Bridging the Normative Gap: Standardization for Sidewalk Robots in a World of Self-Driving Cars, Personal Robots and Automated Industrial Vehicles*

Marko Thiel[1], Noel Blunder[1], Justin Ziegenbein[1], Philipp Braun[1] and Jochen Kreutzfeldt[1]

Abstract— **Sidewalks are increasingly being shared by autonomous mobile robots, creating a safety-sensitive environment that lacks explicit safety-focused standards. Establishing such standards is an essential prerequisite for progressing these vehicles from the laboratory to lager-scale, widespread use. This ongoing research presented here aims to fill this gap by exploring standards in related areas, assessing their applicability, and examining possible derived specifications adapted to mobile robots operating on sidewalks and similar traffic environments. As part of our methodology, we draw upon findings from the development of two delivery robot prototype vehicles and a literature review. By establishing a foundation for the design and assessment of future standard drafts, our research supports the broader adoption of mobile robots and contributes to safer urban sidewalks.**

I. Introduction

Sidewalk-based mobile robots, depending on context also referred to as Sidewalk Autonomous Delivery Robots (SADR) [1] or Public Mobile Robots (PMR) [2], hold great potential to automate various aspects of public life, including last-mile transportation, food delivery, and cleaning tasks [3]–[5]. These robots navigate sidewalks, pedestrian zones, and public squares, effectively operating within public spaces and on public roads. As such, they occupy a unique position: On one hand, they resemble automated robots widely employed for industrial indoor transportation tasks such as automated guided vehicles (AGV) and autonomous mobile robots (AMR); on the other, their application environment resembles the conditions encountered by autonomous passenger cars. Furthermore, their proximity to people reveals distinct parallels to service robots and personal care robots.

Given these complexities, the use of sidewalk robots requires stringent safety measures for the vehicles, their operation, and their development processes, including verification and validation. Standards frequently serve to harmonize the representation of state-of-the-art practices across various domains [6]. This holds true for safety-related subjects as well, making such standards essential for the future widespread deployment of robots in public spaces, both from the perspectives of manufacturers as well as regulatory authorities. In addition, the establishment of clear standards would also benefit research institutions seeking to evaluate robot systems within real-world environments.

To date, only a few publications have addressed the topic of safety standards for mobile robots operating on sidewalks. Salvini, Paez-Granados, and Billard [7] examine hazards from mobile robots, providing crucial groundwork for developing necessary safety specifications. In our own previous work [8], [9], we briefly discuss the application of automotive standards to a mobile delivery robot operating on sidewalks in Germany. However, machine safety standards have also been used for similar vehicles, see for example the transport robot by SEW Eurodrive [10]. Again Salvini, Paez-Granados, and Billard [11] address a related question by examining the extent to which the ISO 13482 [12] standard for personal care robots sufficiently covers safety for bystanders and in public spaces and suggests the need for extensions in this area. Beyond that, efforts are underway to develop a standard for sidewalk vehicles that encompasses not only space management but also a part on safety considerations (ISO 4448 [44]). However, as the standard remains in the development stage, detailed information concerning the specific safety topics it addresses is not yet accessible to the public.

As a result, it is important to determine the extent to which sidewalk robots are already covered by existing standards and identify areas where further standardization may be required. Additionally, it is crucial to determine the specific adaptations or novel requirements that would be advisable for these vehicles. In the context of this contribution, we aim to offer a preliminary overview of our work on this subject, focusing on identifying standardization gaps and highlighting similarities or comparable existing regulations.

II. Methods

Our preliminary findings originate from a practical case study (see [9], [45]) and a literature review. The case study centered on the development of two delivery robot prototypes for deployment on sidewalks in public spaces in the city of Lauenburg/Elbe, Germany. During this process, a technical inspection association (TÜV Nord Mobility) was consulted to provide guidance on the development and validation stages, utilizing automotive standards deemed most appropriate for the task at hand. The supporting literature

*This work is based on research conducted within the projects "TaBuLa-LOG - Combined Passenger and Goods Transport in Automated Shuttles" and "Smart Control Center for Automated Transport Robots and Buses in the City of Lauenburg/Elbe - TaBuLa-LOGplus", both funded by the German Federal Ministry for Digital and Transport.

[1]All authors are with the Institute for Technical Logistics, Hamburg University of Technology, Hamburg, Germany. Contact: marko.thiel@tuhh.de

Declaration of AI and AI-assisted Technologies in the Writing Process During the preparation of this work the authors used OpenAI's ChatGPT (models GPT-3.5 and GPT-4) in order to enhance language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

TABLE I

SELECTION OF EXISTING STANDARDS FOR AUTONOMOUS ROBOTS AND CARS THAT MAY BE APPLICABLE TO SIDEWALK ROBOTS.

Standard	**Subject**	**Topics relevant to sidewalk robots**
EN 61508 [13]–[20]	Functional safety of safety-related systems	Basic standard for safety of E/E/PE systems
ISO 12100 [21]	Safety of machinery – General principles	Risk assessment and risk reduction
IEC 62061 [22]	Safety of machinery - E/E/PE control systems	Requirements for design and verification
ISO 13849 [23], [24]	Safety of machinery – Control systems	Design guidelines and validation approaches
ISO 3691-4 [25]	Industrial trucks - Safety	Requirements and verification for AGV
ISO 13482 [12]	Safety requirements for personal care robots	Requirements, validation, user information
ISO 23482 [26], [27]	Robotics - Application of ISO 13482	Test methods and application guidelines
ISO 19649 [28]	Mobile robots - Vocabulary	Definitions for industrial and service robots
ISO 18646 [29], [30]	Criteria and test methods for service robots	Performance evaluation (**not safety**)
ISO 26262 [31]–[40]	Road vehicles (RV) - Functional safety	Automotive-specific approach to safety
ISO 21448 [41]	RV - Safety of the intended functionality	Safety beyond failures; complements 26262
ISO 21434 [42]	RV - Cybersecurity engineering	Cybersecurity for E/E systems in RV
ISO 22737 [43]	Low-speed automated driving systems (LSAD)	Specific requirements for LSAD $\leq$ 32 km/h

review encompassed an exploration of existing publications discussing standards for mobile robots in public spaces, in addition to probing a standards database for standards related to mobile robotics. An evaluation of our results presented here through expert interviews is yet to be conducted.

III. Preliminary Results and Discussion

We have identified standards that primarily target safety-related electrical, electronic, and programmable electronic (E/E/PE) systems. Table I provides an overview of existing standards that could potentially apply to sidewalk robots. These include generic standards that promote safety by providing general principles (ISO 12100 for a general approach to risk assessment and reduction for machine safety) and by defining processes and work products (EN 61508 as a basic standard with a safety life-cycle and risk-based approaches to hazards assessment and evaluation safety measures). Other standards adapt these to specific domains such as machine control systems (e.g. ISO 13849) or even narrower categories including AGVs (ISO 3691-4) or series-production road vehicles (ISO 26262). In addition, there are standards featuring specific requirements for narrowly defined applications (e.g. ISO 22737 with functional and performance requirements for low-speed automated driving).

However, even for standards that primarily cover processes without stating explicit requirements, differences in context can pose challenges when directly adopting them for mobile sidewalk robots. This is particularly important when considering safety scenarios in distinct environments. Operating in outdoor areas in the presence of pedestrians and other road users places different demands on the scenarios to be considered during design and validation than operating in a warehouse.

While existing standards addressing the safety of E/E/PE systems in mobile industrial robots (AGV/AMRs) provide a solid foundation for tackling safety concerns, they do not specifically cater to robots operating in traffic or pedestrian environments. This applies, for example, to the design of the test specimens required as part of the validation process.

Concurrently, automotive-focused standards cover functional safety throughout the vehicle life cycle, as well as cybersecurity and safety of the intended functionality, emphasizing autonomous driving features in road traffic. Here a critical examination is warranted to determine if the focus on classical road vehicles, which can be significantly larger and faster, is appropriately suited for compact robots that operate at pedestrian speeds and solely transport goods. However, it appears reasonable to take into account the hazards that may arise from misuse or potentially dangerous system behavior, as described in ISO 21448.

Furthermore, initial standards explicitly addressing service and personal care robots fall short in adequately considering the unique context of sidewalks, where robots interact with pedestrians and other road users.

IV. Summary and Outlook

It becomes evident that sidewalk mobile robots are not sufficiently addressed by current safety standards for autonomous robots or cars. The distinct application context of compact robots operating in close proximity to people and navigating within public traffic areas is not considered. Nevertheless, general methodologies for development processes and specific requirements can be derived from standards in related fields. These approaches should be incorporated into ongoing standardization efforts or employed as evaluation criteria for assessing draft standards.

References

[1] M. Figliozzi and D. Jennings, "Autonomous delivery robots and their potential impacts on urban freight energy consumption and emissions," *Transportation Research Procedia*, vol. 46, pp. 21–28, 2020. doi: 10.1016/j.trpro.2020.03.159

[2] B. Grush. (2022) Defining PMRs (from ISO DTS 4448-2). [Online]. Available: https://www.urbanroboticsfoundation.org/post/defining-pmrs [Accessed: 10.04.2023]

[3] H.-L. Mikuteit. (2022) Rewe will in Hamburg bald Lebensmittel mit Robotern liefern [Rewe wants to deliver food with robots soon in Hamburg]. [Online]. Available: https://www.abendblatt.de/wirtschaft/article236720037/einzelhandel-hamburg-rewe-will-in-hamburg-bald-lebensmittel-mit-robotern-liefern.html [Accessed: 09.01.2023]

[4] Gründerszene. (2022) Lieferroboter des Berliner Startups Teraki fahren für Domino's Pizza aus [Delivery robots of Berlin-based startup Teraki drive for Domino's Pizza]. [Online]. Available: https://www.businessinsider.de/gruenderszene/food/teraki-dominos-lieferroboter/ [Accessed: 09.01.2023]

[5] Deutsche Bahn AG. (2022) Manni im Außeneinsatz: Reinigungsroboter der Deutschen Bahn putzt jetzt vor dem Frankfurter Hauptbahnhof [Manni on outdoor duty: Deutsche Bahn's cleaning robot now cleans in front of Frankfurt central station]. [Online]. Available: https://www.deutschebahn.com/pr-frankfurt-de/Manni-im-Ausseneinsatz-Reinigungsroboter-der-Deutschen-Bahn-putzt-jetzt-vor-dem-Frankfurter-Hauptbahnhof-7157380 [Accessed: 2023-01-09]

[6] *Standardization and related activities - General vocabulary (ISO/IEC Guide 2:2004); Trilingual version EN 45020:2006*, DIN EN 45020:2007-03, 2007.

[7] P. Salvini, D. Paez-Granados, and A. Billard, "Safety concerns emerging from robots navigating in crowded pedestrian areas," *International Journal of Social Robotics*, vol. 14, no. 2, jun 2022. doi: 10.1007/s12369-021-00796-4

[8] M. Thiel, S. Tjaden, M. Schrick, K. Rosenberger, and M. Grote, "Requirements for robots in combined passenger/freight transport," in *Proceedings of the Hamburg International Conference of Logistics*, 2021. doi: 10.15480/882.4000 pp. 195–215.

[9] M. Thiel, M. Grote, M. Schrick, and S. Tjaden, "Transport robots in automated shuttles," *ATZ worldwide*, vol. 124, no. 4, pp. 46–51, 2022. doi: s38311-021-0775-6

[10] efeuCampus Bruchsal. (2023) Wissensdatenbank: Komponenten - Systemanforderungen - Transportfahrzeug [Knowledge base: components - system requirements - transport vehicle]. [Online]. Available: https://efeuwissen.efeucampus-bruchsal.de/efeu-wissen/komponenten/transportfahrzeug/systemanforderungen/ [Accessed: 2023-03-13]

[11] P. Salvini, D. Paez-Granados, and A. Billard, "On the safety of mobile robots serving in public spaces: Identifying gaps in en iso 13482:2014 and calling for a new standard," *J. Hum.-Robot Interact.*, vol. 10, no. 3, jul 2021. doi: 10.1145/3442678

[12] *Robots and robotic devices – Safety requirements for personal care robots (ISO 13482:2014); German version EN ISO 13482:2014*, DIN EN ISO 13482:2014-11, 2014.

[13] *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 0: Functional safety and IEC 61508 (IEC/TR 61508-0:2005)*, DIN EN 61508 (VDE 0803) Beiblatt 1: 2005-10, 2005.

[14] *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements (IEC 61508-1:2010); German version EN 61508-1:2010*, DIN EN 61508-1 (VDE 0803-1): 2011-02, 2011.

[15] *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems (IEC 61508-2:2010); German version EN 61508-2:2010*, DIN EN 61508-2 (VDE 0803-2): 2011-02, 2011.

[16] *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 3: Software requirements (IEC 61508-3:2010); German version EN 61508-3:2010*, DIN EN 61508-3 (VDE 0803-3): 2011-02, 2011.

[17] *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 4: Definitions and abbreviations (IEC 61508-4:2010); German version EN 61508-4:2010*, DIN EN 61508-4 (VDE 0803-4): 2011-02, 2011.

[18] *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 5: Examples of methods for the determination of safety integrity levels (IEC 61508-5:2010); German version EN 61508-5:2010*, DIN EN 61508-5 (VDE 0803-5): 2011-02, 2011.

[19] *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3 (IEC 61508-6:2010); German version EN 61508-6:2010*, DIN EN 61508-6 (VDE 0803-6): 2011-02, 2011.

[20] *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 7: Overview of techniques and measures (IEC 61508-7:2010); German version EN 61508-7:2010*, DIN EN 61508-7 (VDE 0803-7): 2011-02, 2011.

[21] *Safety of machinery – General principles for design – Risk assessment and risk reduction (ISO 12100:2010); German version EN ISO 12100:2010*, DIN EN ISO 12100:2011-03, 2011.

[22] *Safety of machinery - Functional safety of safety-related control systems (IEC 62061:2021); German version EN IEC 62061:2021*, DIN EN IEC 62061 (VDE 0113-50): 2023-02, 2023.

[23] *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design (ISO 13849-1:2015); German version EN ISO 13849-1:2015*, DIN EN ISO 13849-1:2016-06, 2016.

[24] *Safety of machinery – Safety-related parts of control systems – Part 2: Validation (ISO 13849-2:2012); German version EN ISO 13849-2:2012*, DIN EN ISO 13849-2:2013-02, 2013.

[25] *Industrial trucks - Safety requirements and verification - Part 4: Driverless industrial trucks and their systems (ISO 3691-4:2020); German version EN ISO 3691-4:2020*, DIN EN ISO 3691-4, 2020.

[26] *Robotics - Application of ISO 13482 - Part 1: Safety-related test methods*, ISO/TR 23482-1:2020(E), 2020.

[27] *Robotics - Application of ISO 13482 - Part 2: Application guidelines*, ISO/TR 23482-2:2019(E), 2019.

[28] *Mobile robots - Vocabulary*, ISO 19649:2017(E), 2019.

[29] *Robotics - Performance criteria and related test methods for service robots - Part 1: Locomotion for wheeled robots*, ISO 18646-1:2016(E), 2016.

[30] *Robotics - Performance criteria and related test methods for service robots - Part 2: Navigation*, ISO 18646-2:2019(E), 2019.

[31] *Road vehicles - Functional safety - Part 1: Vocabulary*, ISO 26262-1:2018-12(E), 2018.

[32] *Road vehicles - Functional safety - Part 2: Management of functional safety*, ISO 26262-2:2018(E), 2018.

[33] *Road vehicles - Functional safety - Part 3: Concept phase*, ISO 26262-3:2018(E), 2018.

[34] *Road vehicles - Functional safety - Part 4: Product development at the system level*, ISO 26262-4:2018(E), 2018.

[35] *Road vehicles - Functional safety - Part 5: Product development at the hardware level*, ISO 26262-5:2018(E), 2018.

[36] *Road vehicles - Functional safety - Part 6: Product development at the software level*, ISO 26262-6:2018(E), 2018.

[37] *Road vehicles - Functional safety - Part 7: Production, operation, service and decommissioning*, ISO 26262-7:2018(E), 2018.

[38] *Road vehicles - Functional safety - Part 8: Supporting processes*, ISO 26262-8:2018(E), 2018.

[39] *Road vehicles - Functional safety - Part 9: Automotive safety integrity level (ASIL)-oriented and safety-oriented analyses*, ISO 26262-9:2018(E), 2018.

[40] *Road vehicles - Functional safety - Part 10: Guidelines on ISO 26262*, ISO 26262-10:2018(E), 2018.

[41] *Road vehicles - Safety of the intended functionality*, ISO/PAS 21448-2019(E), 2019.

[42] *Road vehicles - Cybersecurity engineering*, ISO/SAE 21434:2020(E), 2020.

[43] *Intelligent transport systems - Lows-peed automated driving (LSAD) systems for predefined routes - Performance requirements, system requirements and performance test procedures*, ISO 22737:2021(E), 2021.

[44] EU-ICIP. (2023) Kerbside/ground based automated mobility. [Online]. Available: https://www.mobilityits.eu/kerbside-management [Accessed: 10.04.2023]

[45] C. Gertz, J. Kreutzfeldt, H. Flämig *et al.*, "Endbericht des Projektes TaBuLa-LOG. Kombinierter Personen- und Warentransport in automatisierten Shuttles [Final report of the TaBuLa-LOG project. Combined passenger and goods transport in automated shuttles]," Hg. v. Institut für Verkehrsplanung und Logistik - W8. Technische Universität Hamburg (TUHH). Hamburg., Tech. Rep., 2022.