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Intelligent transport systems — Public-area Mobile Robots (PMR) and automated pathway devices — Part 5: Public-area mobile robot access on human pathways

Systèmes de transport intelligents — Robots mobiles pour espaces publics (PMR) et dispositifs de cheminement automatisés — Partie 5: Accès des robots mobiles pour espaces publics sur les sentiers humains

WD

Contents

Foreword

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This document was prepared by Technical Committee ISO/TC 204 WG19.

This is the first edition of this document.

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

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

Introduction

As public-area mobile robots multiply in functionality, variety and fleet count, they will require traffic control systems (orchestration systems) to manage their mobility behaviour among other users of pedestrianized spaces.

Existing orchestration systems to govern air, rail, road, and vessel traffic share a set of common basics:

- **Safe and efficient movement** of vehicles within their respective domains
- **Regulations, rules, and procedures** that ensure orderly and safe traffic flow
- **Communication and coordination** to manage traffic and prevent collisions
- **Navigation aids** such as beacons, signs, signals, and other technologies to guide vehicles
- **Traffic control centers** to monitor flow and detect potential issues
- **Government regulation and operation**

In addition to these common elements, each of these orchestration systems has unique operational challenges that inform the methods and technologies used within their respective domains.

Air Traffic Control manages altitude, lateral position, and speed of aircraft while operating in 3D space. Aircraft must maintain minimum vertical and horizontal separation; the system must manage multiple flight levels, types of aircraft, runway configurations and international regulations.

Railway Traffic Control operates on fixed tracks, maintains inter-train spacing, manages schedules and signaling systems, share tracks among multiple operators (passenger and freight).

Road Traffic Control manages a 2D network with intersections, multiple road types, widths, and speeds. Signals, signs, lane markings, barriers and police systems regulate traffic and guide drivers. Complexity is due to congestion, weather, road repair, and variations in driver behaviours.

Vessel Traffic Services manage traffic in waterways, ports, and harbors, often with complex navigation channels with tides, currents. Management includes multiple vessel sizes, navigational assistance, weather information, and traffic advisories, in the context of maritime regulations.

PMR Traffic Control (PTC) system

Traffic control systems for public-area mobile robots (PMR Traffic Control systems) will be required as orchestration systems to manage multiple fleets of robotic devices for logistics, security, and maintenance services in public spaces such as sidewalks, crosswalks, and other human pathways, both indoors and outdoors.

The key purpose for such an orchestration system is for any jurisdiction or facility wishing to manage the sharing of pedestrianized space by multiple PMRs fleets, each with an independent operator, task purpose, tool set, and schedule within a described geographical region, but with no ability for those fleet operators (FOs) to coordinate trip planning.

While operating co-temporally and co-spatially, such PMRs will require a traffic control system of equivalent operating reasoning and structure to the control systems we use today for air, rail, road, and water traffic. This will require adapting principles from existing traffic control systems while considering unique characteristics of pedestrian and robot interactions within the infrastructural spaces they share.

System capability

PMR Traffic control systems will negotiate, approve, and queue trip plans for PMRs analogous to the way air traffic control handles flight plans. Such a system would likely communicate only with FOs in order to a reduce system and interface complexity and promote operating privacy. An analogy is that air traffic control manages aircraft but does not manage passengers beyond agreed behavioural and security rules, and passenger list maintenance.

Common definitions would be required for operation among pedestrian traffic, equipment descriptions, pathway descriptions, route planning descriptions, rights-of-way (both robot-to-human and robot-to-robot), and communication of local rules of the road (pathway).

Common safety protocols such as road-crossing rules, emergency pullover procedures, location recovery in the event of loss of communication or location signals, and trip plan management for unplanned trip interruptions or path obstacles.

System prerequisites

Each PMR must be equipped with a **secure ability to navigate** according to trip plans as provided by its FO including all required sensors, location determination, path planning, and real time communication back to its FO. It is immaterial whether this ability is provided via teleoperation or automation.

The control system must **consider environmental factors** such as weather, lighting, pathway and congestion conditions, including and any local size, weight, constraints when providing trip plans.

The system must **incorporate sufficient communication and coordination redundancy** to ensure PMRs cannot become disconnected (lost) from its FO and that no FO can become disconnected from the central control capability. In the event of any such disruption or disconnection, there must be a backup procedure for a safe interlude while waiting for recovery of failed signals or PMRs.

There must be **adequate intersection management** such that PMRs can safely share road crossings with pedestrians, cyclists, road vehicles, and other PMRs. This may include changes in ATS management, and strict rules of engagement for PMRs.

There must be a **FO certification method** to ensure an ability to maintain communication with the central control system to request, acknowledge, and distribute trip plans to its PMRs.

There must be a **PMR certification method** to ensure an ability to maintain communication with its FO in order to accept, acknowledge, and execute trip plans. In addition, PMR certification must ensure that each device has sufficient sensor, software, and teleoperation connectivity for safe execution of trip plans it receives. This is to ensure the PMR's ODD capability matches trip plan assumptions about each intended ODD.

Additional System context

There must be clear **regulatory guidelines** for the operation of a central control system, including both traffic management and the priority of user-rights for other pathways users.

There might be additional **interfaces for pedestrians and other pathway users** to understand robot intentions, to report issues, or receive/report relevant pathway updates.

There should be additional methods to **observe and analyze robot presence and behaviour** to ensure rules are being observed and for purposes of safety and enforcement.

There should be additional methods to **observe and analyze pedestrian flow** to avoid congestion.

There should be additional methods to use both robot and pedestrian data for **continuous management and improvement**.

There should be **public awareness and educational programs** to inform other pathway users about the presence of robot fleets and how to interact safely with them (this includes motor vehicle users, because they also pass over crosswalks).

There should be a **collaboration** among urban planners, robotics experts, transportation engineers, and policymakers to ensure a balance among efficiency, safety, and the needs of pedestrians and other road users.

This document can be used as a standard defining the structure of a PMR traffic control system.

Intelligent transport systems – Public-area mobile robots and automated pathway devices — Part 5: Public-area mobile robot access on human pathways

1 Scope

This document is Part 5 of the 4448 series addressing access management requirements for public area mobile robots (PMRs) operating in public, pedestrianized spaces such as footways, bikeways, roadways and crosswalks.

This part describes orchestrated access for PMRs by way of trip description, reservation and queueing. The orchestration described in this document is intended for multiple PMRs fleets, each with independent Fleet Operators (FOs), task purposes, tool sets, and schedules while operating co-temporally and co-spatially within a described geographical region, but no reliable ability for FOs and individual PMRs to communicate or directly coordinate.

The scope incorporates concurrent use by various types and combinations of automated and non-automated, wheeled, or ambulatory, motorized and non-motorized, mobility-related vehicles and devices as well as for various levels of automated operation of such vehicles. This includes devices and vehicles that move either people or goods.

The scope includes two PMR orchestration approaches:

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

The second approach provides a greater degree of traffic management as given by monetization.

2 Normative references

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

Urban Street Design Guide, NACTO: https://nacto.org/publication/urban-street-design-guide/street-design-elements/sidewalks/ (Accessed October 2022)

Add reference for Shared Streets Linear Reference System

3 Terms and definitions

For the purposes of this document, the terms and definitions in ISO/TS 14812:2022 ~~and in 4448-2~~ apply.

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

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

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

3.1
block-face
extent of sidewalk/pavement on one side of a street between two consecutive intersections crossing that street

3.2
footway
footpath

pavement
sidewalk
lane primarily designed for the movement of pedestrians

Note 1 to entry: A paved footway is called a "pavement" in British English.

Note 2 to entry: Regulations typically allow footways to be used by other ultra-low speed users, such as the users of wheelchairs and strollers.

[SOURCE: ISO/TS 14812:2022, 3.3.3.3]

3.3
kerb
curb
edge where a raised pavement/sidewalk/footpath, road median, road shoulder or road median/central reservation, meets an unraised street or other roadway (ISO 28842:2013)

Note 1 to entry: A unit greater than 300 mm in length, commonly used as edging to a road or footpath (EN 1343:2012)

Note 2 to entry: Border, usually upstanding, at the edge of a carriageway, hard strip, hard shoulder, or footway (ISO 6707-1:2020)

Note 3 to entry: British and Singaporean English; pavement or footpath in Australian English, sidewalk in North America.

3.4
operational design domain
ODD
set of operating conditions under which a given driving automation system or feature thereof is specifically designed to function

EXAMPLE 1 ADS feature designed to operate a vehicle only on fully access-controlled freeways in low-speed traffic, under fair weather conditions and optimal road maintenance conditions (e.g. good lane markings and not under construction).

EXAMPLE 2 ADS-dedicated vehicle designed to operate only within a geographically-defined area, and only during daylight at speeds not exceeding 25 mph.

Note 1 to entry: The conditions can include environmental, geographical, time-of-day, and/or other restrictions.

Note 2 to entry: The conditions can require the presence or absence of certain traffic or roadway characteristics.

[SOURCE: ISO/TS 14812:2022, 3.7.3.2]

3.5
pathway
infrastructure designed for the movement of any combination of pedestrians, cyclists and PMRs within the same space.

Note to entry: Backlanes and human passageways within buildings are also types of pathways.

Note to entry: a *pathway segment* is a portion of a pathway between two subsequent intersections

3.6
public-area mobile robot
PMR
a wheeled or legged (ambulatory) ground-based device that is designed to travel along public, shared, pedestrianized pathways without the use of visible human assistance or physical guides

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

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

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

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

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

3.7
teleoperator
A human with navigation oversight and at least some lateral and longitudinal control of a remote vehicle

4 Abbreviations

ADS	automated driving system
ATS	automatic traffic signals
DDT	dynamic driving task
FO	fleet operator
JDR	journey data recorder
ODD	operational design domain
OM	orchestration manager
PMR	public-area mobile robot
PTC	PMR traffic control
PUDO	pickup/drop off

5 Function Framework

5.1 PTC System Description

A PMR traffic control system (PTC) is an orchestration manager (OM) that negotiates, queues, and communicates *trip plans* for PMRs analogous to the way an air traffic control system generates and manages flight plans.

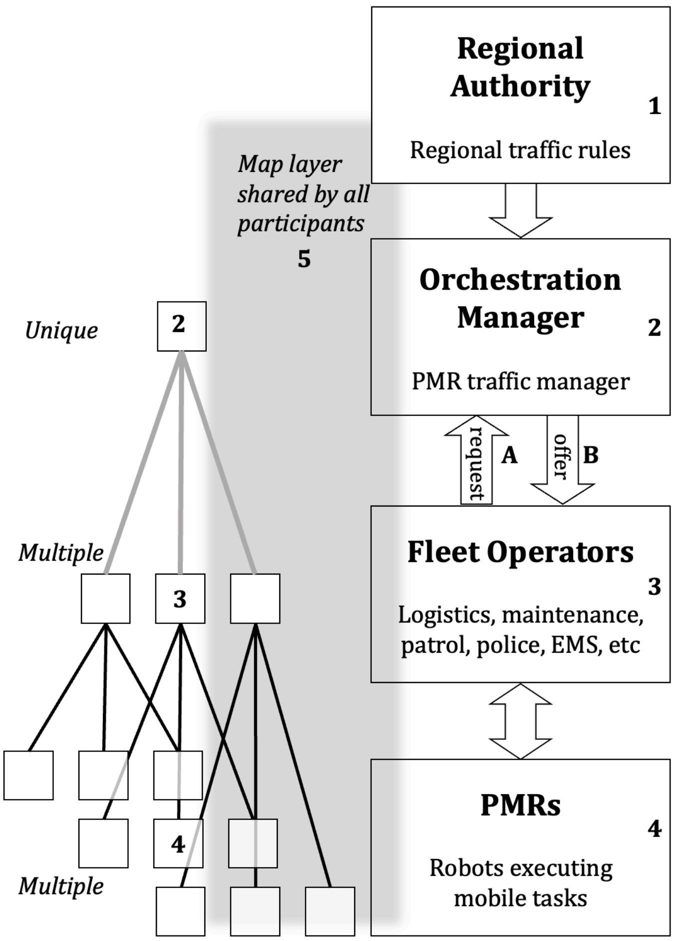
In Figure 1, a PTC system incorporates a body of regional robot-traffic rules [1] to be deployed within a region such that all fleet operators (FOs) [3] operating within that region derive trip plans [A & B] from a unique OM [2].

Each PMR [4] operating within that region is guided by trip plans provided by a FO uniquely and fully responsible for that PMR.

All participants in this system share a map layer [5] such that all PTC rules, communications, and descriptions share an understanding of trip pathways as well as obstacles and expected behaviours within those pathways.

5.2 PTC System Regional Data Flow

Figure 1 illustrates the regional data flow from regional traffic rules, through an orchestration system managing trips including the location congestion, flow and required behavioral elements of individual, managed, PMR trips.



A **Regional authority** manages rules to inform an **Orchestration Manager** that provides *trip plans* according to those rules to **Fleet Operators** managing fleets of **PMRs**.

Every connection is either one-to-one or one-to many.

[**1**] Regulations are set by a regional authority

[**2**] Orchestration manager is unique within a region(s)

[**3**] Fleet operators are responsible for a specific fleet(s)

[**4**] PMRs belong to a specific fleet

[**5**] Map layer is common to all participants

[**A**] Fleet Operator (FO) requests a trip plan

[**B**] Orchestration manager (OM) offers a trip plan

[**A & B**] Trip plan negotiation

Figure 1 — Data flow for managing PMR traffic in public spaces within a jurisdiction

5.2.1 Enablement of global data flow within a jurisdiction

To enable the global data flow within a jurisdiction's operating region that manages PMR traffic:

1. A Regional Authority shall authorize a unique OM for PMR traffic within its authority

2. A Regional Authority shall determine PMR traffic rules and shall parameterize those for its unique OM to distribute in trip plans.

3. The Regional Authority shall require all FOs to accept and execute trip plans from the OM authorized in its jurisdiction

4. There shall be a common (agreed) map [5] managed by the OM that describes all potential trip segments with the properties and usage rules for each segment

5. There shall be a commonly understood method of keeping the shared regional map up-to-date to ensure that trip plans are executable (see 4448-x)

5.3 PTC System Trip Plan Data Flow

Figure 2 illustrates the data flow for trip requests and plans moving between an OM **[2]** and a FO **[3]** using the traffic rules determined by the Regional Authority. A request for a trip plan is initiated by a FO in order to execute a service, delivery or other task. The trip request **[A]** contains sufficient information for the OM to offer a trip plan **[B]** in satisfaction of the trip request.

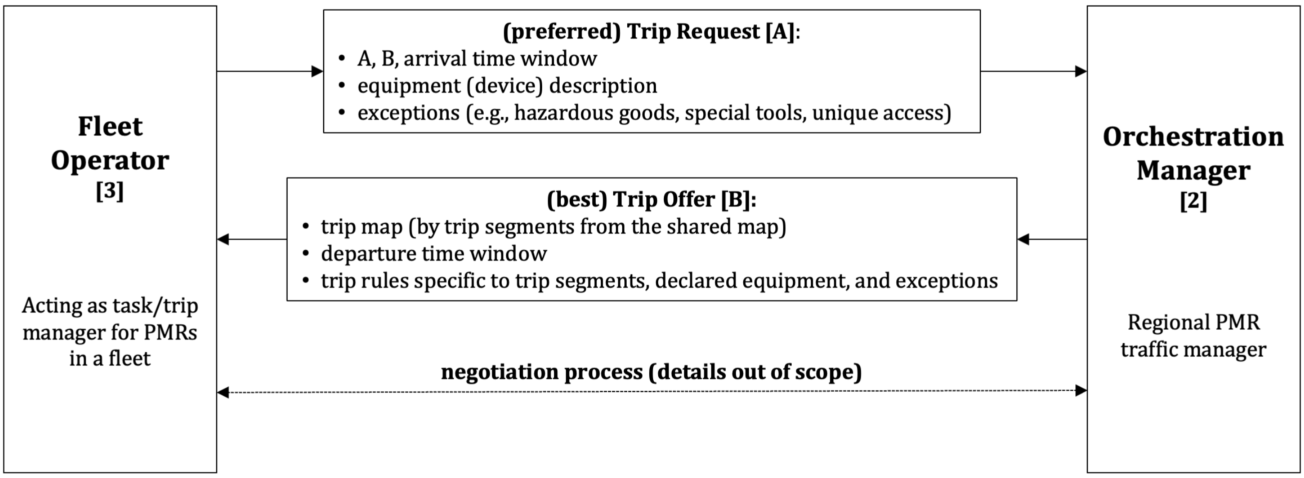


Figure 2: Local data flow for managing a specific PMR trip within a public space

5.3.1 Enablement of data flow between FOs and the OM

To enable trip data to move between a FO and an OM:

1. A participating FO shall be able to construct trip requests according to this document

2. The OM shall be able to read and interpret trip requests as described by this document

3. The OM shall be able to construct and send a trip offer according to the shared map in a way that is designed to satisfy its regional traffic management requirements and as near as possible match any properly constructed trip request

4. In the event that the OM in unable to provide a trip offer in satisfaction of a trip request, there shall be a way to inform the FO, and for the FO to construct an alternate request; a negotiation process is required, but its details are out of scope.

5. A FO shall be able to cancel ("surrender") a trip plan at any point before or during a trip.

6. A FO shall be able to request a new trip plan in replacement of a canceled partial or whole trip plan

7. An OM shall be able to cancel and send replacement trip plans without waiting for a FO to request a cancellation or replacement. Under emergency circumstances, a replacement trip plan is not required to route a PMR to its former destination

8. There shall be a suitable and secure communication system that is agreed among the OM and each participating FO; a suitable system shall include functions such as acknowledge, resend, reject, override, etc. as would be required by any competent communication system (out of scope).

5.4 PTC system Trip Plan elements

Mobile robots operating in public, pedestrianized spaces shall be managed (controlled) to operate within mappable and describable pathways (such as on identified sidewalks, road-crossings, or corridors) that comprise fixed and transient configurations and obstacles. This management shall include:

- Pathway segments that may be used
- Time(s) that pathway segments may be used
- Maximum travel speeds permitted on each segment
- Checklist of sufficient capabilities to plan and execute navigation (maps, sensors, controls)
- Rules of navigation related to specific times, pathways, configurations and other circumstances

Managing PMR traffic requires active *orchestration*. Orchestration manages schedules and priorities in a way to avoid unwanted use of pathway segments, congestion, and conflicts that might cause PMRs to become trapped amongst humans, motor vehicles or other PMRs. Orchestration, as described here, fills the same role for PMRs as traffic lights, signage, and lines painted on the road, does for road vehicles. A major difference is that PMR orchestration is entirely digitalized, with the only required physical manifestation being traffic control centres.

For PMRs, orchestration shall be provided (overseen, supervised) in one of these three ways:

1. **Fleet Operator centric.** A FO determines PMR management rules, and instructs its fleet — via its proprietary arrangement of software, sensors, and human teleoperation. This method, orchestrated by the FO, shall follow whatever traffic and social rules apply to pedestrians within its operating area. This requires no communication with other FOs. The PMRs and teleoperators under the management of such a FO shall follow the commands set by that FO. Such rules shall be available in plain (human) language on demand to the jurisdictional authority responsible for the safety of all users (pedestrians, vehicles, other PMRs) within the operating area (transparency).

2. **By-law centric.** An authority determines PMR management rules, and contracts with, or sets bylaws for, any FO within its jurisdiction. Such PMR management rules shall be consistent among all FOs within a jurisdiction (consistent traffic management). Consistent shall mean that PMR management and orchestration rules will be appropriately constructed, published, distributed, updated, and enforced, while being duly followed by each FO within its jurisdiction.

3. **Traffic Authority centric**. A jurisdictional authority creates or contracts a regional OM, and each FO shall communicate to and comply with that OM. The OM contracted shall be unique within a jurisdiction to ensure a common management system for all FOs. The reason for this is that a traffic orchestration system managed by the OM must coordinate PMRs from multiple fleets within the same spatial environments (for example, multiple PMRs from multiple unrelated fleets at the same at roadway intersection).

The choice of which orchestration approach to use should be based on the number of independent FOs are permitted to operate within a shared geography or facility

5.5 Traffic and Behaviour Orchestration

A traffic authority may permit PMRs to traverse or cross one or more bikeways, footways, roadways and crosswalks. Analogously, a facilities manager may permit PMRs to travel within the corridors and passageways in buildings, or the pathways and trails within a park.

By definition PMRs operate amongst human users such as pedestrians, wheel chair users, cyclists, car drivers and other PMRs.

PMR behaviour may be an admixture of pedestrian behavior, bicycle behaviour or, motor vehicle behaviour, depending on where they are at any moment, under what constraints they may be operating, and how their ODDs (operating design domains) present. A snow plough PMR, likely of considerable curb weight, can be expected to have different properties compared to a small PMR designed to transport a single meal.

PMRs shall behave in a safe, consistent, ordered, and predictable manner so that proximate humans can understand the PMR’s intention or requirements. PMR behaviour in traffic shall not create danger, discomfort or confusion for humans or their pets.

Just as human car drivers and human pedestrians use motion recognition, eye-contact, facial expressions, and hand signals to communicate their intentions or concerns to each other, PMRs require a minimum repertoire of sounds, lights and motions to communicate with humans.

It is important to recognize that the kind of robotic systems that are currently being prepared by multiple operators for multiple purposes and tasks will create a traffic subsystem that overlays and co-mingles with a city’s existing traffic system of bikes, pedestrians, motor vehicles and intersections. Some of these PMRs are designed for a dedicated environment such as sidewalk or airport corridor. Other PMRs can operate in multiple configurations of pedestrianized spaces. In future, it is possible and perhaps likely for a single type/model of PMR to be able to operate competently in any space that a human or motor vehicle can operate. The OM described in this document anticipates that outcome.

In a structured environment such as a factory, warehouse, hospital, mine or agricultural field, it is conceivable that all the mobile robots operating these might be operated by a single FO that manages the movement and behaviours of all devices operating within a closed system.

Increasingly, in these types of operating domains there are a variety of mobile robots from multiple operators. In such cases, there is an overarching, fleet-operator independent, orchestration system that manages (orchestrates) the combined behaviour of these multiple fleets.

Any city or jurisdiction that will permit *multiple fleets* of *independently-scheduled*, *variably-purposed* PMRs with *multiple, competing operators* to operate concurrently in a common public space shared with non-involved humans (bystanders) must deploy centralized, multi-fleet orchestration.

Figure 1 illustrates that multiple fleets of PMRs (machine layer), each with an independent FO (fleet layer) are orchestrated by a unique, regional or jurisdictional orchestration system (orchestration layer). This orchestration layer or system shall be regulated at that jurisdictional level or the jurisdictional level above that, and that regulatory layer whether national, regional, state, or provincial shall be informed by the language, data, and procedural standards of ISO 4448.

Throughout this system formulation, communication is between the OM and the FO. There is no communication between the OM and individual PMRs.

5.6 Orchestration Manager (OM) Overview

Similar to an air or rail traffic control system, multiple fleets of PMRs shall be directed by an OM, a form of ground traffic control system for PMRs. In this scheme, a regional or jurisdictional OM proposes an *offer* (itinerary) within a mapped ODD based on a FO’s request and the FO can choose whether to accept.

A FO trip request (Figure 2) shall consist of:

- Start and end locations
- Preferred arrival time
- Description of the PMR (equipment) to be deployed (including the declaration of any hazardous goods)
- Description of any ODD constraints such as PathSegment or time constraints
    - An example of such constraints would be a FO that is licensed to operate within a specific bounded geography (for example a campus), but is offered a TripPlan that includes PathSegments outside of its licensed operating area.

The equipment description within the trip request allows the OM to match the declared PMR to the permitted parameters along the PathSegments available to offer a route to get the requested PMR to its destination at the requested time. The OM then offers the best available TripPlan that matches the FO's request within the limitations of the mapped ODD, and the OM's traffic management parameters.

The OM attaches to the TripPlan all of the additional trip rules including PMR behavioural rules to be followed during the execution of the TripPlan. If the FO accepts the TripPlan this implies that it has understood and agreed to its use and behavioural rules; otherwise, the TripPlan should be rejected and another requested ("Negotiation" in Figure 2).

5.6.1 Limitations and exceptions

- A match is not guaranteed by the standard; there are ways to maximize matches, but this is out of scope
- The standard assumes accurate equipment declaration from the FO; there is no way to guarantee that a FO will provide this, hence enforcement (out of scope or this standard) may be required
- Enforcement, while expected, may be out of scope for the OM; enforcement is dependent on local intentions, budgets and demands

5.6.1.1 TripPlan negotiation

TripPlan negotiation is appropriate and shall be incorporated in a complete OM system. An example of negotiation might be:

- The FO cannot execute a TripPlan offered by the OM due to a constraint not incorporated within the parameters of the TripPlan. This might be addressed by deployment of an extended TripPlan or another exception format developed in the context of a particular OM and its jurisdiction.

While the method and structure of Trip Plan negotiation is currently out of scope for this standard, there are several ways in which a FO may negotiate a TripPlan. The OM shall provide a necessary and sufficient method to address TripPlan failure, including manual including manual intervention, with the exception of the case in which no legally possible plan is suitable.

- The FO rejects a TripPlan with a reason, and the OM offers a new TripPlan that resolves that reason. This risks an extensive, possibly infinite, loop.
- The operator requests a specific TripPlan, and the OM accepts it or rejects it or offers a close alternative. This also risks no closure.
- The operator rejects a TripPlan with a reason "ODD-Violation" and returns a new request that includes the map constraints of a smaller ODD. This needs more thought.
- The OM permits a form of "fuzzy planning", by offering a small number of reasonably close offers simply permitting the FO choose one.

Note: The OM shall maximize the likelihood of matching the TripPlan offer to the FO's request in order that negotiation can be closed in a very small number of exchanges. This needs more study of the extended TripPlan to ensure an extremely small chance of rejection. Fewer parameters and wider tolerances increase the likelihood of a match.

The contents of trip requests and TripPlans follows in Section 6.5.1

5.7 Map Layer shared in the Regional Stack

The dynamic conditions of active human pathways challenge PMR navigation. This challenge impacts the path **MacroPlanning** (4448-6) aspect of orchestration in that the OM requires a very high assurance that the assignment of each pathway segment to a PMR will be navigable by that PMR during the time for which a TripPlan is intended.

From the OM and Fleet Manager perspective, a PMR (i.e., equipment with a number of physical properties) is described to the OM (equipment declaration, Figure 2) in order that the OM may determine a path match between a map of pathways and the equipment declaration for the purpose of providing a TripPlan that has a near-certain probability of being executable by the PMR as declared.

Any discrepancy between the map and the actual state of the assigned pathway sufficient to lead to **MesoPlanning** or **MicroPlanning** failure (4448-6) on the part of the PMR would mean that a PMR would have to halt during its journey and request a new TripPlan, possibly a TripPlan to return to its start, thereby not completing the intended journey. This is obviously undesirable. Worse, it could mean the PMR becomes trapped, requiring a rescue procedure (4448-16, Machine Breakdown).

The OM map has three critical components:

- **Permanent elements** such as pavement, buildings, curbs, trees, parking meters, fire hydrants, bus shelters, etc. These map elements would change relatively rarely. These permanent elements form the first filter for the match between path segment(s) and a PMR

- **Transient elements** such as street furniture, garbage bins, newspaper boxes, retailers sandwich boards, etc. The location of many of these elements would need to be updated much more frequently, perhaps even hourly. These elements may occasionally create barriers to the journey completion on a pathway segment. Transient elements are amenable to crowdsourcing approaches as described in 4448–13—mapping maintenance for PMRs

- **Behavioural and usage rules** that are local and contextual to the assigned pathway. These are tagged to pathway segments or sometimes at specific locations within pathway segments. Some of these are determined by human planners, some are updated according to realtime conditions.

These three map elements may be represented, updated, and stored in any suitable way by the OM, the FOs and PMRs. This standard assumes that there is a (regional) master map update system managed by the OM, with appropriate elements downloaded by FOs for planning and further distribution to PMRs in TripPlans. (see 4448-xx)

There shall be common methods to represent mapping components so that all FOs have access to an identical understanding of the physical nature of, and expected PMR behaviour on, pathway segments[1]

There shall be methods of updating all elements of these common map layers so that all participants are working concurrently with the same map

There should be methods of using crowdsourced data from multiple PMRs to update appropriate map layers in near-realtime:

- Transient elements may be observed via change detection

[1] [1]See notes 2023.07.13 with Nicolas Paparoditis; [2]Need to decide 2D or 3D. I don't think 4448 should decide this, but should be tech and market driven

- Changes to permanent elements may be flagged by transient elements that do not revert after a given period
- Any suitable change detection method maybe used: image, point cloud, vector, etc
- Every method shall strive for positioning, orientation, and descriptive accuracy
- Every spatial and positioning datum shall have an associated noise (uncertainty) measure
- Changes to permanent elements may incorporate collaboration with public works or facilities management

5.7.1 Map maintenance (move this to 4448-13)

On any human pathway, imagine three information layers.

First is a base-map layer acquired through a high-definition mapping process and sufficient to represent the stationary 2.5D configuration of the pathway (widths, edges, lateral and longitudinal gradients, and all fixed objects within the navigational context of the pathway intended for use by any PMR such as utility poles, trees, street furniture, transit shelters, fire hydrants, and parts of buildings such as stairs protruding into the pathway), the available width of the pedestrian clear way that the PMR is to travel on such that the width and location and of all narrow passages, the width and location of all areas of sufficient width to provide for a place (**WaitingArea, PathwayPullover**) to avoid blocking other traffic, and the location and configuration of all intersection crossings (SPAT, MAP?) and the location and dimensions of their kerb ramps are measured and annotated.

This should be described somewhat more formally. According to Bao et al in *A review of high-definition map creation methods for autonomous driving*, "[t]here is no unique standard HD map structure in the autonomous driving market, however, there are some commonly adopted structures for HD maps…" In 4448, we should not develop any method, but to describe the required elements to be represented, the mapping descriptors (such as bounded position, orientation), the requisite spatial resolution and positioning uncertainty of each. Note that a PMR shall be able to discern its own Journey Microplan (next meter, see 4448-6), hence this map is for the Journey Macroplan (full trip). Hence, this map layer is critical for providing a TripPlan, for a PMR to execute that TripPlan (high-level, correct pathway) and to use that TripPlan in discerning its MesoPlan (tens of meters).

Caution: I have implied that high resolution (cm) is not necessary for macro-planning or meso-planning, and that a PMR must be able to achieve its own high resolution (cm or sub-cm) with its own sensors. One fault in this implication is the case of ground cover, such as snow, water, leaves, sand or certain illumination anomalies, that may make it difficult for a PMR to "see," with its own sensors, edges, cracks, or ramp corners, etc. In such cases, relying on a map with cm accuracy would have value. 4448-5 does not demand a specific accuracy level, but any orchestration system must include accuracy and uncertainty information in its TripPlan distribution and a FO must be prepared to use that information in its ADS, or to provide real time teleoperation when unable to do so.

Second is a transient map layer registered to the base-map layer. This layer includes mid-term (hours, days), transient variations in physical elements. Examples of this include: garbage bins stacked at the curb, a newspaper box moved or tipped over, retail advertising signage standing on the pavement, a tree limb fallen on the pathway, etc. Anything with a permanence of less than days, or perhaps weeks would be measured and annotated in the same way as the base map. The key expectation about this second, transient map layer is that it carries high uncertainty, frequent changes, and considerable cost. It will be impacted by local weather, vandalism, local retail habits, garbage pickup schedules, etc.

There is an opportunity for this second map layer to be updated in near real time by gathering data (image, point-cloud, other?) from participating PMRs as they are executing individual TripPlans. 4448-5 does not require that such "crowdsourcing" be used, but if it is used, here are the critical specifications:

Crowd-sourced data from participating PMRs shall be:

- Used only for map updates (privacy guidance typically provides for no other use unless specifically provided for in public agreement, but privacy guidance differs among countries)

- Provided in as timely fashion as possible (as soon as there is sufficient telecommunication resources to transmit the data to a facility that merges map data); ideally this would be in realtime, but doing this after a trip is completed, or when the PMR is at an appropriate facility satisfies this requirement

- Understood to prevent a subsequent PMR from experiencing navigation difficulties that could have been avoided by incorporating this new information into subsequently generated TripPlans

- Shared without prejudice among all other TripPlans, i.e., participation at the orchestration level is not competitive

- Provided as accurately as possible, and with uncertainty measures included

- Uncoerced. No FO shall be forced to participate.

The standard does not demand participation on the part of FOs.

The map shared by the regional stack shall have the following properties:

- up-to-date within a few minutes lag of the most recent input

6 Rules and Procedures

Everything below will be restructured to be self-contained to avoid referring to 4448-2.

There are several groups of PMR rules:

- Rules for Updating System Components and Parameters
- Rules for General Machine Registration and Certification
- Rules for Pathway Specific Registration and Certification
- Rules for Location-related Registration and Certification
- Rules for Granting and Managing TripPlans
- More (??) TBD)

The forms of each rule type will follow a rigid formulation (with some exceptions).

6.1 Rules for Updating System Components and Parameters

Rules are required to establish and maintain a traffic control and orchestration system. Many rules pertain to modifying system maps, measurements, parameters, schedules, certifications, etc. Each system component has a preferred change lead time. For example, if the weight limit or schedule for permitted traffic volume in a specific location is to be lowered, such a change might need a multi-week lead time — perhaps longer if a given area is to be excluded from use. This is to give logistics planners sufficient notice in the event that they would have reduced access or reduced capacity rules. Most rules would need only a 24- or 48-hour lead time such as changing a speed limit.

Some data elements such as minFriction [4448-2, Table 3] might be updatable every few minutes given a suitably distributed sensor system and hence would demand shorter update cycles. Managing these update cycles are a low frequency form of system tuning. Each system parameter is given a preferred lag time set by the traffic authority. All update parameters have:

- Units, quarter hour
- Default, 192 (48 hours)
- Tolerance, 16 (4 hours)

This subset of rules merely recognizes that there needs to be a period of time between a rule change and its deployment. These periods of time will likely vary within a particular system. Update lag rules are decided by the deploying jurisdiction.

6.1.1 Rules for Updating Maps

An orchestration system map has three defined layers:

- Geographic layer using the Shared Streets Referencing System
- (https://sharedstreets.io/how-the-sharedstreets-referencing-system-works/)
- Basic description and behavioral layer
- [optional] Extended description and behavioral layer

6.1.1.1 Geographic Layer

The geographic layer required for an orchestration system shall be accessible to all participants — there shall be a single map maintained in a way that all participants can read that map in real time. It shall not be possible to have any update lags amongst all the participants. Every FO shall be able to see the identical map that the OM is using to construct TripPlans.

The OM (or its jurisdictional authority) shall be responsible for map updates, and for making sure that all participants are able to read the same map.

This map is constructed according to the Shared Streets Linear Reference System (4448-2):

- Table 7: SSLR Block-face descriptors
- Table 8: SSLR Block-face IDs (SSRID)

Figure 3: Every PathSegment and crosswalk in the network that is accessible to PMRs is given a unique Shared Streets Reference ID (SSRID)

(The definition “Crosswalk” needs an upgrade because crosswalk is also a PathSegment.)

- This geographical map is a connected graph of SSLR descriptors and IDs (Figure 3).
- Crosswalks are added as PathSegments.
- Every PathSegment must be connected to another PathSegment at each end (This requires a stub PathSegment for a cul-de-sac).
- The geometric description internal to a PathSegment is not required
- Start and end positions of a TripPlan are within these mapping segments (excluding crosswalks (will the standard permit an endpoint in a crosswalk? What about a robot that is painting the crosswalk or attending an emergency within the crosswalk. This needs an override mechanism.))
- Most, but not all PathSegments have a connecting crosswalk at either end (need to add this to the SSLR mapping system in 4448-2).

This map update lag, mapUpdateLag, is:

- Units, days
- Default, 7
- Tolerance, 1

This means that the jurisdictional authority must distribute an updated map at least mapUpdateLag days before it goes into effect. With the map distribution, there is a go-live minute. This defaults to 0300 local time. This must be done to ensure that logistics planning is using the map that will be effective at the time of trip deployment.

6.1.1.2 Basic Description and Behavioral Layer

Each block-face has over 40 base properties (for conditions, limitations, and usage rules) according to tables in 4448–2 (current draft). These are:

