

Mobile Robots on Sidewalks: Legal Context and Resulting Requirements for Autonomous Last-Mile Delivery in Germany*

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Abstract—As demand for last-mile deliveries increases, there is a growing interest in deploying autonomous delivery robots on sidewalks. However, this presents significant technical and legal challenges that need to be addressed. These systems must not only be capable, robust, and safe but also comply with applicable traffic laws. This paper explores the legal context and resulting technical and operational requirements for mobile robots on sidewalks using Germany as an example. As the largest economy in Europe and the first country with a legal framework for autonomous vehicles, Germany offers valuable insights into the integration of robots into public spaces and traffic. We outline specific technical and legal requirements for implementing delivery robots on sidewalks by taking a traffic law perspective and using two prototype vehicles as a case study. In consultation with a technical inspection association and local approval authorities, the necessary technical equipment features, operating requirements, and required permits were determined. The insights gained from this research not only provide valuable information on this pressing issue but also contribute to international discussions on the future and technical constraints of last-mile automation. Our study offers significant insights into the integration of any type of compact robot on sidewalks beyond just delivery robots and can assist the development of technical and legal requirements for mobile robots in urban public spaces.

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I. INTRODUCTION

In times of continuing growth in e-commerce, increasing delivery traffic on the last mile poses major challenges, such as conflicts over available space or high noise and CO2 emissions. One possible solution is the use of electrically powered mobile robots that utilize sidewalks for transportation. Such

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delivery robots also promise additional advantages, such as optimized delivery by choosing suitable, individual time windows [2]. However, hurdles for widespread use include an unclear or unsuitable legal situation for approval and operation [3].

Typically, two types of vehicles fall into the category of delivery robots: compact, wheeled robots, that move on sidewalks, and robots inspired by traditional transport vehicles, which operate on the road [4]. While the latter embodies another application of conventional automated driving, especially small mobile robots on sidewalks represent a significant special case. On the one hand, such driverless vehicles have not yet been explicitly defined in German road traffic law, which is why specific regulations are lacking. On the other hand, as a vehicle in public traffic, they are nevertheless subject to the general requirements of road traffic law and thus to the design and operating regulations as well as provisions for licensing or approval [5].

Currently, there are only isolated pilot tests with mobile robots or delivery robots in public spaces in Germany [6], [7], [8]. At the same time, many stakeholders pursue commercial interests, therefore only limited information about these trials is available.

In the following, the term "mobile robots" is used to refer to "wheeled delivery robots", although the results are also applicable to other types of ground-based robots in public space, e.g. cleaning robots [9].

The final report on the research project TaBuLa-LOG [10] as well as [5], [11] have already summarized some initial results on the legal classification of mobile robots and their design implications.

A. State of the Art

So far, there is very little literature addressing the legal classification of mobile robots and resulting requirements in Germany. Essential is the study by Brandt et al [3], which investigates the pilot operation of delivery robots by the company Starship Technologies in Hamburg, Germany, and summarizes the legal considerations. This already includes the legal classification of robots as motor vehicles as well as the need for exemption permits, possibly with further conditions (see chapter 3.1). Hoffmann and Prause discuss in [12] the possibility of evaluating mobile robots based on existing vehicles, which are already allowed to be used on sidewalks according to German law - in this instance for electric mobility scooters respectively electric wheelchairs.

In addition, further literature can be found on the classification of compact automated vehicles for last-mile deliveries, e.g. [13], but without a deeper focus on legal aspects. Overall, the question of requirements for automated or autonomous mobile robots in public road traffic is only incompletely answered.

B. Research Question and Contribution

This work aims to establish the legal framework applicable to mobile robots in public space in Germany and to identify the specific requirements that such robots must meet, thereby making a valuable contribution to the fields of:

- 1) Classification of mobile robots on sidewalks within the current legal framework and supplementing existing literature, including identification of regulatory gaps (chapter 3.1),
- 2) Presentation of requirements for the design, operation, and approval of mobile robots on sidewalks using the example of a prototype delivery robot (chapter 3.2).

II. METHODOLOGY

The results presented in this paper are based on a practical case study: As part of the "TaBuLa-LOG" research project, two compact delivery robots were designed, constructed, and practically tested from January 1, 2020, to June 20, 2022 [10]. Due to constant monitoring and supervision during testing, the degree of automation according to SAE was specified as level 2, which, however, does not imply any restrictions on the autonomous capabilities of the robots. To reduce the scope of required validation evidence, the operating envelope has been restricted with regard to unfavorable weather conditions. The robots were deployed on public sidewalks and squares in the city of Lauenburg/Elbe in the German federal state of Schleswig-Holstein. Figure 1 shows one of the delivery robot prototype vehicles.

As part of the robot development, extensive investigations were carried out into the legal classification and the resulting requirements. This included a literature review as well as the involvement of traffic authorities, approval authorities, and a technical inspection organization. The authorities involved included the ministry responsible for transport in the German federal state Schleswig-Holstein (MVATT), the state road construction and transport authority (LSV.SH), and the road traffic department in the Duchy of Lauenburg district where the robots were operated. Multiple companies of the TÜV Nord Group were involved as technical inspection organizations, hereinafter referred to collectively as TÜV Nord.

III. RESULTS AND DISCUSSION

The paper's results and their discussion are divided into three sections: (III-A) introduces the legal framework for mobile robots on public sidewalks in Germany and classifies such robot vehicles accordingly, (III-B) presents the resulting requirements for mobile robots and their operation based on the legal framework, and (III-C) discusses the limitations of the study's findings as well as challenges that need to be addressed.



Fig. 1. Delivery robot prototype in the city of Lauenburg/Elbe, Germany.

A. Legal Framework for Mobile Robots on Sidewalks

Last-mile delivery robots move in public spaces or on public roads (which may include private land such as parking lots [14, p. 9 and p. 797]) to perform their tasks. Thus, they are considered road users [15, p. 1762]. In Germany, road users are bound by road traffic laws. The legal basis for this is both international law and national law. International law applies either directly (e.g., EU regulations) or sets objectives that must be implemented into national law (e.g., EU directives) [16, pp. 2]. The core of German road traffic law is the Road Traffic Act (*Straßenverkehrsgesetz - StVG*) together with supplementary ordinances. In the context of the research question, the following laws and regulations are particularly relevant (*laws and regulations listed below are referenced only by their German short names*):

- Road Traffic Act (StVG [*Straßenverkehrsgesetz*])
- Road Traffic Licensing Regulations (StVZO [*Straßenverkehrs-Zulassungs-Ordnung*])
- Vehicle Registration Regulations (FZV [*Fahrzeug-Zulassungsverordnung*])
- Road Traffic Regulations (StVO [*Straßenverkehrs-Ordnung*])
- Driver Licensing Regulations (FeV [*Fahrerlaubnis-Verordnung*])
- Autonomous Vehicles Approval and Operation Regulations (AFGBV [*Autonome-Fahrzeuge-Genehmigungs-und-Betriebs-Verordnung*])
- Compulsory Insurance Act (PflVG [*Pflichtversicherungsgesetz*])

A significant portion of the legal framework to be considered already arises from the fact that mobile robots in public space are bound by road traffic law. Whether the robots are teleoperated or autonomous is initially irrelevant. Additional regulations that specifically address automated and autonomous vehicles have only recently been introduced through amendments to the StVG as well as the enactment of the new AFGBV. These will be discussed separately at the end of this section.

1) *Mobile Robots as Motor Vehicles:* Any land vehicles not restricted to tracks and propelled by machine power are classified as motor vehicles (§ 1 para. 2 StVG, cf. § 2 para. 1 FZV). Thus, mobile robots are also to be classified as motor vehicles [3, cf.]. In order to be allowed to operate motor vehicles on public roads in Germany, these must be approved for traffic (§ 1 para. 1 StVG). While the StVZO mainly includes regulations on operating permits, type approval, as well as design and operating regulations, the FZV governs registration procedures and requirements [14, p. 792]. There is an important exception to this: The FZV is only applicable to motor vehicles that have a maximum design speed of more than 6 km/h (§ 1 FZV). If the speed of a mobile robot does not exceed 6 km/h due to its design, it is therefore exempt from the regulations of the FZV and does not require registration. This also eliminates the need for an operating permit, in contrast to the assessment in [3]. However, as soon as the maximum design speed of a vehicle exceeds 6 km/h, registration, and type approval or operating permit are required. In this context, the approval of vehicles via EC type approvals is largely harmonized, but no suitable vehicle class exists for mobile robots yet (cf. Regulations (EU) 2018/858 and 168/2013). In the case of higher speeds, approval would initially have to be granted nationally on the basis of an individual approval for each robot in accordance with § 21 StVZO or a type approval in accordance with § 20 StVZO. However, due to the operation of the robots on sidewalks, a restriction to 6 km/h seems reasonable. For example, mobility scooters or electric wheelchairs may only be used on sidewalks at walking speed (§ 24 para. 2 StVO, see also [12]).

Even in cases where neither registration nor operating permit is required, vehicles must comply with the regulations of the StVZO (cf. § 16 para. 1 StVZO). Vehicles that meet the design and operating regulations of §§ 30-67 StVZO as well as § 23 para. 1 StVO (lighting equipment) are considered to be in compliance [16, p. 1713]. These regulations do not include any requirements that specifically address mobile robots, since such vehicles are neither explicitly found in the StVZO (in contrast to e.g. industrial trucks as forklifts) nor can they be assigned to an existing EC vehicle class (as described above).

In addition, due to the particularities associated with robots, numerous regulations are not directly applicable or do not apply (see III-C). For deviations from the StVZO, § 70 StVZO provides for exceptions which may be approved by the federal state authorities or designated bodies (§ 70 para. 1 sentence 2 StVZO). However, these exceptions are always discretionary decisions [16, p. 1971]. Exemptions may be subject to conditions (cf. § 71 StVZO).

2) *Mobile Robots on Sidewalks:* The classification of mobile robots as motor vehicles is particularly significant for their intended operation on sidewalks. In this regard, the general traffic regulations of the StVO, which regulate and guide public traffic [14, p. 9], must be taken into account. According to § 2 para. 1 sentence 1 StVO, vehicles must use roadways. Therefore, the use of sidewalks and shoulders is

prohibited [16, p. 540]. However, analogous to the StVZO, the StVO also provides for exemptions, regulated in § 46 StVZO. Road traffic authorities can approve exceptions to the road use specified in § 2 to allow the operation of mobile robots on sidewalks. For safety reasons, these exceptions may also be subject to conditions or obligations [16, p. 1070].

3) *Driver's License and Insurance for Mobile Robots:* There are no clear requirements regarding the need for a specific driver's license to operate mobile robots. In general, in order to legally drive a motor vehicle on public roads in Germany, a driver's license is required (§ 4 para. 1 sentence 1 FeV, cf. StVG § 2). In the absence of a suitable vehicle class for robots, however, robots can neither be assigned a precise driver's license class according to § 6 FeV nor do they fall under any of the exceptions listed there.

With regard to the insurance of mobile robots, the PflVG must be taken into account. For motor vehicles with a regular location in Germany, liability insurance must be taken out (§ 1 sentence 3 PflVG). However, there is again an exception for motor vehicles with a maximum design speed of no more than 6 km/h: According to § 2 para. 1. sentence 1. no. 6a PflVG, the insurance obligation does not apply to such vehicles.

4) *Automated and Autonomous Driving Functions of Mobile Robots:* Automated driving functions of SAE level 3 have been directly addressed by the StVG since 2017 (see *Achtes Gesetz zur Änderung des Straßenverkehrsgesetzes* [Eighth Act Amending the Road Traffic Act] of June 16, 2017, BGBl. I. p. 1648). The new §§ 1a - 1c regulate the necessary functional scope of the technical equipment and define the rights and obligations of the vehicle driver. Since 2021, the StVG also includes requirements for autonomous driving according to Level 4 (see *Gesetz zum autonomen Fahren* [Act on Autonomous Driving] of July 12, 2021, BGBl. I. p. 3108). Sections 1c - 1l StVG describe the operation and testing of autonomous vehicles in specified operating areas, as well as the prerequisites and permits required for this. The new regulations include a so-called technical supervisor according to § 1d para. 3 StVG - a person who can approve driving maneuvers but also interrupt autonomous operation. Requirements were only recently substantiated by the AFGBV of June 24, 2022. In addition, the annexes to the AFGBV explicitly list international standards to be taken into account:

- ISO 26262 Road vehicles - Functional safety
- ISO/PAS 21448 Road vehicles - Safety of the intended functionality
- UN ECE R 155 - Uniform provisions concerning the approval of vehicles with regards to cyber security and cyber security management system

These standards describe processes, activities, and work products throughout the life cycle of vehicles, including their development, to ensure safe operation. They are aimed at series-produced road vehicles, not explicitly at compact mobile robots. Nevertheless, these standards are designed to ensure safe operation in traffic contexts, so the general processes and methods specified there are believed to be

applicable to robots. This holds particularly true in the absence of a more dedicated standard.

B. Resulting Requirements for Delivery Robots on Sidewalks

As described in the previous section, mobile robots intended for use in public space must comply with the requirements of the StVZO, in particular the design and operating regulations according to §§ 30 ff. StVZO. Specific paragraphs frequently refer to the annex of the StVZO, which in turn contains references to international regulations. Right at the outset § 30 para. 1 sentence 1 StVZO addresses the road safety of vehicles with a general rule (cf. [16, 1776]): "Vehicles must be designed and equipped in such a way that their usual operation does not harm anyone or endanger, obstruct or inconvenience anyone more than is unavoidable, [...]" (translated from the German regulation text). The individual requirements of the StVZO that have been identified as applicable are summarized in table I. In contrast to the report in [3], a turn indicator was found to be not needed currently.

When examining the delivery robot prototypes built in the TaBuLa-LOG project, deviations from the regulations of the StVZO were found for the following regulations (summarized from a commissioned expert assessment of TÜV Nord):

- § 35a para. 1 - Seats: No seat available for the person operating the vehicle,
- § 38 para. 1) - Steering device: Bluetooth connection between the control device (*remote control of the robot*) and the robot,
- § 41 - Brakes: Bluetooth connection between steering device and robot; 868 MHz radio link to activate the auxiliary and parking brake (*separate remote control; brake realized as failsafe brake*),
- § 49 - Noise emission: Determined according to UN R138.

During an expert assessment, it was determined that safe operation is still ensured despite these exceptions. To obtain an exemption permit according to § 70 StVZO (deviations from the design and operating regulations), the following conditions were proposed (summarized from a commissioned expert assessment of TÜV Nord):

- In automated mode (longitudinal and lateral guidance), the robot must be constantly monitored by an accompanying person.
- The accompanying person must have a valid driver's license of at least class "M" according to German and European rules. Also, a training on operating the robot including a practical exam must be completed.
- The accompanying person must wear a reflective high-visibility vest.
- The robot must be equipped with a red flag significantly protruding above its height.
- The robot must be equipped with white lights and reflectors to the front, red lights and reflectors to the rear, and yellow reflectors to both sides.

- During operation, relevant driving data must be recorded for traceability of the driving status.
- The remote control must be immediately accessible for the accompanying person.
- The Bluetooth connection between the robot and the remote control must be monitored. If the connection is unstable or interrupted, the robot must come to a stop.
- The robot must be marked in accordance with § 64b StVZO (*owner clearly indicated in indelible writing*).

Further conditions arise from the special situation of a research project:

- Automated rides must initially be carried out with an additional person from the development team to monitor the perception and planning systems and preemptively identify unexpected behavior.
- No operation in the following weather conditions: heavy rain, snowfall, road ice, heavy fog and darkness.
- No operation on or next to heavily trafficked roads and when relative speed is too high (maximum speed of other road users below 50 km/h) (*this only applies to the automated operation of the delivery robot prototypes*).

Commercial manufacturers who can demonstrate the safety of their vehicles under a wider range of weather conditions and operating states may receive fewer or adapted requirements. Further, it can be assumed that the scope of the obligations and conditions imposed can be reduced as the technical maturity of robots increases. The aspect of required accompanying persons is also addressed by the new legal framework for autonomous driving in Germany (see § 14 in table II).

In addition to implementing the technical requirements and conditions, the robots were developed, validated and audited in accordance with ISO 26262 and ISO/PAS 21448. Any additional safety requirements that may arise from this depend on the specific vehicle architecture and intended use, which is why no further details are provided at this point. At the time of the robots' development, an approach based on these standards was the most appropriate representation of the state of the art, even though the standards are actually intended for classical series production vehicles.

Manual or remote-controlled operation of the delivery robot prototypes on sidewalks was approved with conditions throughout the city of Lauenburg/Elbe in accordance with § 46 StVO. The conditions are in detail (summarized from the exemption permit):

- The exemption permit must be carried along,
- Special care and consideration are required towards pedestrians and cyclists, if necessary with stopping the robot.
- The road authority or the administration responsible for the traffic safety obligation shall be released from third-party compensation claims within the scope of the approved operation.

For the automated operation on sidewalks, only the test report for the application of the written exemption is available so far. The following additional requirements have already

TABLE I
STVZO REGULATIONS RELEVANT TO MOBILE ROBOTS IN GERMANY (REQUIREMENTS ABBREVIATED/SUMMARIZED)

	Subject of regulation	Requirement
§ 30a	Maximum speed determined by design	Maximum speed cannot be easily modified; changes must be easily recognizable
§ 30c	Protruding exterior edges	Exterior edges must be rounded (radius < 5 mm)
§ 32	Dimensions of vehicles	<i>Regulations for determining vehicle dimensions</i>
§ 34	Axle load and total weight	Maximum axle load may not exceeded specific values
§ 35b	Devices for safe vehicle operation	Devices for operating the vehicle must be easy and safe to use; ensure sufficient field of view
§ 35e	Doors	Doors must not open unintentionally
§ 38	Steering device	Steering must be easy and safe
§ 39	Reverse gear	Reverse driving possible from driver's seat
§ 39a	Actuating devices, indicator lights and indicators	Correct labeling of actuating devices
§ 41	Brakes and wheel chocks	Two independent braking systems, at least one mechanical; parking brake suitable for the steepest slope; mean full deceleration of 3.5 m/s ² by service brake, 1.5 m/s ² by auxiliary brake
§ 49	Noise generation	Low noise generation according to the state of the art
§ 49a	Lighting equipment, general principles	Use only lights approved as permissible; symmetrical attachment
§ 53	Rear lights, brake lights, reflectors	Two red rear lights, two red reflectors; not mounted lower than 35 cm above the road
§ 54	<i>Turn indicators</i>	<i>Not required after consultation</i>
§ 55	Acoustic signal devices	At least one horn; no frightening or harassing; no more than 105 dB (A) at a distance of 7 m
§ 55a	Electromagnetic compatibility	Proof of electromagnetic compatibility according to UN ECE-R10 in an approved testing laboratory
§ 59	Factory plates, vehicle identification number	Attachment of a factory plate with information about the vehicle (e.g. manufacturer, year of manufacture, vehicle identification number, permissible total weight)
§ 62	Electrical equipment of electrically powered motor vehicles	Electrical equipment must not injure people or damage property during normal use
§ 64b	Identification	Attachment of company name and address on the left side of the vehicle

been agreed upon with the responsible lower traffic authority on the municipal level:

- Automated operation on sidewalks is approved only for specific robot operating areas.
- Operation is allowed only on or next to roads with a maximum speed of 30 km/h.

It remains an open question how the effort to acquire permits for large-scale sidewalk operations could be reduced. Restrictions based on high relative speeds, on the other hand, are likely to be addressed through increased technical maturity.

If the SAE level of an autonomous vehicle is increased to 4, the newly enacted regulations of §§ 1d ff. of the StVG will result in additional requirements. These are specified in the AFGBV, but without explicit reference to compact mobile robots. Assuming that robots are treated in the same way as traditional vehicles, a selection of resulting requirements is listed in table II. For a detailed list, please refer in particular to the annexes to the AFGBV. Annex 1 to the AFGBV provides detailed functional requirements for vehicles. Overall, it should be noted that these regulations have only recently come into effect and extensive experience is lacking. To further illustrate this: It was not until the end of November 2022 that a driverless parking car was approved

for the first time by the Federal Motor Transport Authority (KBA [Kraftfahrt-Bundesamt]).

C. Limitations and Challenges

It should be noted that the delivery robot prototypes under consideration were developed in consultation with only one technical inspection organization and the approval authorities of only one German federal state. The novelty of mobile robots as motor vehicles in public spaces in particular requires decisions to be made on a case-by-case basis. The specific operational environment of the robots is a central aspect of many considerations. Furthermore, the development of the delivery robot prototypes was aimed at a test operation with a small number of vehicles instead of a commercial deployment of a larger fleet of series production vehicles. Commercial manufacturers also face further requirements arising, for example, from product safety laws or radio equipment laws.

Challenges arise in the application of the new German legal framework to the design and operation of autonomous robots, as such robots have not been explicitly considered so far. It needs to be clarified where potentially reduced requirements arise and how the processes and specifications originally intended for classic vehicles can be adapted. This

TABLE II

AFGBV REQUIREMENTS RELEVANT TO MOBILE ROBOTS IN GERMANY (SELECTION; REQUIREMENTS ABBREVIATED/SUMMARIZED)

	Subject of regulation	Requirement
§ 2	Operating license	KBA operating permit for specified operating areas
§ 3	Application for type approval by the manufacturer	Application contains (selection): Operating manual, safety concepts for functional safety and in the area of information technology, catalog of test scenarios
§ 8	Application for approval by the holder	Application contains (selection): Description of the operating area, proof of the capability to deactivate the autonomous driving function, proof of persons and technical supervision
§ 12	Requirements for the manufacturer	Safety concepts, hazard analyses, and safety verification; recurring technical vehicle monitoring (<i>list of functional requirements in Annex 1 to the AFGBV, e.g. for collision avoidance and interaction with other road users</i>)
§ 13	Requirements for the holder	Implementation of various controls incl. documentation; <i>specification of requirements for executing persons (e.g. technical degree as well as training)</i>
§ 14	Requirements for technical supervision	Only suitable persons (certain degrees as engineer or technician); termination of the minimum risk condition only after investigation incl. documentation
§ 15	Data storage	Storage of various data (according to Annex 2 to the AFGBV, e.g. position data, number and times of maneuver clearances)
§ 16	Testing permit	Test drives only with test approval from the KBA; requirements: approved vehicle, deactivation and override capability of the systems, application with detailed development concept (<i>contents are further specified</i>)

applies, for example, to the required safety evidence and the approval tests to be carried out. It also remains to be investigated how technical supervision for autonomous robots can be implemented, taking into account the specific characteristics of such vehicles and their operating environment.

IV. SUMMARY AND OUTLOOK

If mobile robots are to be operated in public spaces in Germany, e.g. on sidewalks for last-mile deliveries, road traffic laws must be taken into account. This results in requirements for the development and technical equipment of such robots as well as approvals and necessary permits. Mobile robots in public space are classified as motor vehicles under German road traffic law - regardless of whether they drive autonomously or are teleoperated. While it is possible to forego registration and operating permits at low vehicle speeds, further provisions of road traffic law must still be taken into account. These include, above all, the design and operating regulations of the StVZO, which describe the necessary technical equipment of vehicles. As a new category of vehicle, delivery robots are not explicitly covered by these regulations, which is why exemption permits are required in any case - combined with specific conditions imposed by approval authorities. However, these conditions are at the discretion of technical inspection organizations and approval authorities, which is why there may be deviating requirements in individual cases. Further exemptions are required for the use of sidewalks, which generally may not be used by motor vehicles.

A specific legal framework has recently been created for the operation of highly automated and, in particular, autonomous vehicles in Germany. However, this research study shows that these novel rules in Germany are not suitable for

the certification and operation of mobile robots. A myriad of individual rules and regulations have to be considered in the design of a mobile robot to operate safely and securely in public spaces. Still today a person for ensuring safety is required throughout the whole process. It is advised to examine how to simplify the certification process in order to streamline the development and operation of mobile robots in public space, in Germany and elsewhere.

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