surface friction related to temperature or precipitation.

Note that the draft standard indicted here, while providing metrics, formats and defaults, does not require that every element be updated in real time. Clearly, there will be differences in the deployed capability of regional orchestration level systems depending on local requirements. Any shortcomings will necessarily be absorbed at the lower system levels for fleet and machine (Fig. 3).

Ancillary System Components for a Robot Orchestration Process

It would be possible to simply set up an orchestration system, apply the ISO/DTS 4448 defaults, and expend only a modicum of effort on real time management. In fact, this will be the likely approach until the number of operators, robots, and trips begins to grow, and a degree of congestion management is required. The assumption is that if public-space robotic technology becomes as pervasive as its visionaries promise, then fleet coordination and congestion management will clearly become an issue, if accessibility, livability, and pedestrian advocates don't lobby for other constraints first. This implies that the success of this pending industry within our cities and our active transportation and vulnerable users will rely on a highly competent and socially acceptable fleet orchestration capability.

In order to learn how to adjust appropriate system parameters to consistently optimize the orchestration layer (Fig. 3), data will be needed about pathway conditions and congestion factors. To maintain good order, data will be needed about infractions such a speed or rogue robots (without trip contracts). The management of some of the social behaviors such as auditability and visibility of prescribed robot sounds and lights will also require observation data.

Some of this data may come from the robots themselves, some may come from proximate robots (although that would seem a very difficult approach), and some may come from data capture through sensors on fixed IoT networks.

An enforcement capability will be required, but would be defined locally. Enforcement and its digitalization will depend on the depth of capability embedded in the orchestration layer.

Conclusion

The problem of managing deployed robots is very different from the pure mechatronics problem of designing a robot to perform a particular, well-described task. The easiest cases are factory robots performing a repetitive assembly task in a fixed, bounded space ("caged robots"). The next harder case is an automated mobile robot (AMR) to pick-move-place loads from one spot to another in a factory, warehouse, or mine setting or to plough or spray a given agricultural area.

As we move to the problem of roboticized work in public spaces, we introduce at once the need for robotics management platforms to consider untrained, non-attentive, and noninvolved persons; persons of varying abilities; and complex spaces comprising urban sidewalks with less predictable and highly variable surfaces and barriers.

As we deploy in this new environment with multiple fleets from multiple vendors performing multiple categories of tasks, we engage one of the most difficult, nonmilitary applications for AMRs. This is the context for the vision of using AMRs at scale from a plurality of independent operators for multiple, mundane tasks within shared urban spaces that include pedestrians of every physical, sensory, and cognitive ability.

The value of the services that are envisioned to be provided by these robots is extraordinarily high from livability and commercial perspectives. The opportunity provided by competent fleet orchestration is to manage these services in a way that maximizes their value and minimizes their threat. That much is obvious.

What is less obvious is how to go about doing that. This entry has presented such a proposal but because the related standard is itself still in draft form, this proposal must also be read as a draft.

Cross-References

- ▶ Age-Friendly Future Cities
- ▶ Artificial Intelligence and the City
- ▶ City Visions: Toward Smart and Sustainable Urban Futures
- ▶ Disruptive Mobility
- ▶ Emerging Directions and Technologies in Digital City Models for Urban Planning
- ▶ Getting Our Built Environments Ready for an Aging Population
- ▶ Governance of Smart Cities
- ▶ Green and Blue Infrastructure (GBI) in Urban Areas
- ▶ Green Cities
- ▶ Improving Social Equity and Community Health and Well-Being in Low-Income Suburbs and Regions
- ▶ New Cities
- ▶ Planning Healthy and Liveable Cities
- ▶ Public Space
- ▶ Regulation of Urban and Regional Futures
- ▶ Residential Crowding in Urban Environments
- ▶ Shaping Transport Demand and Delivering Transport Supply
- ▶ Shrinking Towns and Cities
- ▶ Smart Cities
- ▶ Smart City
- ▶ Smart Densification
- ▶ Smart(er) Cities
- ▶ Sustainable Urban Mobility
- ▶ Systemic Innovation for Thrivable Cities
- ▶ Transport Resilience in Urban Regions

- ▶ Transportation and Mobility
- ▶ Transportation and Mobility : Low/zero-carbon transportation
- ▶ Urban Electric Mobility
- ▶ Urban Futures
- ▶ Urban Resilience: Moving from Idealism to Systems Thinking
- ▶ Urban Structure and Its Impact on Mobility Patterns: Reducing Automobile Dependence Through Polycentrism

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