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Intelligent transport systems — Public-area Mobile Robots (PMR) and automated pathway devices — Part 6: Journey planning sufficiency for public-area mobile robots

Systèmes de transport intelligents — Robots mobiles pour espaces publics (PMR) et dispositifs de cheminement automatisés — Partie 6: Suffisance de la planification des déplacements pour les robots mobiles des espaces publics

WD

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

The activity of determining, via computation or teleoperation, the optimal movement of a mobile robot is known as *path planning*.

A human example illustrates path planning. Ruth, a pedestrian, intends a 2 km walk to a fixed destination. Ruth plans an overall route to get to the destination, deciding which sidewalks or trails (pathways) to use. This is her macro-plan.

On the way, she would be closely focussed on each “next step” so as not to stumble, slip on ice, or bump into a person or tree. This is her micro-planning, which she is constantly performing even if she is hardly aware.

At a wider proximity radius, Ruth would retain some awareness of what is a several meters around her, especially those things further ahead in order to anticipate anything she needs to prepare for or be ready to avoid. Her perceptual and decision focus would fall off as a function of distance, so that she might be somewhat unconcerned for something that was 40 m away, and likely even less so for something 80 m further on. These example distances would differ if Ruth had decided to jog or take a bike instead of walking. We call this meso-planning.

Public mobile robots have an analogous planning problem. To provide context for PMR journey planning, these three distinct levels of mobility planning are defined: macro-, meso- and micro-planning.

Path-planning is a still-developing field of robotics innovation having many forms and purposes and addressing many objective functions. Typical objective functions are to optimize journey time, cost of journey, energy use, or safety.[1]

In the case of PMRs, there may be additional objective functions. For example, minimizing travel in busy pedestrian areas, avoiding difficult urban terrain, avoiding areas with a high likelihood of vandalism, avoiding dangerous intersections, etc. These might be understood by the path planner or they may be imposed on the path planner as initial conditions. It is very likely that the overall journey planning activity for public mobile robots, would include a high number of objective functions. Automated path planning for PMRs would generally be complex, and would involve multiple levels of planning each with different inputs and computational paradigms.

This document is primarily concerned with **Meso planning**. **Macro planning** is described in 4448–5 as ***TripPlans***, and **Micro planning** is out of scope for 4448. Nonetheless, it is critical to understand where meso planning fits in the planning spectrum.

[1] Sánchez-Ibáñez, J.R., Pérez-del-Pulgar, C.J., García-Cerezo, A. Path Planning for Autonomous Mobile Robots: A Review. Sensors 2021, 21, 7898. https://doi.org/10.3390/s21237898

Intelligent transport systems — Public-area Mobile Robots (PMR) and automated pathway devices — Part 6: Journey planning sufficiency for public-area mobile robots

1 Scope

This document is Part 6 of the 4448 series addressing

TBD

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.

TBD

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/

TBD

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

3.2
block-face
extent of sidewalk/pavement on one side of a street between two consecutive intersections crossing that street

3.3
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]

3.4
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.

3.5
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]

3.6
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

3.7
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.

3.8
teleoperator
A human with navigation oversight and at least some lateral and longitudinal control of a remote vehicle

4 Abbreviations

TBD

ADS	automated driving system
FO	fleet operator
JDR	journey data recorder
ODD	operational design domain
OM	orchestration manager
PMR	public-area mobile robot

5 Journey planning for mobile robots on a public pathway

The nature of unstructured environments that comprise public shared spaces are dynamic and the planned pathway (macro plan map) may be interrupted unexpectedly, say by a large group of pedestrians or a tipped over garbage container. PMRs shall be able to anticipate such interruptions with enough distance (time) to either smoothly alter its course or request an alternate route. We want to avoid a robot navigating into a "trap" only to be required to do a U-turn, or, worse, require rescue. Waiting until the last moment increases the chance of the robot becoming trapped and having a more difficult (costly) time extricating itself from the interruption.

Planning for a complete PMR trip or journey is comprised of three elements. It is not material whether a trip is executed by an ADS, teleoperation, or collaboratively by a mixture.

1. **A Macro plan** (*kilometers*) for a full trip "from A to B." This must be completed to accomplish a mission or to arrive at a location at which a task can be executed. A macro plan is provided once for a trip and is examined constantly while a trip is being executed. As an exception, a new macro plan can be provided in the event that the initial macro plan cannot be executed.

2. **A Meso plan** (*meters*) for a "next chunk" of a trip that a PMR is readily able to anticipate or compute based on its visual field. This must involve sufficient foresight so as not to wander into a trap or a dead end. A Meso plan is constantly refreshed as a PMR is executing its Macro plan.

3. **A Micro plan** (*centimeters*) for the next short distance that must be navigated so as not to hit any obstacles or deviate from its permitted pathway. This distance must be greater than its braking distance and must be great enough to be able to execute smooth, rather than jerky, movements. A Micro plan is refreshed many times per second as a PMR is executes its Meso plan.

This document is primarily concerned with meso planning. Macro planning is described in 4448–5 as TripPlans, and micro planning is out of scope for 4448. Nonetheless, it is critical to understand where meso planning fits in the planning spectrum.

5.1 Location-related perception for a PMR

Sensors and other components used for environmental awareness are vital for a PMR to detect its surroundings. These components and their integrated software facilitate situational awareness in order to maintain safe operation.

This part of the standard is concerned with ensuring PMR situational awareness and response capability (an issue of software and effectors); it is agnostic about the number or types of sensors.

A PMR shall have:

- 360° field of view for full-surround awareness from the ground to a height of 2m; an acceptable blindspot shall be the ground directly beneath the PMR plus a 20 cm perimeter beyond that
  - A blindspot so described means that if a PMR becomes entangled in some way or slips into a damaged area of a pathway, it will not be able to 'see' its circumstance unless it has captured a prior image of the problem
- minimum visual detection bubble (ellipsoid)
  - forward view: 12 sec to anticipate and plan (This PMR reports identifying objects at 60m (200ft): https://www.wevolver.com/specs/starship-technologies-starship-robot)
  - backward view: 10 sec to cover a full arterial intersection width at 6 kph in case of a need to reverse, protect or record

- sideways view: 5 sec to anticipate cross traffic while moving in a crosswalk; this allows a PMR to avoid motor vehicles that might overshoot an intersection

Some of the reasons that a PMR must have a 360° view are:

- To execute a U-turn a PMR must understand what is behind it prior to micro planning. This is especially important if a U-turn will be executed within a crosswalk.
- A PMR that is being followed too closely by another entity (pedestrian, jogger, PMR, etc.) needs to be able to provide a warning ("social alarm" sound). An example of this is a robot that may be stopped for a traffic reason, and a distracted pedestrian is about to walk into it from behind.
- Any PMR subject to vandalism would be at a disadvantage if it had a rear-facing blind spot.

~~Sensors adopted for this task shall be deployed to meet the following criteria:~~ (move to 4448-16)

- ~~Sensor units shall continue to function if a PMR is tipped. (UL 3300 7.3)~~
    - ~~An exception to this is the sensor(s) on the side on which a PMR has fallen~~
    - ~~What about sensors pointing up in the event of being tipped?~~
    - ~~The teleoperation assist system shall correct image orientation to maximize teleoperator comprehension~~
- ~~Sensors shall be self-checkable or remotely checkable by a teleoperator in real time~~
- ~~Sensors should be easily removable and replaceable for rapid on-site repair (UL 3300 8.7) This ensures easy, less disruptive, on-street repair~~

5.2 Macro planning for PMR journeys

Macro planning for a PMR journey or task is determined by a fleet operator prior to the beginning of a task. This activity would be sufficient to provide a rough plan for the entire task-journey on the assumption that finer details (micro plan) would be sensed and computed as the journey unfolds. For example, the macro plan for a snow ploughing task would include the time and route to re-locate from a starting position (A), to the place where snow is to be ploughed (B), the activity of ploughing the snow, then returning (A), or proceeding to a new location (B'). The ISO 4448 standard is silent in regard to the *activity* of macro planning, but assumes that such planning must occur (4448-5) and that there must be specific inputs available to the process (e.g., 4448–10, –11, –13). The data source for macro planning may be a fleet operator (FO) who operates a fleet within an ODD, or it may originate with a regional orchestration manager (OM) that provides a TripPlan on request to the fleet operator for the target PMR (4448-5).

5.3 Micro planning for PMR journeys

Micro planning for a PMR is the close-range, second-by-second or cm-by-cm planning required during a journey. This is central to a mobile robot's intelligence in addition to whatever specialized task a robot may undertake during or at the end of a journey. It is the part of the robot's activity that a teleoperator would be overseeing or possibly assisting as a PMR journey unfolds. In general, micro-planning during a package delivery journey might include continuous planning of the next tens or hundreds of centimeters, depending on the ODD context. This standard is silent in regard to the *activity* of micro planning, except that journey plans be executed in a safe, structured and transparent manner (4448-7, -8, -9, -16). This standard recognizes that no PMR can proceed without micro-planning specific to the task, the ODD, and the PMR design —all of which are out of scope for 4448.

5.4 Planning for mobile robots in unstructured environments

Inside a factory or a warehouse, the paired roles of macro planning (fleet orchestration) and micro planning (path planning for IMR or AMR mobility) are generally designed to leave no operating gap. Such structured ODDs are fully understood (mapped in detail) by the macro planner, diligently managed by the business operator to remain spatially structured and fully recognizable (computable) by the micro planner (software).

This is not the case in unstructured, public, pedestrianized spaces for PMR journeys that easily extend over two or three km and where there may be significant gaps between macro and micro planning. Unstructured navigation spaces from a PMR perspective may change rapidly, may differ from hour to hour, and may only approximately match mapped expectations. A tree may have just fallen, a house may have caught fire, an arrest might be in progress, a small crowd may have gathered around a bus stop or a store front, a crash may have occurred at a crosswalk, several dozen children from a school may entering the sidewalk in a surge beside the school, a UPS van may have parked on the pavement, or someone may be walking behind the PMR to play a prank (vandalism). These are all things that may happen without notice and within the duration and space of a macro plan, but occur outside the close range of micro planning. Controlled factory or warehouse spaces would not admit these as common occurrences. The same cannot be said of public, shared-space environments.

When unmapped, unexpected circumstances occur within a PMR ODD, a near-sighted PMR would more readily move into circumstances that may develop in to a barrier. Having insufficient advanced awareness, a near-sighted PMR may have to reverse or find itself trapped. Because the micro planning range may be over-constrained, the PMR may find itself entangled in unplanned situations among unappreciative human bystanders. Such situations can precipitate edge cases.

Another common problem behaviour inherited from near-sighted micro planning in unstructured environments is the sudden path adjustments and recoveries which exhibit as rapid micro changes in PMR acceleration (|jerk|). A related behaviour is exhibited by pedestrians, who are looking at a phone or other distraction, as they approach another pedestrian and suddenly find themselves jumping aside or oscillating side-to-side to negotiate passage. Encountering this micro-acceleration (|jerk|) behaviour in a PMR that is moving in front of a pedestrian who is attempting to overtake that PMR, or in a PMR that is approaching and about to pass a pedestrian is confusing and disconcerting.

How can a PMR afford the necessary and sufficient understanding of its surrounding environment to avoid journey traps while flowing smoothly — MIN(AVG(ABS(jerk))) — among the dynamic obstacles and humans that share its ODD? The answer to this question is currently poorly resolved, differs among ODD circumstances and according to PMR speed.

5.5 Meso planning for PMRs

Nothing in this sub-clause describes how a PMR is to perform meso planning; rather this clause specifies only that a PMR shall be enabled way of sensors, software and or teleoperation to be able to carry out meso planning, and what the range and impact of that planning, shall be. The perception of any threats to the PMR macro plan that may be discovered through the meso planning process shall be carried out automatically or via a teleoperator or in cooperation between the two.

In between the macro and micro levels of journey planning for PMRs is meso-planning. In regard to PMRs moving among pedestrians and other dynamic, active transportation users in shared landscapes such as sidewalks, parking lots, crosswalks, parks and airports, it is critical that a PMR is able to make approximate plans for its surrounding area by anticipating further ahead in time and distance than is required for micro planning. This is important for things such as:

- Planning the complete crosswalk traversal of a multilane roadway
- Estimating the probability that the PMR can complete the remainder of a pathway segment (4448-2) immediately in front of it (tens of meters) without requesting a change in macro planning (a new TripPlan)
- Awareness of a sufficient distance forward to assess that a PMR is approaching a police, fire or medical emergency with enough notice to plan avoidance, such as asking for a new TripPlan
- Recognizing that something to be avoided is happening a few meters to the rear or the side (one case is a motor vehicle that may not to be stopping in time prior to a crosswalk boundary)

- General awareness of what is to the side or to the rear so that a PMR can prepare a defensive response if necessary

Meso planning does not plan micro responses; meso planning operates at a higher level than micro planning, but at a lower level than macro planning.

Meso planning shall:

- assess multiple seconds and multiple meters into the future, depending on task, speed, and ODD (Table 1)
- ensure that the PMR will be highly unlikely (threshold?) to find itself trapped on the way to this intermediate place (note: being trapped is not the same as being unable to complete)

Meso planning shall answer two questions:

- How likely (threshold?) will the PMR be able to continue on its macro plan when it reaches this intermediate place?
- How likely (threshold?) will the PMR be able to determine and execute a micro plan when it reaches this intermediate place? (this second question is redundant; by definition a PMR must be able to determine and execute a continuous micro plan in order to complete a macro plan)

A PMR shall have sufficient sensors to perceive all threats to its macro plan within a 360° surround to estimate with 99% (?) certainty that it can continue its macro plan within its meso planning radii.

A PMR shall have sufficient software and/or be assigned sufficient teleoperator bandwidth and attention to continuously assess potential threats within the appropriate radii as defined in Table 1. The intention is that the collaboration between PMR software and teleoperator is sufficient to ensure that the PMR shall be unlikely to become stranded or trapped or behave in ways that confuse, alarm, startle or disrupt bystander mobility.

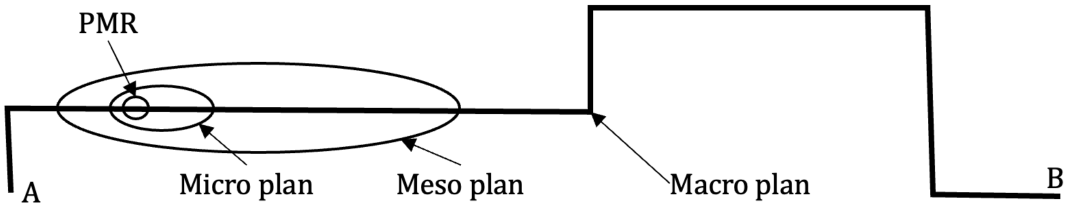

Figure 1: How the three PMR planning levels are related

Figure 1 illustrates PMR travel along a macro plan from A toward B. The radius of micro and meso plans are shown as ellipses (radii) with the major axes along the direction of travel, and the PMR situated toward the relative lagging foci of the ellipses. Compare this to driving an automobile—the majority of driver attention is forward, with much less behind and to the sides. While, this illustration shows nothing novel about following a path (macro plan) current meso planning for PMRs is often poor or ineffective.

The measures in **Table 1** pertain to the ability of a PMR and/or its teleoperator to understand its near-surroundings. This local awareness must be sufficient to permit a PMR to make near-range crash avoidance decisions (micro-planning), mid-range navigational decisions (meso-planning), and to execute an alarm immediately prior to a mishap such as pending fear of tipping or other vandalism.

Table 1 is designed so that a PMR is able to detect barriers or threats to the completion of the current macro plan (Trip Plan) with sufficient time (at sufficient distance) for a PMR to request a new macro plan in order to avoid a delay or trap.[2] Within this same sensory radius (or generally much less than), the PMR must also be able to adjust its current micro plan to minimize |jerk|.[3] There shall be no radial blind spots in the ellipse so described, although there may be a small blind area at the base of the PMR depending on how cameras are mounted. (See **Figure 2**).

Table 1: The meso planning capability of a PMR

Capability	Time horizon	On Walkway 6kph = 1.7 m/s	On Bikeway 25kph = 7 m/s	On Roadway 40kph = 11.1 m/s
Forward awareness	10-12 sec	17-21 m	70-85 m	111-133m
Side awareness	4-5 sec	7-9 m	28-35 m	45-56 m
Rear awareness	8-10 sec	14-17 m	56-70 m	88-111 m

Any PMR perception system(s) shall be tested to ensure that objects can be identified.

Any PMR effector system shall be tested to ensure that obstacles can be avoided.[4]

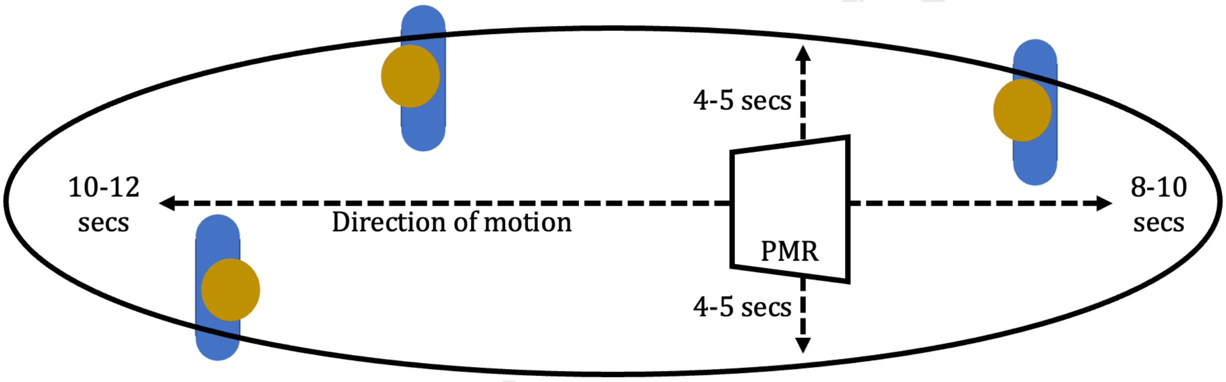

Figure 2: The surround-awareness ellipse within which a PMR (or its teleoperator) is able to detect, interpret, and determine the presence of objects and events for micro-planning, meso-planning, macro-plan replacement, self-protection and recording in regard to intersection safety or vandalism.[5] (See Table 1)

The test to determine whether a PMR has sufficient configuration of sensors, software, and teleoperator attention for meso planning can be determined by:

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2 The numbers proposed need some evidentiary backup before they can be set as a standard. Until they are properly defended, they should to be set as variables. *(See the Grush-Kretz conversation in the Appendix…)*

3 For smooth flow among pedestrians

4 Physical testing or computer simulation? Needs more investigation.

5 The “surround-awareness ellipse” or the “navigation confidence envelope” in the PRIOR VERSION of the figure above, caused considerable discussion at our winter roundtable. Concerns included: [1] over specifying the ability of the robot, [2] many things would occlude the view of the robot sensors (buildings, parked cars), [3] little need to see behind, [4] some bicycles in bikelanes go very fast, hence this should be specified in terms of response *time* instead of *distance*, [5] it won’t be possible to have zero blind spots. This update addresses many of these comments. **Blind-spots** will depend on how sensors are mounted. It would be easy for the PMR to have a significant blind-spot at its base & unable to see at its wheels or feet. This would make it vulnerable to being ensnared maliciously. It was understood a robot would have a blind-spot equivalent to at least its footprint or more. One suggestion was 1 m beyond the footprint. That was not acceptable, because small children like to run to robots, to engage, and such a child, would very quickly be within the blind-spot (dangerous), so an extension of 5 cm beyond the footprint was suggested… There was considerable discussion of the importance of shrinking any blind-spot. The blind-spot aspect is undecided.

- the average |jerk| recorded by the JDR (how to determine how low this should be ?)[6]
- the frequency of a PMR being caught by surprise, any circumstance that requires high |jerk| to recover or avoid mishap, bystander complaint, sounding of a last-second warning alarm, a PMR being trapped (unable to U-turn), or________.

The specification is intended for safe navigation, and bystander comfort; it does not consider the current state of technology or preferred cost expectations. The specification relies on the ability of a fleet operator to provide a teleoperator to satisfy any meso planning requirement that is not reliably automated.

In addition to confirming the viability of forward planning in completion of a macro plan, a PMR may require:

- a plan for a U-turn (the worst case for which would be in a road crossing); having some understanding of what is unfolding behind the PMR during such a manoeuvre would be invaluable; extra seconds could save bystander lives
- Rearward and side-visibility to anticipate vandalism, wayward vehicles or pedestrians

6 There are innumerable online videos (social media, YouTube), showing a PMR approaching a pedestrian and making sudden micro-direction changes (|jerk|) in the final meter before passing that pedestrian. This has the effect of confusing or alarming the pedestrian. Such last-second direction changes amount to delayed gestural communication. If the pedestrian is distracted, (looking at a phone), then there is a risk that the PMR would startle such a pedestrian by turning aside only at the last moment.

6 Appendix – Conversation about pedestrian anticipation

Here is a LinkedIn conversation between Bern Grush and Tobias Kretz, PTV — Week of 2023 03 06

(I'm not sure how to document this or if I should, but it adds some weight to the meso planning table.

BG: I am trying to understand the buffer distance approaching sighted pedestrians need to be visually aware to avoid oscillating back-and-forth while negotiating opposite-direction passage on walkway. (Relates to cell phone distraction). You seem to understand this.

TK: You mean in reality or in a particular model of pedestrian dynamics?

BG: My problem is "in reality", but I am drafting an ISO standard, so I have to think about "models". I am trying to define the minimum sensor-perception envelope required for a public-area mobile robot (PMR) moving in pedestrianized space. (Common examples of PMRs are delivery or surveillance robots moving on sidewalks, but there are many more types and places than those.)

Industrial Mobile Robots (IMR) operating in factories and warehouses have two key levels of planning. Macro planning sets out the general plan for an entire journey, including any task embedded in that journey ("From A, go to B, pick up object X, take it to C, return to A"). Micro planning deals with the close-up, cm-x-cm, or metre-x-metre, execution of that journey ("there is an unplanned object 600 cm ahead, turn 19° to the right to go around it").

In structured environments (factory, warehouse, farm field) careful pairing of macro and micro planning are generally sufficient for a navigation problem-solving approach. Once you move a mobile robot into an unstructured space, such as sidewalk, bike lane, or parking lot, a robot with a detailed micro planning capability that extends only a metre or two, is extremely nearsighted, and micro-planning at longer ranges becomes explosively expensive very quickly.

It can very easily occur that something happening 10-20 m ahead might require a modified macro plan, but the PMR won't determine that, until it is much closer, and this can lead to "traps" in which a PMR comes so close to a barrier, that it becomes very hard for it to reverse course or otherwise extract itself from the problem. A robot can become stranded. (e.g., it becomes entangled in a group of 20 people waiting at a bus stop.)

What I'm looking to define are the requirements for a level of planning (meso planning) that permits a PMR to begin rough planning out in front of its micro plan, far enough ahead to dramatically reduce the probability of becoming trapped, but not so far out (and also without fine detail), as to become computationally unaffordable. Basically, we want the PMR to estimate far enough ahead to confirm a very high likelihood that the current macro plan remains sustainable. The answer is related, of course, to speed, visibility, the ability of the PMR to change course, and several others.

So, I turned to you a suggest a minimum distance related to the distance that an able-bodied, fully-sighted, attentive, adult pedestrian, without children in hand, would use in anticipating oncoming pedestrian traffic on a sidewalk, without bicycles, on a clear day, so that said pedestrian would never find herself having to oscillate left and right, trying to negotiate passage on a narrow sidewalk? Would you venture a proposed distance? Everything goes up from there!

By the way, the distance used today by our primitive PMRs is likely less than whatever number you will propose and this is causing difficulties for pedestrians trying to anticipate what a PMR is about to do AND it causes a lot of non-zero jerk in PMR travel paths. Jerk should be near zero during PMR flow among proximate pedestrians.

TK: It's an interesting question. For you to estimate the reliability of my answer: I have actually thought about variants of it for years, but it has not had a high relevance in my work of developing pedestrian simulation software.

The first value I would say comes not from my professional experience, but from my experience as an amateur runner who practiced for years in a group. At some point I became aware how large the distance is at which the group reorganises its internal distribution in case that another group is approaching in opposite direction or if it appears that another group must be overtaken. It's almost "as soon as they get into sight", 30, 40, 50 meters.

On the other hand, at a crowded festival no one reacts to someone that far away, as it means that one has to react to hundreds of people. As a variant: if you see a family member or a friend 100 m away on an empty field or hill, you would recognise them, if they are part of a crowd (but still visible in geometric terms) there is only a small chance. In terms of photons which reach the eye, it's the same amount of information in both situations. However, obviously, we are not able to scan for a familiar person in a crowd of strangers as effectively as we can when they are in an inanimate environment. People occlude people from the mind.

In our simulation software we have two cut-offs for interaction between pedestrians: the number of people taken into account and the distance. The default values are 8 people and 15 meters (for reasons of computational efficiency, these are guaranteed minimum values for cut offs. It can happen, that more than 8 people at a larger distance than 15 m mutually trigger a change of speed). This rule of 15 m applies only to pedestrian-pedestrian interaction. Navigation planning always reaches to the next destination, i.e., in our simulation a pedestrian knows in each moment the direction of the shortest path (considering static obstacles, and as - as a computationally costly option - also crowded regions as "soft obstacles" which means that there can be very far-reaching interactions between people in an aggregated - "meso" - form) to its next destination, no matter how far away it is. This means that they never can get trapped in dead-ends formed from static obstacles. A second annotation is that there can be settings where the 15 m are not sufficient and a user complains that pedestrians bump into each other. I'm not sure, if this has a relevance for reality, because the pedestrians in the simulation are quite dumb and real people in the same situation would have found a way to resolve this. Therefore, I would add: the smarter the conflict resolution algorithm is, the shorter can be the awareness distance.

The "people occlude people from the mind" thought has led to a publication:
https://www.researchgate.net/publication/310606375

The navigation method is described here: https://www.researchgate.net/publication/51916028