Enabling Independent Mobility for Wheelchair Users in Railway Vehicles: A Multi-stakeholder Dialogue for the Derivation of Requirements for Vehicle Boarding Aids

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Abstract. A data-driven analysis of Germany's rail mainline network revealed frequent boarding situations with mismatched platform and vehicle entrance heights, undermining the principle of maximum independence in personal mobility (Art. 20 UN CRPD) of persons with reduced mobility (PRM). Over the next decades, platform height harmonization in Germany will only be achieved at 760 and 550 mm, requiring additional measures, including adapting heights of vehicle entries, implementing platforms with multiple heights, and using boarding aids (BA) such as ramps or lifts. It is crucial that vehicle BA be designed for independent use by wheelchair users without causing delays that compromise time-efficient travel for other passengers or affect operators' schedules. The technical adaptation of both BA and vehicles must be feasible and economically efficient. To achieve this, a stakeholder consultation was conducted involving passenger and disability associations, vehicle and BA manufacturers, rail operators, and standardization experts. Discussions covered boarding scenarios, existing BA, best practices from the urban transport sector, and regulatory constraints. The aim was to create a stakeholder-derived requirement catalogue for independently useable BA to guide future tender processes, rolling stock retrofitting decisions, and the further development of technical standards.

Keywords: Accessibility · Inclusive mobility · Stakeholder dialogue · Boarding aids · Rail transport

1 Introduction

Regional and long-distance rail systems continue to exclude persons with reduced mobility (PRM) from full and autonomous participation. Ensuring independent and equal access to public transport remains a key requirement of the United Nations Convention

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on the Rights of Persons with Disabilities (UN-CRPD) [1]. Article 20 enshrines the right to personal mobility for persons with disabilities, including access to quality boarding aids (BA). Article 4 obliges State Parties to research and develop universally designed goods, services and facilities while consulting and closely involving persons with disabilities in policy design and implementation – directly underpinning the participatory methodology of this study.

In the railway sector, accessibility is strongly influenced by the Platform-Train-Interface (PTI). A persistent challenge in Central Europe and especially in Germany due to historical reasons is the coexistence of two main platform heights – 550 mm and 760 mm – combined with a heterogeneous rolling stock fleet with different entry heights even for the same vehicle models. While both levels are legally recognized as "standard heights", the lack of harmonization results in situations where wheelchair users cannot enter or leave trains independently [2]. Legacy infrastructure will also continue to include platforms with a height of 380 mm or less for the next 10 to 15 years [3]. This situation was highlighted by a prior quantitative study which showed, that only 53% of boarding situations had a vertical gap of 50 mm or less and only 10.4% of regional railway lines maintain consistent platform heights [4].

Level boarding at every train door would be the ideal solution for barrier-free mobility, yet Germany cannot achieve this in the near future due to infrastructural, technical, organizational and political constraints [5]. Consequently, BA will remain necessary to assist PRM in getting on and off rail vehicles. Solutions such as mobile ramps, staff-based assistance or mixed-height platforms provide only partial relief. In particular, reliance on railway staff conflicts with the principle of autonomous access without external assistance [6].

The present study addresses requirements for BA from multiple perspectives. It combines a stakeholder dialogue with a systematic review of normative frameworks. The goal is threefold:

- **Document** and synthesize stakeholder perspectives, identify common ground and conflicting positions.
- **Map** these requirements against relevant standards and regulations to identify regulatory conflicts and compliance gaps in clauses related to user autonomy.
- **Derive** requirements that reflect user needs and ensure technical and operational feasibility for inclusion in future rolling stock tenders in Germany.

2 Methodology

The methodological approach combines a **stakeholder dialogue** with a structured **normative analysis**. During the period from January 2025 to February 2026 a total of 9 stakeholder meetings were held: five general online meetings, three online stakeholder-specific sessions and a two-day presence workshop, moderated by the DLR with support from the DZSF. Participants represented:

- Associations of persons with disabilities and passenger associations
- Railway operators and their associations
- Rolling stock manufacturers and BA suppliers
- Infrastructure managers and public transport authorities

– Transportation and accessibility standards bodies

The stakeholder dialogue was designed to **document stakeholder positions**, enable exchange between groups and identify requirements rather than reach immediate consensus. Meeting notes, written stakeholder statements and personal experience reports on real-life boarding situations were analysed. Stakeholder requirements were consolidated using participant weighting from the workshop and survey responses.

In parallel, **a meta-analysis of the most important regulation and standards** related to requirements for BA in railway vehicles was conducted, focusing on identifying where norms intersect with the topic of independence by wheelchair users, where gaps or contradictions exist, and how regulatory tolerances impact practical accessibility, especially without assistance.

Furthermore, a survey of conventional and innovative BA in rail and road transport was carried out, incorporating prior work on BA from the "PubTrans4All" project [7]. Technical specifications from these BA served as a reference point for stakeholder discussions.

3 Results

3.1 Stakeholder Requirements

Although all groups participated in the stakeholder dialogue, wheelchair users proved most active in formulating requirements, reflecting their direct reliance on BA, while other stakeholders focused on pointing out operational and technical restrictions. As a result, the following list primarily reflects the perspectives of wheelchair users and serves as an entry point for the subsequent mapping against normative frameworks, which indirectly incorporates the viewpoints of operators and manufacturers. The identified requirements can be clustered into three thematic areas:

Independence/Autonomy and Usability

– BA must enable independent boarding for wheelchair users. Staff-dependent BA are rejected and do not comply with BGG §4 [6]. Accordingly, BA must be designed for user-friendly gradients, dimensions, etc. Staff-operated BA (e.g., mobile ramps) are acceptable only as interim or backup options.
– Multiple operating options must be provided to allow operation by persons with varying degrees of physical impairments.
– BA should enable spontaneous use without prior registration.

Safety and Reliability

– Concerns about safe handling include reaching buttons near platform edges in crowds and unclear procedures for autonomous ramp and door operation.
– A safe BA deployment and retraction process must be achievable without supervision from trained staff.
– BA operation shall ensure passenger comfort and safety through smooth operation and appropriate guard rails.

– Reliable BA and boarding/alighting processes are required for operation without assistance.

System Aspects - Fully Accessible Travel Chains

– Reliable, up-to-date information on all relevant aspects of the travel chain shall be accessible, e.g. operational readiness of BA and platform elevators.
– Broad and accessible design on trains and platforms is essential, especially sufficient manoeuvring space at doors and inside vehicles.
– Support services and staff must remain available in case of incidents.
– True level boarding should be comprehensively implemented as soon as possible, as it is clearly preferred over BA.

3.2 Normative Framework and Practical Contradictions

Participants assessed selected clauses from European and national regulations and standards (e.g. TSI-PRM [8], DIN EN 16586–2 [9], DIN EN 14752 [10], DIN 18040–1 [11]) and relevant legal frameworks (e.g. UN-CRPD [1], German Equal Opportunities for People with Disabilities Act (BGG) [6], Swiss Disability Law (BehiG) [12] and guidelines such as the one from the Austrian Mobility Research (FGM) [13]. Table 1 summarizes the most relevant findings.

The normative analysis exposes a mismatch between European regulatory frameworks and user capabilities. While the TSI-PRM [8] allows ramp gradients of up to 18%, it also sets a dynamic stability threshold of 10% for wheelchairs on ramps; in contrast, the FGM recommends a maximum gradient of only 6% [13]. In stakeholder discussions, disability associations fixed an 8% "red line", whereas operators considered up to 10% as still feasible in practice. No consensus between these positions was reached, though manufacturers confirmed that both ranges are technically achievable.

These considerations are reflected in Fig. 1, where slopes of 6%, 8%, 10% and 18% are included to illustrate both regulatory limits and stakeholder expectations. In rail vehicles, the potential ramp-compatible vertical gap is $\Delta h \approx 210 \pm 50$ mm (difference between 550 mm and 760 mm plus clearances). The comparison reveals that only a handful of rail ramp systems are available – and the slopes they present are too steep for independent wheelchair use. In contrast, ramp systems used in urban buses are more mature – particularly in jurisdictions where automated ramps are mandatory – offering a wider selection of models and features. The systematic use of the kneeling function in urban buses reduces the effective vertical gap by around 70 mm [14]. This enables a broader range of ramp slopes with comparable or slightly longer ramp platform lengths. Additionally, floors with an inclined section near the doors decrease the vertical gap by roughly 20–30 mm (not shown in Fig. 1), a feature common to urban buses, trams and partially in some rail vehicles, further diminishes the effective ramp slope. A ramp threshold of 15 mm has been included for all models in Fig. 1.

From a geometric perspective, ramp length scales linearly with the vertical gap. However, as the vertical gap increases, the absolute differences in required ramp length between different slope thresholds become more pronounced. This explains why relatively small reductions in vertical gap (e.g. through kneeling) have a disproportionately

Table 1. Normative provisions and user critiques

Issue	Provision	User critique
Gap tolerance for level boarding	≤ 75/50 mm horizontal; ≤ 50/30 mm vertical; [8]/[13]	Tenders cite TSI PRM compliance, and bidders maximize tolerances, causing overruns that make boarding difficult.
Ramp gradient	≤ 18% slope [8]; ≤ 6% [11] [13]	An 18% slope exceeds stability limits and wheelchair feasibility, making autonomous use impractical.
Ramp edge	Up to 20 mm [9]	It reduces PTI height gaps yet still blocks boarding.
Door release	Staff-controlled door/BA release [8, 10]	Pressing outer-wall buttons can be unsafe and delay boarding.
Staff assistance	Staff's duty to assist [8]	All stakeholders agree that staff must still be ready to assist.
Lift operation	Constant manual pressure required [8]	Too demanding for some wheelchair users during the different lift phases.
Fallback provisions	Trains may run up to six days without BA [8].	Accessibility fails even with assistance, undermining travel reliability.
Responsibility for assistance	Vehicle-infrastructure operator split [8]	Creates accountability gaps; infrastructure staff only available on working times.
Level-boarding availability	One level-boarded long-distance train/h [12]	Reduced frequencies undermine PRM equality; longer connection wait times.

strong effect on the feasibility of autonomous use of ramp systems. This also underlines the request from disability associations to redefine level boarding in the TSI PRM as essentially zero vertical gap, while the current clearance values should be clearly marked as exceptional (see Table 1). Active car body lowering systems for rail vehicles are either under development or slated for launch in Europe [15].

Extending ramp lengths can reduce gradients but also add integration challenges: additional storage space, increased weight, more complex handling mechanisms, and restrictions on narrow platforms. A more robust approach may lie in combinations of BA. Additionally, onboard lifts can bridge vertical gaps at the PTI of up to 600–1200 mm thereby serving both low platforms (≤ 380 mm) and higher suburban platforms (approximately 960 mm). However, lifts generally take longer to operate (about 2 min) and present challenges in their adaptation for fully autonomous use.

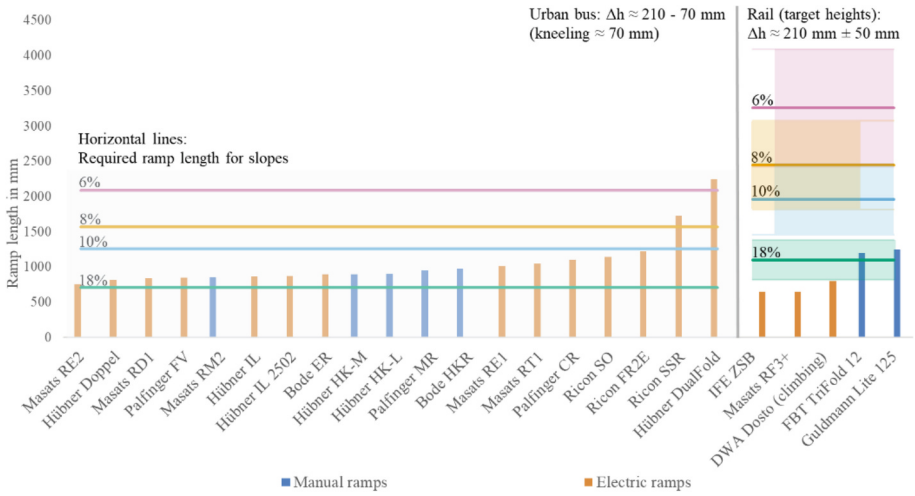


Fig. 1. Comparison of ramp lengths required to overcome a vertical gap (Δh) at slopes of 6%, 8%, 10% and 18%. For urban buses (left), Δh ≈ 140 mm due to kneeling. For rail applications (right), Δh ≈ 210 mm with tolerance bands of ±50 mm

3.3 Competing Requirements, Dissent Points and Areas of Consensus

Integrating the stakeholder dialogue and normative analysis reveals several structural tensions in the design of BA for autonomous use. Table 2 summarizes the main supposedly competing requirements and dissent points from the stakeholder's perspective identified during the dialogue. While user perspectives emphasize autonomy, usability and reliability, operators and manufacturers highlight cost efficiency, dwell times and technical feasibility as key constraints.

Despite these tensions, a core set of consensus areas has emerged, providing a clear, actionable roadmap for next-generation BA that users can operate independently:

1. The right for **spontaneous mobility** is defined as enabling the use of BA autonomously without prior registration or complex BA handling.
2. **Cycle times** of BA for independent use must not result in longer dwell times than those of the current staff-supported BA under comparable conditions.
3. **Robustness through BA redundancy**: Beyond the existing secondary manual handling of automated ramps or lifts, reliability and autonomy can be enhanced by combining independent electric and manual systems on the same door or distributing them across multiple doors. This approach improves performance in both regular operation and fault scenarios. Redundancy concepts also encompass using platform-side lifts both to sidestep the 6-day repair clause for onboard BA, and at curved stations, enabling the use of less-steep onboard ramps throughout ramp-compatible networks.
4. Sensor-based **technical monitoring** of the deployment area of BA for autonomous use is preferred over physical security barriers, in order to prevent additional obstacles for visually impaired passengers while preserving safety.
5. External onboard lifts intended for autonomous use must be large enough to carry a wheelchair and its belongings – items that have previously required assistance to be

Table 2. Identified competing requirements and dissent points

Aspect A	Aspect B	Example/implication
User Autonomy	Safety	Measures ensuring safety (e.g. staff-operated BA, clearance area blocking) often impede independent boarding.
User Autonomy	Operational Efficiency	Users demand full independence, while operators stress cost and punctuality by keeping dwell times as planned.
Redundancy & Reliability	Cost Efficiency	Backup systems boost robustness, especially in preparation for future BA operation without staff assistance, but add cost and maintenance.
Feasible Solutions	Affordability	Ambitious solutions exist, yet procurement is split between rolling-stock and infrastructure, each side favouring cheaper, minimally-compliant options or other investments.
Legacy Infrastructure	Rolling Stock	Platform reconstruction is slow and costly; operators rely on interim vehicle solutions.
Legacy Infrastructure	Standardization/Harmonization	The 76 cm federal target clashes with entrenched 55 cm regional standards in eastern and south-west Germany and neighbouring states.
Universal Thresholds	User Diversity	Fixed slope and gap tolerances cannot cover the differing degrees of disability.

brought onto the train. Accordingly, the participants agreed on a **lift-platform size of 1400 mm in length and at least 800 mm in width**. In addition, their load capacity should be increased to a minimum of 350 kg; however, disability associations still regard this figure as insufficient.

6. Wheelchair users must (and want to) issue an **active BA start command** – rather than the BA initiating itself – while the BA continuously monitors the system and the context.
7. Autonomous use does not mean without **interaction** with staff – or potentially with the driver, as is common in urban buses. The staff's normative duty to assist during regular operation and especially in evacuations must remain.

4 Conclusions

Stakeholder dissent points show, that accessibility at the PTI cannot be reduced to the application of the existing regulative framework. It demands a balance of user autonomy, safety, operational efficiency, economic feasibility and long-term system planning. The normative analysis and stakeholder dialogues reinforced this observation, revealing a mismatch between the standards and the real usability of BA. Nevertheless, the discussion rounds yielded several converging areas, even if not all participants were present at every meeting: the need for redundant BA systems; a common understanding of the concept of spontaneous, unregistered use of BA; technical instead of physical monitoring of BA unfolding areas; non-autonomous BA activation commands; and suitable lift dimensions.

The detailed findings are included in a set of consolidated requirements that aim to guide future tendering and standardization activities. The long-term goal is to ensure that upcoming fleet procurements and retrofitting measures do not reproduce current shortcomings but instead enable more reliable and independent mobility for all.

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