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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

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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

Path planning incorporates the activity of determining, via computation or teleoperation, the optimal movement of a mobile robot.

To illustrate an example of path planning, Ruth, a pedestrian, intends a 2 km walk to a park. As she plans a route to this destination, she decides which pathways (sidewalks, trails, etc.) to use. This is her macro-plan.

On her way, Ruth will focus on each step so as not to stumble on uneven pavement, slip on ice, or bump into anything. She would be constantly performing this watchfulness in real-time, even as she is likely unconscious of her effort. We call this activity micro-planning.

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

Path-planning. Public-area mobile robots (PMRs) require an analogous planning regime. This document recognizes three distinct levels of PMR path planning: macro-planning, meso-planning, 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, and safety. [1]

Structured 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. There is often no need for meso-planning, since structured ODDs are fully understood (mapped in detail) by the macro-planner and managed by the business operator to remain spatially structured and fully recognizable (computable) by the micro-planner (software).

Unstructured environments. In less structured public spaces—especially outdoor pedestrian environments—PMR journeys easily extend to two or three km. In such cases, there may be significant anticipatory gaps between macro and micro-planning. Such navigation spaces 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 engage in vandalism or a prank. 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. While controlled factory or warehouse spaces would not admit these as common occurrences, the same cannot be assumed for public environments where PMRs mix with bystanders.

When unmapped, unexpected circumstances occur within a PMR ODD, a near-sighted PMR could readily move into circumstances that represent a barrier. Having insufficient advanced awareness, a myopic PMR may have to reverse or find itself stuck, unable to proceed. If its micro-planning range over-limited, a PMR may more easily find itself entangled in unplanned situations among unappreciative human bystanders. Such situations can precipitate unanticipated edge cases.

A common PMR behaviour exacerbated by 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 similar behaviour is exhibited by a pedestrian as they approach another pedestrian only to find themselves jumping aside or oscillating side-to-side to negotiate passage. Encountering this jerky 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 for bystanders.

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

In addition to optimizing journey costs (time, distance, energy, safety), PMRs often need to weigh additional objective functions—e.g., avoiding busy pedestrian areas, difficult urban terrain, areas with a high likelihood of vandalism, or dangerous intersections. These might be understood by automated or human path planners or they may be imposed on the path planner as initial conditions. It is very likely that the total journey planning activity for PMRs, would include a high number of objective functions. Automated path planning for PMRs would generally be complex. The levels of path planning recognized in this document each involve different inputs and computational paradigms:

- Macro-planning describes a full plan "from A to B." This includes sufficient information for a PMR, its human overseer, and/or its teleoperator to complete a trip or task on the scale of kilometers or a large task-area. Aspects of macro-planning are included in this document as well as in other parts of the 4448 series.
- Micro-planning incorporates realtime navigation decisions at sub-second and sub-meter scale as a micro-plan is being executed. Micro-planning is critical to support safe, standardized behaviour on public pathways. Aspects of micro-planning are included in this document as well as in other parts of the 4448 series.
- Meso-planning is critical to establish a high likelihood of a PMR being able to anticipate sufficiently far in distance and time to anticipate any need to adjust or abandon its macro-plan. Meso-planning insures a PMR is far-sighted as a way to help avoid unintended costs. Meso-planning is the principal concern of this document.

A note on research that models pedestrian navigation

Researchers have developed models to describe pedestrian motion, "speed-density relations," and "social force models" that apply to public pedestrian travel behavior. [2] [3] These can be helpful in modelling the dynamics of PMRs moving among (somewhat) free-flowing pedestrians. What is apparent from this research is that pedestrians anticipate a modest distance (time) projected along their intended travel path. This will have impacts on travel efficiency, social interactions and near-to-mid-distance travel planning.

While it is not clear how directly this research applies to small human-operated micromobility devices, bicycles, etc., as they mix with pedestrians, this literature can sensitize the developer of navigation software for PMRs, and that understanding would be mediated by the intended ODD of the PMR design. Specifically, it will matter whether a PMR is intended for walkways, bikeways, hallways, or roadways, and how many PMRs can be anticipated to be travelling in proximate formations.

In an informal, unpublished description from one of these researchers, Tobias Kretz, it was observed that "from experience as an amateur runner, I became aware how large the distance is at which a running group reorganizes its internal distribution when another group is approaching in the opposite direction or if it appears that another group must be overtaken. It's almost 'as soon as they get into sight' at 30, 40, or 50 meters." This comment strengthens an understanding or intuition that pedestrians (in this case joggers) plan a few tens of meters in advance of their current position. This is a common experience. It is this sense of medium distance, anticipatory planning that motivates the standard description of PMR meso-planning in this document.

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 addresses the purpose, definition, sensor capability, and situational awareness metrics for the mid-distance risk anticipation activity of a public-area mobile robot (PMR) while executing (navigating) a trip.

NOTE This planning activity is called meso-planning and bridges the micro-planning (close-up meter-by-meter navigation decisions) and macro-planning (full-trip planning/mapping) aspects of PMR navigation.

NOTE The adequacy and architecture of software (perception stack) required to execute planning and control PMR effectors is out of scope.

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.

ISO/TS 14812, *Intelligent transport systems — Vocabulary*

ISO/TR 4448-1, *Intelligent transport systems — Public-area mobile robots*

3 Terms and definitions

For the purposes of this document, the terms and definitions in ISO/TS 14812:2022 and ISO/TR 4448-1:202X 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
pathway
use TR 4448-1

3.2
public-area mobile robot
PMR
use TR 4448-1

3.3
teleoperator
use TR 4448-1

4 Abbreviations

ADS	automated driving system
AMR	automated mobile robot
IMR	industrial mobile robot
ODD	operational design domain
PMR	public-area mobile robot

5 Journey planning for mobile robots on a public pathway

5.1 Overview

Journey planning for a complete PMR journey or trip is comprised of three elements. For these three elements, it is not material whether a trip is navigated by an ADS, teleoperation, or a collaboration between ADS and teleoperation.

1. **A macro-plan** (*kilometers*) describes 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 based on foreknowledge in the form of pathway and terrain descriptions, and is typically provided prior to a trip start to be used as the base navigation reference (map) during trip or task execution. As an exception, a new macro-plan can be provided by the PMR operator or PMR oversight system in the event the initial macro-plan cannot be executed by the PMR.

2. **A meso-plan** (tens of *meters*) is constructed in real-time for the next mid-distance segment of a trip (macro-plan). This is done from the perspective of what a PMR is able to anticipate or compute based on the reach of its sensors. This must provide sufficient foresight so as not to wander into a hazard or dead-end from which its macro-plan must be suspended. A meso-plan is continuously refreshed as a PMR is micro-planning to execute its macro-plan. The activity of meso-planning may be executed by instructions within a PMR's ADS, by its human overseer or teleoperator, or by a collaboration of these.

3. **A micro-plan** (*centimeters*) is determined for the PMR's next short distance that must be navigated so as not to hit any obstacles or deviate from its planned pathway (macro-plan). This distance must be greater than the PMR's braking distance and must be sufficient to guide smooth, rather than jerky (significant third derivative) movements. A micro-plan may be refreshed many times per second as a PMR moves.

The environments that comprise public, shared, active-transportation spaces are often unstructured and almost always dynamic. A planned pathway (macro-plan map) may be interrupted unexpectedly by a tipped over garbage container, a large group of pedestrians at a transit stop, or an emergency such as a fire, medical, or police action. A PMR shall be able to anticipate such interruptions within enough distance (time) to either smoothly alter its course (micro-plan) or request an alternate route (macro-plan). Such anticipation may rely on the PMR's ADS capability, its human overseer or teleoperator, or a collaboration among these.

A PMR's navigation systems shall minimize the likelihood of navigating into a hazard requiring it to do a U-turn in an unanticipated, crowded or difficult circumstance or, worse, require rescue. Waiting until too late to request a course change (macro-plan) increases the chance of a PMR becoming stuck and having a more difficult time (cost) extricating itself (meso-plan, micro-plan, teleoperation, or rescue) from the interruption.

NOTE The identification of meso-planning and micro-planning as two descriptions implies nothing about the architecture of their integration—such as their independence or contiguity—within the perception stack of a navigation system. This identification merely recognizes that the time and spatial resolution of decisions and the immediacy of actions may differ at these two scales. For example, micro-planning generally has immediate impact on the disposition of PMR effectors, while meso-planning generally has impact on higher-order planning such as whether the current macro-plan needs an alternative. How that difference is managed by a PMR is outside the scope of this document.

5.2 Sensor capability for a PMR

Sensors and other components used for spatial or situational awareness are vital for a PMR to be competent within its surroundings. These elements and their integration facilitate situational awareness to maintain safe operation.

This document is concerned with ensuring PMR situational awareness and capability so that its software, effectors and remote overseer is able to execute safety and assuredly. It is agnostic regarding the number or types of sensors and the nature of human remote intervention or oversight.

A PMR shall have:

- A 360° ellipsoidal field of view for full-surround awareness from the ground to a height of 3m (?); the only acceptable blind spot shall be the ground directly beneath the PMR plus a 10 cm (?) expanded perimeter beyond that from a bird's-eye view.
    - NOTE A blind spot so described implies that if a PMR becomes entangled in some way or slips into a damaged area of a pathway, it may not be able to 'see' the circumstance around its wheels, legs, or tracks unless it has captured a prior image of the circumstance and possesses a capability of object continuity—an uncommon capability for most mobile robots.
    - NOTE A blind spot so described would make it impossible for a small child or a midsize dog to come close enough to the PMR as to be hidden from view of its vision sensors.
    - NOTE A blind spot beneath the PMR has implications for vandalism as well as PMR seizure during an enforcement action.
    - NOTE Bystanders, buildings, parked cars, etc. may occlude the field of view of PMR sensors.
- A minimum visual field of view ellipsoid with:
    - A forward view of 12 sec relative to the expected speed of the PMR into the pathway future of its the macro-plan to anticipate and plan; [4]
    - A backward view of 10 sec to fully view an arterial traffic intersection of six lane-widths at 6 kph in case of a need to reverse, protect or record;
        - NOTE Six lane-widths assumes two through lanes in each direction (=4), plus one right- and one left-turn storage lane (=total,6). Wider roadway crossings shall require additional capabilities; (Assume average lane width = 3m)

- Left- and right-side views of 5 sec to anticipate cross traffic while moving in a crosswalk; this is to allow a PMR to be fully aware of bystander activity on either side and to avoid motor vehicles that overshoot while approaching an intersection.
- NOTE Operational detection implies sufficient sensor depth of field and resolution, as well as ADS capability or remote overseer attention; this document only specifies the sensor range and acuity sufficient for situational awareness. ADS operation and remote oversight are out of scope.

A PMR or its human overseer shall be able to interpret the obstacles and events within its 360° field of view:

- To execute a U-turn a PMR must perceive what is behind it prior to micro-planning a U-turn. This is especially important if a U-turn will be executed within a crosswalk;
- A PMR that is being followed closely by another entity such as a pedestrian, jogger, or other PMR, shall be able to move aside or provide a warning ("social alarm") sound and light sequence. For example, a PMR may be stopped or slowed for a navigation or task reason and a distracted pedestrian appears likely to walk into it from behind or side;
- A PMR subject to vandalism would be at a disadvantage if it had a rear-facing blind spot;
  - NOTE PMR vandalism implies potential risks for bystanders, as well as for the PMR itself.

5.3 Macro-planning for PMR journeys

Macro-planning for a PMR journey or task is determined by a human fleet operator or route-planning software. A macro-plan is typically initiated prior to the beginning of a journey or task, or it can be modified during execution. The purpose of a macro-plan is to provide an instruction for the entire task/journey on the assumption that higher resolution details (micro-plan) would be sensed and determined 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 at (B), then returning to (A), or proceeding to a new location (B').

This document is silent in regard to the formation and management of macro-plans, but assumes that such planning occurs and that there will be specific inputs available to that process (suitable pathway, appropriate environmental conditions, sufficiently accurate map, etc.). The data source for macro-planning can be a fleet operator operating a fleet within an ODD, or an orchestration system that provides trip plans (macro-plans) within a ground-control system in response to the request of a fleet operator.

5.4 Micro-planning for PMR journeys

Micro-planning for a PMR is the sub-second, sub-meter real-time planning required during a journey. This is central to a mobile robot's capability 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 an operator intended to automate or a remote operator would be overseeing or assisting as a PMR journey unfolds. For example, micro-planning during a package delivery journey might include continuous planning of the next tens or hundreds of centimeters, depending on the nature of its operation (automated or teleoperated), its field of view, and its ODD context. This document is silent in regard to the method of micro-planning, except that journey plans shall be executed in a safe and structured manner and that the resulting behaviour shall be understood by bystanders so that they will not be surprised, alarmed, or confused. This document 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 this document.

5.5 Meso-planning for PMR journeys

Meso-planning occurs between the macro-planning (clause 5.3) and micro-planning (clause 5.4) activities of journey planning for PMRs. As PMRs move among pedestrians and other dynamic, active transportation users in shared public spaces such as sidewalks, parking lots, crosswalks, parks, hospitals, airports, etc. A PMR shall be able to confirm near-range plans by anticipating risks further ahead in time and distance than is required for micro-planning.

EXAMPLE It is likely inappropriate for a PMR to approach a large group of bystanders waiting for a bus on the assumption that it can micro-plan its way through when it gets there. Should this PMR wait a given distance away until this group of bystanders departs?

EXAMPLE It is likely inappropriate for a PMR to approach an emergency medical team that is evacuating a heart patient, on the assumption that it can find a way through. Should this PMR request an alternate route from its fleet operator?

The perception of any threat to a PMR's macro-plan that can be discovered through the meso-planning process shall be carried out either automatically, via a remote human operator, or via a collaboration between the two.

NOTE Nothing in this clause describes the method of performing meso-planning; rather this clause specifies that a PMR shall be enabled by way of sensors, software and/or teleoperation to carry out meso-planning, and what the range and outcome of that planning shall achieve.

Meso-planning shall be capable of:

- Ensuring the PMR can complete the traversal of a multilane roadway prior to commencing the crossing;
- Estimating the probability a PMR can safely complete the pathway segment immediately in front of it (multiple seconds, Table 1) without requesting a new macro-plan (alternate route);
- Awareness of a sufficient distance forward to assess that a PMR is approaching a police, fire or medical emergency or an infrastructural change unexpected in its macro-plan with enough notice to plan avoidance, such as acquiring a new macro-plan;
- Recognizing that something to be avoided is happening to its rear (e.g., a distracted pedestrian is so close that it might crash into or be intent on vandalizing the PMR);
- Recognizing that something to be avoided is happening a few meters to the side (e.g., a motor vehicle may be entering beyond the crosswalk perimeter), and
- Sufficient time and distance awareness of what is to its side or rear so that a PMR can prepare a defensive response or issue a timely emergency warning or report, as appropriate.

Meso-planning operates at a longer distance and lower resolution than micro-planning, and at a shorter distance and greater resolution than macro-planning. Meso-planning does not need to plan micro responses; it only needs to determine the likelihood of being able to generate an execute micro-plans.

Meso-planning shall always be able to continuously and reliably determine:

- Whether its surrounding space (Figure 2) holds any threat to its macro-plan;

- NOTE it is likely impractical to describe a single threshold to assess such threats. Methods and thresholds for threat assessment will be ODD dependent. This document defines the space within which it shall be possible to assess such threats.

- Threat assessments multiple seconds and meters into the future, depending on task, speed, and ODD (Table 1);
- How likely the PMR will be able to execute its macro-plan when it reaches this anticipated, intermediate place?
- How likely the PMR will be able to determine a successful micro-plan when it reaches this intermediate place?
    - NOTE Whether a PMR can execute its macro-plan or determine a successful micro-plan may result in the same outcome, but the issues and determinations are distinct.

A PMR shall have:

- Sufficient sensors, supported by software and/or remote operator support, to perceive all threats to its macro-plan within a 360° surround (Figure 2) to estimate with certainty that it can execute its macro-plan within its meso-planning radius (ellipse).
    - NOTE The interpretation of "sufficient sensors" differs according to the task and ODD, and may include visual, auditory, temperature, dust, etc. The sensors needed for a floor scrubbing PMR differ from those needed for a security PMR used to help seniors and children to cross roadways. For example, any PMR that crosses roadways must be alert to emergency sirens.
- Sufficiently capable software and/or be assigned sufficient attention from a remote operator to continuously assess potential threats within the meso-planning radius as defined in Table 1. The collaboration between PMR software and remote overseer shall be sufficient to ensure that the PMR shall be highly unlikely to become stranded, blocked or behave in ways that bring harm, confusion, alarm, startle or disruption to bystanders.
    - NOTE Interpretations of "sufficiently capable" and "highly unlikely" will be ODD-determined and evolve. Currently, there is no reliable description of how to determine thresholds for these measures. It shall be possible for the provider (manufacturer or operator) of the PMR(s) to provide meaningful descriptions for these, within the target ODD. It shall also be possible for the consumer (user, purchaser) of PMRs or PMR services to include such descriptions within licensing, insurance, or other contractual agreements.

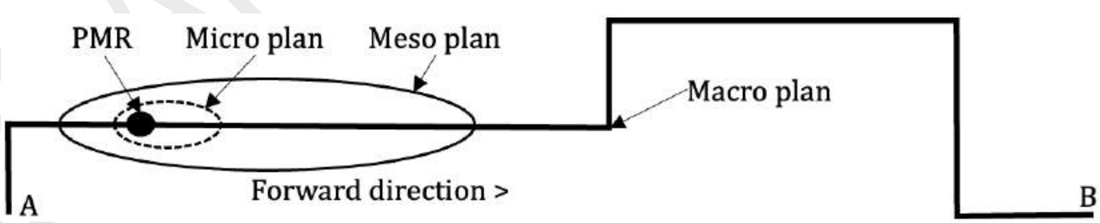

Figure 1: How the three PMR planning levels are related

Figure 1 illustrates PMR travel along a linear 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 lagging (relative) 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 of the vehicle driver. While this illustration shows nothing novel about following a path (macro-plan), current meso-planning for PMRs is sometimes insufficient, causing such a PMR or its remote overseer to experience blind spots or be nearsighted hence possibly unaware of some risks unfolding in the near future of its macro-plan.

The measures in **Table 1** pertain to the ability of a PMR and/or its remote overseer to understand its near-surroundings. This situational awareness shall be sufficient to permit a PMR to make near-range collision avoidance decisions (micro-planning), mid-range navigational decisions (meso-planning), or to trigger an alarm or report in anticipation of a pending mishap such as crash, tipping or vandalism that might be beyond its micro-planning range.

Table 1 is designed so that a PMR shall be able to detect barriers or threats to the completion of its current macro-plan with sufficient time (at sufficient distance) for a PMR to acquire a new macro-plan in order to minimize risk, delay, or barrier to completing the PMR's current task. Within this same sensory radius, or generally much less, the PMR must also be able to adjust its current micro-plan to minimize jerk.

There shall be no blind spots in the ellipse so described (Figure 2), although there may be a small blind area beneath the base of the PMR depending on how its cameras are mounted.

- NOTE For smooth flow among pedestrians, jerk (3rd derivative) can be a product of poor vehicle dynamics programming (micro-planning), and it can be a product of situational awareness myopia if the PMR is not afforded sufficient anticipation time (meso-planning). PMR navigation shall minimize the impact of unexpected events coming too late into the micro-planning field of view. Also, some PMRs carry human passengers, so jerk—as well as getting delayed or stuck—can have significant consequences.

Table 1: The meso-planning dimensions for PMRs (confirm these numbers)

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

Table 1 defines the measures for the situational awareness ellipse, (**Figure 2**), within which a PMR's ADS or remote operator is able to detect, interpret, and determine the presence of objects and events for micro-planning, meso-planning, macro-plan replacement, self-protection and/or recording especially in regard to intersection safety or vandalism.

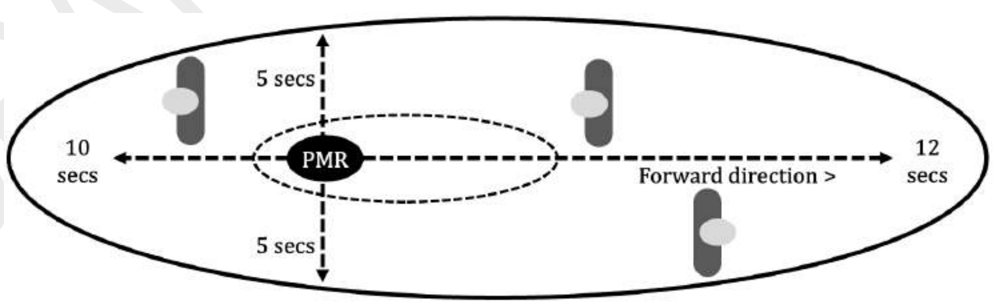

Figure 2: The situational awareness ellipse for PMR meso-planning (confirm these numbers)

Tests to determine whether a PMR has sufficient configuration of sensors, software, and overseer attention for meso-planning may involve:

- the frequency of a PMR being caught by surprise
- circumstances that require high jerk to recover or avoid mishap
- frequent bystander complaints
- frequency of sounding of last-second warning alarms
- a PMR being unable to extract itself (e.g. a U-turn)
- PMR needing rescue by a human or another system.
- The average |jerk| recorded by a journey data recorder (how to determine how low this should be)

NOTE There are innumerable online videos showing PMRs approaching pedestrians and making sudden micro-direction changes (jerk) in the final sub-meter before passing that pedestrian. This can have the effect of confusing or alarming the pedestrian. Such last-second direction changes are effectively delayed gestural communications. If the pedestrian is distracted, there is a risk that the PMR would startle such a pedestrian by turning aside only at the last moment.

NOTE This document is intended for safe navigation and bystander comfort; it does not consider the current state of technology or preferred cost expectations.

NOTE This document relies on a fleet operator to provide teleoperations to satisfy any meso-planning requirement that is not reliably automated.

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

NOTE Any PMR effector system shall be tested to ensure that obstacles can be avoided.

NOTE 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; having some understanding of what events are unfolding behind the PMR during such a maneuver would be invaluable, and extra seconds could save bystander lives (a risky case for this would be while executing a road crossing), and

- Rear- and side-visibility to help anticipate vandalism, wayward vehicles or pedestrians.

6 Bibliography

[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

[2] Kretz, T., Lohmiller, J., Schaich, J. (2016) "The Inflection Point of the Speed-Density Relation and the Social Force Model." https://www.researchgate.net/publication/310606375

[3] Kretz, T., Große, A., Hengst, S., Kautzsch, L., Pohlmann, A., Vortisch, P. (2011) "Quickest Paths in Simulations of Pedestrians." https://www.researchgate.net/publication/51916028

[4] https://www.wevolver.com/specs/starship-technologies-starship-robot describes a PMR with an "Object identification distance up to 200 feet" (60m)

