Plan Now, Ride Later: Simulation-Based Fleet Optimisation and Inclusive Service Design for Cities

Isabella Hinterleitner, Daniel Deutsch, Katharina Köglberger, Victoria Mentin

(Dr. DI, Mag. Isabella Hinterleitner M.Sc, Tech Meets Legal GmbH, Gersthofer Straße 9, 1180 Wien, hinterleitner@techmeetslegal.at)
(Daniel Deutsch LL.M., M.Sc,, Tech Meets Legal GmbH, Gersthofer Straße 9, 1180 Wien, d.deutsch@techmeetslegal.at)
(DI Katharina Köglberger Bakk. Phil, Tech Meets Legal GmbH, Gersthofer Straße 9, 1180 Wien, koeglberger@techmeetslegal.at)
(Mag. Victoria Mentin, BA, Tech Meets Legal GmbH, Gersthofer Straße 9, 1180 Wien, mentin@techmeetslegal.at)

DOI: 10.48494/REALCORP2026.2090

1 ABSTRACT

Public transport systems of all sizes face a common dilemma in the mobility transition: introducing flexible, on-demand services to reduce private car dependency without incurring the financial risks of oversized fleets. While Mobility-on-Demand (MoD) promises efficiency, authorities often lack empirical data to determine the exact "tipping point" where service quality justifies the cost. The integration of MoD solutions is often hard to predict due to different city networks as well as supporting measures for the integration of MoD services. Furthermore, ensuring equitable access for vulnerable groups remains a critical challenge.

This paper presents a novel simulation framework to bridge a multidimensional planning gap. Based on the funded project FLIPFLOP (Flexible Line and On-demand Public transport) the simulation focuses on a representative real-world city network in Austria. Using an open-source agent-based python simulation dynamic transit operations have been modelled by applying the Alonso-Mora algorithm for on-demand high-capacity ride-pooling. The approach supports the theory that the generation of on-demand ride pooling solutions depend on the relevant public city network, population size, job availability, cultural locations and many more variables. The research further focuses on a quantitative sensitivity analysis of fleet sizes under peak-hour stress tests, distinguishing itself by embedding diversity-specific constraints – such as wheelchair accessibility and varying digital literacy levels – directly into the dispatching logic.

While project FlipFlop has focused on the city of Klagenfurt the wider simulation framework will in addition support the cities of Graz, Innsbruck, Linz and Vienna, where on-demand ride pooling can be integrated within public transport.

Simulations reveal a non-linear efficiency frontier and have identified a distinct operational "sweet spot" at a specific fleet density that sustains a good service rate with average wait times stabilizing at a few minutes. Reducing fleet capacity by just a few percent below this threshold causes rejection rates to spike disproportionately, rendering the service unreliable. Preliminary simulations suggest accessibility features can be operationally integrated without evident service collapse, contingent on validation with real demand patterns and target user populations.

Validating parameters through agent-based simulation facilitates providing a “Digital Twin” methodology that empowers planners to test service levels before procurement, offering modern mobility services that are tailored to user needs and cost-efficient. Suburban areas may be integrated seamlessly in the deployment design, as may be non- technical aspects, like compliance with the Austrian Transport Law, EU passenger rights, and equality laws. The results offer a validated roadmap for implementing inclusive on-demand transit that complies with modern service standards, ensuring that future investments are based on hard, dependable data rather than rough estimates.

Keywords: Ridepooling, Agent-Based Simulation, Urban Planning, Inclusive Mobility, Social Impact

2 INTRODUCTION

2.1 Challenges of medium-sized cities in Austrian in the field of mobility

In Austria, cities between 4500 and 250 000 inhabitants are classified as midsized cities, where Klagenfurt can be identified as one as well as Innsbruck (132.499) and Salzburg (156,852).(Veneri et al., 2025) The logistics of transport within these cities is based on private vehicle trafficespecially due to the fact that commuters come to the city during day time. For example, in Klagenfurt a lot of comuters travel from Villach or Wolfsberg to Klagenfurt, in Salzburg from the surroundings following six main corridors with hotspots as Mülln and Salzburg Süd, and in Tirol from the “Innsbruck-Land” district. These circumstances result in a much higher number of private cars than in larger Austrian cities such as Graz and Linz, and even twice as many as in capital cities with good public transport systems and/or high proportions of cyclists.

City	**Number of citizens**	**Private cars/ 1.000 habitants**	**Year**	**Source**
Bregenz	~ 29.000	396	2023	VCÖ(VCÖ, 2025)
Eisenstadt	~ 15.000	515	2023	VCÖ(VCÖ, 2025)
Graz	~ 300.000	391	2024/25	VCÖ(VCÖ, 2025)
Innsbruck	~ 132.000	333	2024/25	ORF (ORF, 2025)
Klagenfurt	~ 104.000	523	2023	VCÖ(VCÖ, 2025)
Linz	~ 210.000	414	2023	ORF (ORF, 2023)
Salzburg	~ 156.000	383	2024/25	VCÖ(VCÖ, 2025)
St. Pölten	~ 27.000	464	2023	VCÖ(VCÖ, 2025)
Wien	~ 1.980.000	284	2024/25	(W24, 2024)
Amsterdam	~ 882.000	250	2023	Gemeente Amsterdam – Mobiliteitsmonitor(GAS, 2024)
Berlin	~ 3.850.000	282	2022	Amt für Statistik Berlin-Brandenburg (AFB, 2023)
Copenhagen	~ 632.000	209	2020	Radkompetenz Dänemark (RDM, 2020)
London	~ 9.400.000	280	2021	Office for National Statistics (ONS) (ONS, 2021)
Paris	~ 2.165.000	270 – 330	2023	Atelier Parisien d'Urbanisme (APURa, APURb 2023)

Table 1: Comparison of cities – Ratio of population and number of private cars per 1,000 inhabitants

Public transport in Klagenfurt, as well as Salzburg and Innsbruck is mainly based on busses. Innsbruck is the only one of these three cities with a small tram network around the inner city.In Klagenfurt as well the bus network leads to the inner city. In Salzburg the bus line network is less focused on one place in the city center.

2.2 Mobility-on-Demand (MoD) in Austria and Europe

In Austria, Mobility-on-Demand is still in its early stages. Projects such as Postbus Shuttle(POST, 2024), ISTmobil(IST, 2023) and RegioFlink (REG, 2023) primarily serve rural and suburban areas, while in cities like Salzburg, Innsbruck, and Klagenfurt, the share in the modal split remains marginal (below 0.5%). These services complement traditional public transport but are largely pilot initiatives. Salzburg is testing flexible minibuses in peripheral zones, Innsbruck integrates on-demand services into the Tyrolean transport association (VVT, 2024) , and Klagenfurt relies on regional call-bus systems. In comparison, European metropolises such as London and Paris show slightly higher usage (1–2%), mainly through ride-hailing services like Uber and Bolt as well as city-run on-demand buses. (RIDE, 2022)(OECD, 2022) Overall, MoD's market share across Europe is still very small but is seen as a strategic complement for the "last mile" and to relieve private car traffic. Within this article we will focus on comuters that travel from the suburbs to the inner city center by using MoD such as demand-oriented transport.

2.3 Definition of MoD

Mobility-on-Demand (MoD) refers to flexible, user-centric transport services – such as ride-hailing, shared shuttles, and on-demand minibuses – that operate without fixed routes or timetables, and are dynamically dispatched based on real-time requests, typically via digital platforms. This model complements traditional public transit by offering customizable, point-to-point or stop-to-stop solutions, especially useful for first/last-mile connectivity and in low-density areas such as Graz, Klagenfurt, and Innsbruck. (UITP, 2024)

2.4 Potentials and advantages of MoD for cities

Mobility-on-Demand (MoD) offers cities a flexible and user-centric alternative to traditional public transport. Unlike fixed-route and fixed-schedule systems, MoD services are demand-responsive, providing tailored routing and dynamic dispatching based on real-time requests. This adaptability makes MoD particularly valuable for areas where conventional transit is economically or operationally challenging, such as low-density neighborhoods or during off-peak hours. While mass transit excels at moving large volumes efficiently, MoD complements it by improving coverage and accessibility, especially for first- and last-mile connections.

According to International Association of Public Transport(UITP) (UITP, 2023), shared and on-demand mobility solutions improve cities in five key ways:

- Reducing congestion – By pooling rides and optimizing routes, MoD decreases the number of single-occupancy vehicles on the road.
- Lowering emissions – Shared services and integration with electric fleets help cut CO_2 and air pollutants.
- Enhancing accessibility – MoD bridges gaps in public transport networks, serving areas underserved by fixed routes.
- Optimizing space – Fewer private cars mean less demand for parking and more space for people and green infrastructure.
- Supporting multimodality – MoD integrates seamlessly with public transport, cycling, and walking, creating a more sustainable urban mobility ecosystem.

Together, these benefits position MoD as a strategic complement to traditional transit, enabling cities to become more sustainable, efficient and inclusive. Being mobile is a measure of social inclusion nowadays.

2.5 Challenges for cities to introduce MoD

While Mobility-on-Demand (MoD) offers flexibility and improved accessibility, its implementation in cities comes with significant challenges. The integration of MoD solutions is often hard to predict due to different city networks as well as supporting measures for the integration of MoD services. Unlike traditional public transport, which benefits from economies of scale and established infrastructure, MoD requires complex digital platforms, real-time data integration, and dynamic fleet management. This technological dependency can be costly and demands strong coordination between operators, municipalities, and IT providers. Another major challenge is financial sustainability. MoD services often have higher per-passenger costs compared to mass transit, making them difficult to scale without subsidies or innovative pricing models. Cities must also address regulatory and legal frameworks, including licensing, insurance, and labor conditions for drivers, which vary widely across jurisdictions. Furthermore, space and traffic management pose issues: if MoD services are not well integrated with public transport, they risk increasing congestion rather than reducing it. Finally, user adoption and equity are critical – ensuring that MoD does not become an exclusive service for tech-savvy or affluent users, but remains accessible to all, including vulnerable groups. In summary, while MoD can complement traditional transit, cities must overcome barriers related to technology, cost, regulation, and social inclusion to make these services truly sustainable.

2.6 Project FlipFlop

FLIPFLOP (Flexible Line and On-demand Public transport)is a collaborative research project funded by the Austrian Research Promotion Agency (FFG) within the program AI for Green. The consortium brings together leading partners: AIT Austrian Institute of Technology, Tech Meets Legal GmbH, Landeshauptstadt Klagenfurt am Wörthersee, KMG Klagenfurt Mobil GmbH, pdcp GmbH and DatenVorsprung GmbH. Running from 2024 to 2026, FLIPFLOP addresses the challenge of integrating on-demand mobility into public transport systems for medium-sized cities. The project develops AI-driven algorithms and digital platforms to optimize dynamic routing, fleet management, and demand prediction, aiming to reduce operational costs and improve accessibility. By combining real-time data analytics with inclusive service design, FLIPFLOP seeks to create scalable, sustainable solutions that complement traditional transit and support multimodal urban mobility. (FLIP, 2024)

3 METHODOLOGY

3.1 Alonso-Mora-Algorithm and FleetPy

Using an open-source agent-based python simulation dynamic transit operations have been modelled by applying the Alonso-Mora algorithm for on-demand high-capacity ride-pooling. This algorithm, introduced by Alonso-Mora (Alonso-Mora et al.,2017), solves the dynamic trip-vehicle assignment problem for ride-pooling services. (Engelhardt et al., 2022) It works by generating all feasible combinations of passenger requests and vehicle routes under strict constraints such as maximum waiting time and detour limits. These combinations are then optimized using an Integer Linear Programming (ILP) approach to minimize system-wide costs, such as total travel time, while maximizing the number of served customers. The algorithm is particularly suited for high-capacity pooling scenarios because it efficiently handles large sets of requests and vehicles in real time.

To implement and test such algorithms, the FleetPy framework has been developed as an open-source, modular simulation tool for Mobility-on-Demand (MoD) services. FleetPy is written in python and designed for highly detailed modeling of user-operator interactions, including real-time request-offer decision processes. Its modular architecture allows researchers and operators to integrate multiple MoD providers, customize fleet control strategies, and simulate complex behaviors such as repositioning, dynamic pricing, and charging management. FleetPy supports different simulation flows – Immediate Decision Simulation (IDS) and Batch Offer Simulation (BOS) – to model either instant responses or batched optimization of requests. The framework also includes advanced routing modules, demand modeling, and infrastructure components, enabling realistic studies of operational efficiency and regulatory impacts. By combining these features, FleetPy provides a flexible environment for evaluating algorithms like Alonso-Mora's under various urban mobility scenarios, from small-scale pilots to large metropolitan networks.

3.2 Fleetpy for FLIP-FLOP and Use Case-Definition

Several use cases highlight the need for integrating diversity factors into on-demand mobility solutions. First, universities and educational institutions experience strong demand peaks at specific times, requiring flexible routing and dynamic fleet allocation to handle fluctuating volumes. Second, digital competence significantly influences accessibility: users with limited digital skills face barriers when booking rides via apps, which can lead to algorithmic bias favoring tech-savvy users. Third, families with multiple children need tailored solutions such as semi-flexible pickup points, longer boarding times, and predictive capacity planning to accommodate strollers and additional luggage. Across all scenarios, incorporating diversity features – such as age, mobility limitations, and socio-economic conditions – into simulation and forecasting models ensures fairer, more inclusive service design.

The approach used in FLIPFLOP supports the theory that the generation of on-demand ride pooling solutions depends on the relevant public city network, population size, job availability, cultural locations and many more variables. The research focuses on comparative scenario analysis of fleet sizes under peak-hour stress tests, modeling diversity through adjusted parameters – such as extended boarding times for wheelchair-accessible vehicles (60s vs. 30s), increased capacity requirements for strollers and wheelchairs (2 seats per unit), and varying digital literacy levels through different booking decision windows – which are integrated into the fleet control system's time and capacity constraints.The simulation in FLIPFLOP focuses on a representative real-world city network of Klagenfurt in Austria. The simulation framework has been uploaded in GitGub as a private repository and will be shared after the planned enhancement as a public repository.

3.3 Methodological Limitations and Ongoing Work

3.3.1 Current Limitations

The present analysis employs two network configurations across scenarios: One network for peak-hour simulations, and one network for all-day and accessibility use cases. This design decision, driven by computational constraints during rapid prototyping, confounds spatial and temporal effects, limiting causal inference about demand density impacts. Controlled re-runs isolating network topology from demand variables are planned for Phase 2.

Demand synthesis for Klagenfurt scenarios currently employs synthetic generation based on aggregate commuter flow data from Statistik Austria and gravity model principles. Validation against disaggregated trip diary data from planned 2026 Klagenfurt mobility surveys remains pending. Temporal demand distributions (uniform vs. clustered) have not been empirically validated; sensitivity analyses exploring alternative distributions are underway.

Accessibility modeling via "WaitingTimeSensitiveLinearDeclineRequest" represents a methodological innovation integrating user patience dynamics and decision times (20–300 seconds) directly into dispatch logic. Parameter calibration is based on literature estimates and preliminary stakeholder interviews; systematic validation with target user groups (seniors, persons with disabilities) is scheduled for Q2 2026.

Statistical limitations: Current results report single-run point estimates without confidence intervals. Multiple replications (n=10+ per scenario) with stochastic sensitivity analysis are planned but not yet completed due to computational resource constraints. Sample sizes for UC2/UC3 (5–7 served requests per 350 total) fall below thresholds for robust statistical inference.

These limitations motivate cautious interpretation of findings and do not invalidate the simulation framework's utility for comparative scenario analysis and threshold identification.

3.3.2 Empirical Demand Calibration via MOIA Partnership

To address synthetic demand uncertainties, the FLIPFLOP consortium is partnering with MOIA Mobility Analytics (Volkswagen Group) in Q1-Q2 2026 to acquire operational ridepooling data from Hamburg. MOIA's dataset (11M+ rides, January 2023-March 2024) represents the only European city-scale on-demand service with research-grade data granularity. MOIA operates 500+ electric vehicles (including 15 wheelchair-accessible) across a 270 km² service area with 12,500 virtual stops (10,000 wheelchair-accessible), serving 2.9M passengers annually (2023) and achieving 77% pooled trip rates with 11-minute average wait times.

Validation methodology:

- Temporal clustering verification: Compare Klagenfurt's peak-hour concentration (50 req/h over 2h) against MOIA Hamburg patterns scaled to population ratio (105k:1,900k). Test hypothesis that peak demand represents similar % of daily total across city sizes.
- Spatial hotspot validation: Benchmark synthetic origin-destination matrices against MOIA's district-level demand flows (e.g., suburban-urban asymmetries, university district peaks).
- User patience calibration: Replace assumed WaitingTimeSensitiveLinearDeclineRequest decision times (20-300s) with empirical distributions from MOIA's 445,000 users (2023). Stratify by demographics (students 20s vs. seniors 300s assumptions tested against reality).
- Demand sensitivity incorporation: Integrate MOIA's event-impact coefficients (6× baseline demand for transit strikes, 2-11% increase for sports/concerts, temperature/precipitation non-significant) into Klagenfurt scenario design.
- Accessibility benchmark comparison: Test UC2/UC3 assumptions (extended boarding times, fleet capacity impacts) against MOIA's real-world performance

3.4 Implementation beyond FLIP-FLOP

While project FLIPFLOP has focused on the city of Klagenfurt the wider simulation framework will in addition support the cities of Graz, Innsbruck, Linz and Vienna, where on-demand ride pooling can be integrated within public transport.

4 DATABASE

4.1 Dataset availability for MoD

The development and evaluation of Mobility-on-Demand (MoD) systems rely heavily on high-quality datasets that capture real-world travel demand, network conditions, and user behavior. In Europe, however, publicly available datasets for MoD research remain scarce compared to North America and Asia. Most European cities provide aggregated mobility statistics or open transport data portals (e.g., GTFS feeds for public transport), but detailed trip-level datasets for ride-pooling or on-demand services are limited due to privacy regulations (GDPR) and fragmented data ownership among operators. Researchers often resort to synthetic demand generation or rely on non-European datasets (e.g., NYC TLC Taxi dataset) adapted for Amsterdam for simulation studies. Initiatives such as MaaS pilot projects and EU-funded programs (e.g., Horizon Europe) are starting to encourage data sharing, but standardized, open-access MoD datasets for European cities are still in early stages. (Gregurić et al., 2025)This lack of granular data poses challenges for algorithm development and scalability studies, making simulation frameworks and synthetic augmentation techniques increasingly important for research.

4.2 Used dataset

This study employs the FleetPy/FLIPFLOP simulation framework (Technical University of Munich, open-source) to analyze ridepooling deployment for Klagenfurt, Austria (105,000 inhabitants). The Klagenfurt transportation network (3,435 nodes, 6,870 edges, radiocentric structure) was extracted from OpenStreetMap. Given the absence of publicly available ridepooling operational data for Klagenfurt – a challenge common to most European cities – current simulations utilize synthetic demand scenarios to test fleet sizing and operational strategies under controlled conditions. These scenarios (e.g., 100-500 trip requests distributed over 2-16 hour periods with peak-hour concentrations) enable algorithmic performance evaluation and sensitivity analysis but are not calibrated to actual Klagenfurt travel behavior. While the spatial distribution of synthetic requests reflects urban structure (higher density near city center, university, and main station), the absolute demand volumes and temporal patterns are estimates rather than data-driven predictions, limiting their use for precise market sizing or adoption forecasting. Validation gap: Current demand synthesis lacks calibration against disaggregated trip-level data (actual origin-destination pairs, temporal clustering patterns, user demographics). Phase 2 MOIA partnership will provide empirical benchmarks for validation and recalibration

4.3 Planned Enhancement: MOIA Demand Transfer Model:

Future work will integrate evidence-based demand forecasts using the Spatial Regression Transfer Model developed by Zwick & Axhausen (Zwick & Axhausen, 2022) in collaboration with MOIA Mobility GmbH. This methodology addresses the data scarcity problem by transferring ridepooling demand patterns learned from cities with operational data to new deployment locations. Trained on 1.2 million real MOIA trips from Hamburg and 330,000 from Hannover (2019-2020, proprietary), the model uses SLX regression (Spatial Lag of X) to predict zone-level demand based on publicly extractable urban characteristics: population and employment (Statistik Austria), points of interest – restaurants/culture/shops (OpenStreetMap, with gastronomie explaining ~35% of variance), public transit accessibility (GTFS), and centrality measures (distance to main station, ~25% variance explained). The Hamburg→Hannover validation demonstrated 19% demand overestimation with spatially random errors. For Klagenfurt, we anticipate 30-60% forecast uncertainty due to: (1) larger extrapolation gap (Hamburg 1.9M → Klagenfurt 105k inhabitants = factor 18 vs. Hamburg→Hannover factor 3.5), (2) substantially higher car ownership (523/1,000 vs. ~400/1,000 – highest in Austria), (3) different transit structure (radial bus system vs. comprehensive metro/S-Bahn), and (4) tourism seasonality (Wörthersee lake proximity). Klagenfurt-specific calibrations will incorporate university demand cycles (Alpen-Adria-Universität: 12,000 students, semester on/off periods), regional commuter flows from Villach/Wolfsberg (ÖSTAT pendler data), and summer tourism adjustments (+30% May-September weekends). Simulations will employ ±40% demand variation scenarios to ensure fleet sizing recommendations remain robust across plausible adoption ranges. While MOIA's operational data is proprietary, the regression methodology is fully documented in peer-reviewed literature, and all predictor variables are extractable from public sources (OpenStreetMap, Statistik Austria, GTFS), enabling methodological reproducibility.

5 LEGAL FRAMEWORK

Implementing Mobility-on-Demand (MoD) s services in cities requires, among other things, the adaptation of operating procedures to national transport law, EU passenger rights, equality and anti-discrimination regulations, and the EU AI Act for AI-supported dispatching and forecasting systems. This overview provides only a superficial sketch, highlighting potential problem areas and challenges without claiming exhaustive coverage.

5.1 Austrian Transport Law

The organizational and financial framework for public passenger and regional transport in Austria is governed by the Öffentlicher Personennah- und Regionalverkehrsgesetz 1999 (ÖPNRV-G). The primary legal basis for passenger transport is provided by the Kraftfahrliniengesetz (KflG) and the Gelegenheitsverkehrs-Gesetz (GelverkG), which distinguish between scheduled and non-scheduled commercial passenger transport. The applicable legal basis in individual cases depends substantially on the specific design of the transport service. Mobility-on-Demand models (MoD) as Micro-PTV are fundamentally permissible as alternative operating forms under § 5 para 2 ÖPNRV-G, whereby depending on the design, both the KflG and the GelverkG may apply, though other models are also conceivable, leading to no concrete classification and creating legal uncertainties with corresponding need for action (Kahl, 2023).

5.2 EU Passenger Rights

Passenger rights thus vary significantly by category, from full protection for long regular journeys to reduced rights for short regular journeys and occasional services. Regulation (EU) No 181/2011 establishes passenger rights in bus and coach transport and clearly distinguishes between regular and occasional services, as well as between long and short journeys. According to Art 2 para 1, the regulation "shall apply to passengers travelling on regular services available to all users of the service where the boarding or alighting point is situated on the territory of a Member State and where the scheduled distance of the service is 250 km or more". In such cases, passengers have comprehensive rights, such as compensation for long delays or cancellations, support services like meals and accommodation, and extensive information and complaint rights. For regular services under 250 km, a limited set of passenger rights applies under Art 2 para 2, particularly the prohibition of discrimination, special protection for persons with disabilities and reduced mobility (including compensation for damaged mobility aids), and obligations for adequate information and an effective complaint procedure. For mobility services classified as occasional services, only minimal rights apply under Art 2 para 3, such as anti-discrimination rules, accident compensation, and assistance for persons with disabilities. In Austria, relevant regulations supplement EU passenger rights depending on the mode of transport by imposing additional operator obligations regarding fares, carriage conditions, accessibility, safety standards, and customer service. State-level rules or concessions often establish further protective layers, such as binding service quality requirements, accessibility provisions, replacement transport arrangements, and enhanced documentation and information duties. (APF, 2026) This creates a multi-layered framework. EU rights serve as the binding minimum standard, reinforced by national, transport-specific requirements that purposefully enhance passenger protection across Austria.

5.3 Equality & Accessibility (National and Länder level)

Mobility-on-Demand services must comply with Austrian anti-discrimination law, which is based on constitutional principles, international agreements such as the UN Convention on the Rights of Persons with Disabilities (CRPD) and EU-level foundations such as the Equal Treatment in Goods and Services Directive (2004/113/EC), the Employment Equality Directive (2000/78/EC) or the Racial Equality Directive (2000/43/EC). Anti-discrimination law, as a cross-cutting matter, is regulated by both the federal government and the states within their respective constitutional competencies, meaning there is no uniform regulatory authority (Greif & Ulrich, 2019).At the federal level, equal treatment acts such as the Gleichbehandlungsgesetz (GlBG) must be considered, while the Bundes-Behindertengleichstellungsgesetz (BGStG), the Behinderteneinstellungsgesetz (BEinstG) and the Bundesbehindertengesetz (BBG) ensure equality and specific protection for persons with disabilities. This is supplemented by the European Accessibility Act (2019/882/EC), whose transposition into the Barrierefreiheitsgesetz (BaFG) standardizes the digital accessibility of apps and platforms and obliges the private sector to ensure accessibility for users with disabilities. Depending on the circumstances, the equal treatment and anti-discrimination laws of the federal states may also be relevant. State-level anti-discrimination law is likewise inconsistent and encompasses varying scopes of application (Greif & Ulrich, 2019).

5.4 EU AI Act – obligations for AI-enabled MoD platforms

Dispatching based on artificial intelligence, demand prediction, or dynamic pricing could fall within the AI, the EU AI Act (in force since Aug 1, 2024, with staged applicability to Aug 2, 2026) (EU, 2024)imposes a risk-based framework. Furthermore, High-risk AI systems require:

- Risk management, data quality and representativeness, technical documentation, logging, transparency to downstream users, human oversight, and accuracy/robustness/cybersecurity measures (Art. 9–15).
- Organizational duties (registration, conformity assessment, CE marking, information and record-keeping, incident reporting, cooperation with authorities). Transparency duties may also apply to chatbot interfaces used in customer service. For foundation models/generative AI, specific obligations (Art. 28b) cover governance and data management.
- Fundamental Rights Impact Assessment for High-Risk AI Systems (Art. 27)

6 PRELIMINARY FINDINGS AND OPEN QUESTIONS

6.1 Validated Proof-of-concept: Peak-Hour Demand Concentration

Simulations of 100 requests over 2 hours (50 requests/hour, 07:00–09:00) on the Klagenfurt network demonstrate operationally viable service rates across fleet sizes of 20–40 vehicles (8 seats each, 30-second boarding time). Figure 1 containing four plots summarized this:

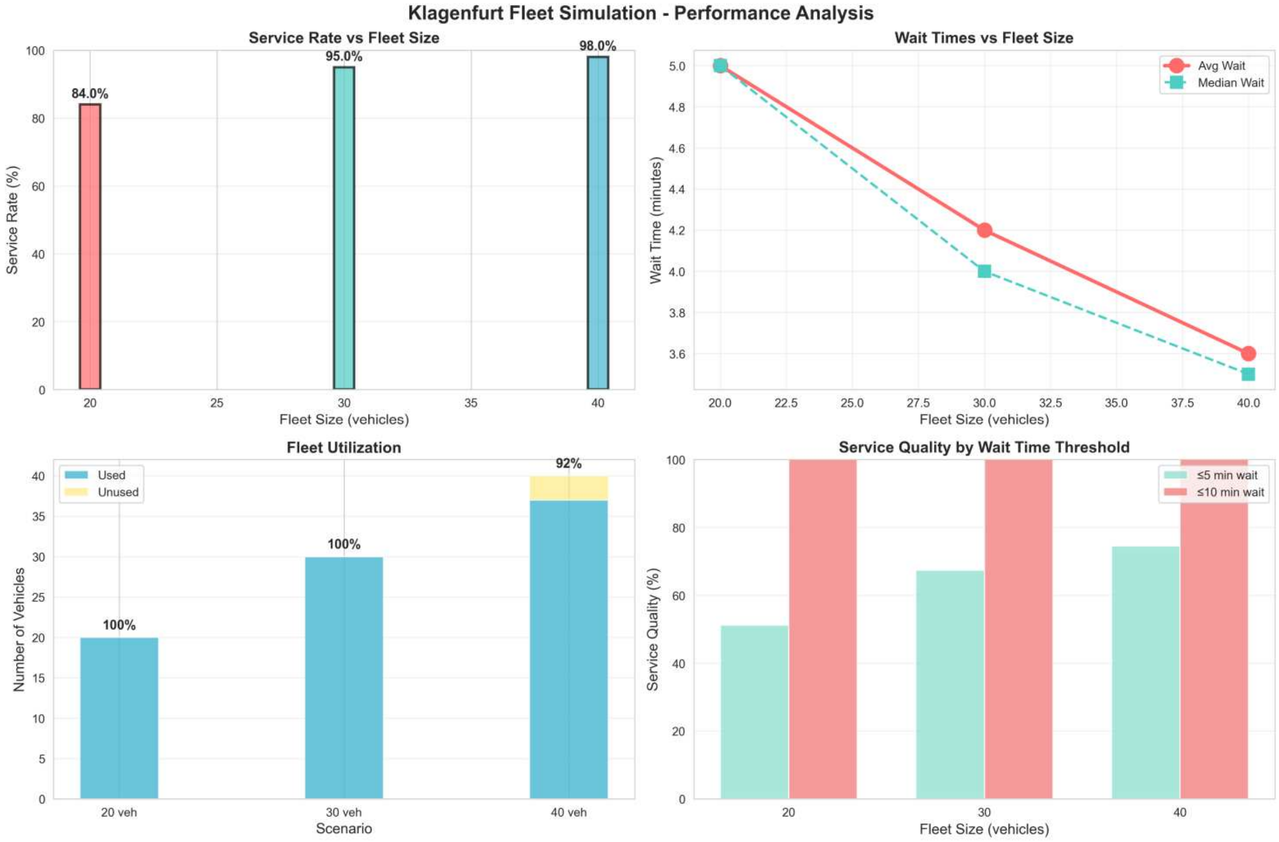

Figure 1 Left top: fleet size scaling from 20 to 40 vehicles. Left bottom: Fleet utilization from 20 to 40 vehicles. Right top; Average wait time in dependence of the fleet size. Right bottom: service quality in dependence of fleet size.

Critical density threshold: Fleet scaling from 20 to 30 vehicles (+50% capacity) yields a disproportionate service rate improvement (84%→95%, +13 percentage points absolute), suggesting a non-linear efficiency frontier consistent with ride-pooling literature. Below this threshold, vehicle supply constraints cause rejection rates to spike (16% rejection rate at 20 vehicles drops to 5% at 30 vehicles); above it, marginal returns diminish (30→40 vehicles: +3 percentage points improvement).

This pattern aligns with Mühle (2023), who demonstrate that fleet size N scales with demand according to a power law N ≈ Demand^1.15, implying increasing returns to scale until capacity saturation. The observed threshold suggests a critical fleet density of approximately 0.6 vehicles per req/h (30 vehicles / 50 req/h) to maintain >90% service rates.

Wait time performance: Average wait times decline from 5.0 minutes (20 vehicles) to 3.6 minutes (40 vehicles), remaining within user acceptability thresholds and comfortably below the 8-minute maximum wait constraint. Vehicle utilization reaches 100% for constrained fleets (20–30 vehicles), confirming demand sufficiency during peak periods and indicating no idle capacity waste.

Planning implications: For mid-sized cities with comparable peak-hour demand profiles (~50 req/h morning commuter concentration), a fleet of ~30 vehicles (0.6 vehicles per req/h) represents a preliminary critical density benchmark for maintaining >90% service rates. This finding informs go/no-go decisions for pilot deployments targeting concentrated commuter demand.

6.2 Geographic Coverage vs. Capacity Constraints: Context-Dependent Fleet Sizing

Preliminary finding on capacity-fleet trade-offs: The study compares 8-seat vehicle configurations across 8, 16, and 24-unit fleets. While capacity increases (relative to previous consortium studies using 4-seat vehicles) provide operational benefits in some scenarios, the minimum viable fleet size for 92% service coverage in Klagenfurt's current 100 req/2h peak-hour demand (distributed across 6 zones) remains approximately 24 vehicles – requiring further investigation to determine whether this reflects genuine capacity-irrelevance or context-specific constraints.

6.3 Three competing hypotheses warrant investigation in Phase 2:

- Geographic coverage dominates (our initial interpretation): Zone-level service distribution requires minimum fleet size regardless of per-vehicle capacity. If true, this would diverge from high-density benchmarks (Alonso-Mora et al. 2017: NYC achieves capacity-fleet trade-offs at 12,000 req/h with 10-seat vehicles).
- Low pooling rates suppress capacity advantage: With only 50 req/h across 6 zones, vehicles rarely carry >2 passengers simultaneously (implying low pooling rates). At low simultaneity, increasing capacity from 4→8 seats provides minimal benefit, consistent with Zech et al. (2022): "capacity constraints reduce effective available vehicles... with low demand density, capacity advantage decreases as vehicles operate below capacity."
- Constraint interaction effects: If maximum wait time (8 min) or detour factor (40%) constraints frequently bind before capacity, then adding capacity provides no service rate improvement. This would be unique to Klagenfurt's network geometry and demand distribution.

6.4 Inclusive fleet configurations

The simulation framework enables testing of diversity-specific operational scenarios to address accessibility gaps for vulnerable user groups. Two use cases were modeled:

UC2 (Digital Competence): Elderly users with limited digital literacy face barriers when booking rides via apps. The simulation incorporates extended decision windows (allowing longer booking confirmation times), phone support alternatives (manual operator-assisted booking), and simplified interface pathways. These adjustments are modeled through parameter variations in the booking process rather than algorithmic modifications, testing whether service quality can be maintained when user response times vary by demographic group.

UC3 (Physical Accessibility): Families with strollers and wheelchair users require larger, barrier-free vehicles. The framework models mixed-fleet scenarios combining standard 8-seat vehicles (30s boarding time) with wheelchair-accessible 12-seat vehicles (60s boarding time). Accessibility requirements are represented through increased capacity allocation (wheelchair/stroller users occupy 2 seats vs. 1 for standard passengers) and extended boarding durations. Planned simulation scenarios test fleet compositions ranging from 0% to 50% accessible vehicles to identify the minimum proportion required to maintain service rates for the estimated 15% of demand requiring accessibility features.

Current Status: Quantitative results for UC2 and UC3 scenarios are subject to ongoing validation with improved demand synthesis. Initial framework testing confirms that diversity requirements can be incorporated through adjusted operational parameters (boarding times, capacity allocation, decision windows) without modifying core dispatch algorithms. Full sensitivity analyses comparing baseline performance to inclusive fleet configurations will be completed following integration of the MOIA demand transfer model, enabling robust recommendations on whether social equity requirements compromise operational efficiency or can be managed through intelligent repositioning and capacity planning.

7 CONCLUSION

Validating parameters through agent-based simulation facilitates providing a "Digital Twin" methodology that empowers planners and cities to test various service levels before procurement, offering modern mobility services tailored to user needs and cost-efficiency. This research demonstrates the FleetPy framework successfully models Klagenfurt's real-world network topology and integrates accessibility constraints operationally, enabling scenario-based deployment design for suburban and urban areas alike.

Crucially, fleet sizing estimates will be calibrated against MOIA's 1.2M real Hamburg ridepooling trips using validated spatial regression methodology (Zwick & Axhausen 2022, 19% transfer accuracy proven Hamburg→Hannover), transforming synthetic predictions into empirically grounded forecasts. Compliance with the Austrian Gelegenheitsverkehrsgesetz, EU passenger rights (181/2011), and equality laws is statute-grounded and directly actionable (Section 6.4). While Klagenfurt-specific demand carries 30–60% forecast uncertainty due to structural differences from Hamburg, this bounded range is manageable through scenario planning and enables planners to stress-test deployment across multiple adoption curves.

Accessibility equity performance will be quantitatively validated by Q2 2026. Combined with a phased pilot approach (2026–27) and adaptive fleet sizing, this framework transforms theoretical feasibility into operational reality, ensuring that future investments in Klagenfurt's inclusive on-demand transit are based on hard, dependable data anchored in real ridepooling operational evidence rather than rough estimates or synthetic assumptions.

8 ACKNOWLEDGEMENT

The research was conducted within the project FLIP-FLOP, funded within the framework topic "Digital Technologies", program “AI for Green 2023 by the Austrian Federal Ministry for Innovation, Mobility and Infrastructure (BMIMI) and managed by the Austrian Research Promotion Agency FFG.

9 REFERENCES

AFB (2023): Amt für Statistik Berlin-Brandenburg: Bestand an privaten Personenkraftwagen in Berlin 2022. Berlin, 2023.

Alonso-Mora et al. (2017): Alonso-Mora, J., Samaranayake, S., Wallar, A., Frazzoli, E., Rus, D.: On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment. In: Proceedings of the National Academy of Sciences, Vol. 114, Issue 3, pp. 462–467. Washington D.C., 2017.

APF (2026): Agentur für Passagier- und Fahrgastrechte: Ihre Rechte als Fahrgast im Busverkehr. Wien, 2026.Available athttps://www.apf.gv.at/bus-allgemeines

APURa(2023): Apur – Atelier Parisien d’Urbanisme: Mobility and On-Demand Services in Île-de-France. Paris, 2023.

APURb(2023): Apur – Atelier Parisien d’Urbanisme: Mobilité et déplacements en Île-de-France – Motorisation et tendances 2023. Paris, 2023.

BaFG (2023): Bundesgesetz über Barrierefreiheitsanforderungen für Produkte und Dienstleistungen (Barrierefreiheitsgesetz – BaFG) BGBl 2023/76 idgF.

BBG (1990): Bundesgesetz vom 17. Mai 1990 über die Beratung, Betreuung und besondere Hilfe für behinderte Menschen (Bundesbehindertengesetz – BBG) BGBl 1990/283 idgF.

BEinstG (1970): Behinderteneinstellungsgesetz (BEinstG) BGBl 1970/22 idgF.

BGStG (2005): Bundesgesetz über die Gleichstellung von Menschen mit Behinderungen (Bundes-Behindertengleichstellungsgesetz – BGStG) BGBl I 2005/82 idgF.

Council of the European Union (2000): Council Directive 2000/43/EC of 29 June 2000 implementing the principle of equal treatment between persons irrespective of racial or ethnic origin. OJ L 2000/180, 22. https://eur-lex.europa.eu/eli/dir/2000/43/oj

Council of the European Union (2000): Council Directive 2000/78/EC of 27 November 2000 establishing a general framework for equal treatment in employment and occupation. OJ L 2000/303, 16. https://eur-lex.europa.eu/eli/dir/2000/78/oj/eng

Council of the European Union (2004): Council Directive 2004/113/EC of of 13 December 2004 implementing the principle of equal treatment between men and women in the access to and supply of goods and services. OJ L 2004/373, 37. https://eur-lex.europa.eu/eli/dir/2004/113/oj/eng

Council of the European Union (2019): Directive (EU) 2019/882 of the European Parliament and of the Council of 17 April 2019 on the accessibility requirements for products and services (Text with EEA relevance). OJ L 2019/151, 70. https://eur-lex.europa.eu/eli/dir/2019/882/oj/eng

CRPD (2008): Übereinkommen über die Rechte von Menschen mit Behinderungen sowie das Fakultativprotokoll zum Übereinkommen über die Rechte von Menschen mit Behinderungen (Convention on the Rights of Persons with Disabilities) BGBl III 2008/155 idgF.

Engelhardt et al. (2022):Engelhardt, R., Dandl, F., Syed, A.-A., Zhang, Y., Fehn, F., Wolf, F., Bogenberger, K.: FleetPy: A Modular Open-Source Simulation Tool for Mobility On-Demand Services. Munich, 2022.

European Parliament and Council of the European Union (2011): Regulation (EU) No 181/2011 of the European Parliament and of the council of 16 February 2011 concerning the rights of passengers in bus and coach transport and amending Regulation (EC) No 2006/2004. OJ L 2011/55, 1. https://eur-lex.europa.eu/eli/reg/2011/181/oj

European Parliament and Council of the European Union (2024): Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules on artificial intelligence and amending Regulations (EC) No

300/2008, (EU) No 167/2013, (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1139 and (EU) 2019/2144 and Directives 2014/90/EU, (EU) 2016/797 and (EU) 2020/1828 (Artificial Intelligence Act) (Text with EEA relevance). OJ L 2024/1689, 1. https://eur-lex.europa.eu/eli/reg/2024/1689/oj/eng

FLIP (2024): FFG – Austrian Research Promotion Agency: FLIPFLOP Project Description – Flexible Line On-Demand Public Transport. Vienna, 2024.

GAS (2024): Gemeente Amsterdam – Onderzoek & Statistiek: Verkeer in cijfers 2024: Autodichtheid en mobiliteitstrends in Amsterdam. Amsterdam, 2024.

GelverkG (1996): Bundesgesetz über die nichtlinienmäßige gewerbsmäßige Beförderung von Personen mit Kraftfahrzeugen (Gelegenheitsverkehrs-Gesetz 1996 – GelverkG) BGBl 1996/112 idgF.

GlBG (2004): Bundesgesetz über die Gleichbehandlung (Gleichbehandlungsgesetz – GlBG) BGBl I 2004/66 idgF.

Gregurić et al. (2025): Gregurić, M., Vrbanić, F., Ivanjko, E.: Towards Synthetic Augmentation of Training Datasets Generated by Mobility-on-Demand Service Using Deep Variational Autoencoders. In: Applied Sciences, Vol. 15, Issue 9, p. 4708. Zagreb, 2025.

Greif & Ulrich (2019): Greif, E.,Ulrich, S.: Legal Gender Studies und Antidiskriminierungsrecht. Wien, 2019.

IST (2023): ISTmobil GmbH: Demand-Responsive Transport in Lower Austria – Project Report. St. Pölten, 2023.

Kahl(2023): Kahl, A.: Mikro-ÖV im aktuellen verkehrsgewerblichen Rahmen und Anpassungsbedarf. In: Kahl & Autengruber (Hrsg.), Mobilitätswende: Verkehre unter dem Einfluss von Nachhaltigkeit und Digitalisierung, S. 15-34. Innsbruck, 2023.

KflG (1999): Bundesgesetz über die linienmäßige Beförderung von Personen mit Kraftfahrzeugen (Kraftfahrliniengesetz – KflG) BGBl I 1999/203 idgF.

Mühle (2023): Mühle, S.: An analytical framework for modeling ride pooling efficiency and minimum fleet size. In: Multimodal Transportation, Vol. 2, Issue 2, p. 100080. Göttingen, 2023.

OECD(2022): OECD/ITF – International Transport Forum: Innovative Mobility for Cities – Demand-Responsive Transport. Paris, 2022.

ONS (2021):Office for National Statistics (ONS): Vehicle licensing statistics for London – Private car ownership. London, 2021.

ÖPNRV-G(1999): Bundesgesetz über die Ordnung des öffentlichen Personennah- und Regionalverkehrs (Öffentlicher Personennah- und Regionalverkehrsgesetz 1999 – ÖPNRV-G 1999) BGBl I 1999/204 idgF.

ORF (2023): ORF Oberösterreich: Motorisierung in Linz – Statistik 2023. Linz, 2023.

ORF (2025): ORF Tirol: Kfz-Bestand in Innsbruck – aktuelle Zahlen 2025. Innsbruck, 2025.

POST (2024): Postbus AG: Postbus Shuttle – Flexible Mobility for Rural Regions. Vienna, 2024.

RDM (2020): Radkompetenz Dänemark: Mobilität in Kopenhagen – Pkw-Bestand und Radverkehrsentwicklung. Copenhagen, 2020.

REG (2023): RegioFlink: Pilot Project for Demand-Oriented Mobility in Carinthia. Klagenfurt, 2023.

RIDE(2022): Centre for London: Ride-Hailing and On-Demand Mobility in Greater London. London, 2022.

UITP (2023): UITP – International Association of Public Transport: How Shared Mobility Solutions Can Improve Our Cities and Towns. Brussels, 2023. Available at https://www.uitp.org/news/shared-mobility-solutions-improve-cities/

(UITP, 2024): UITP – International Association of Public Transport: On-demand Mobility. Brussels, 2024. Available at https://www.uitp.org/knowledge-research/on-demand-mobility/

VCÖ (2025): VCÖ – Verkehrsclub Österreich: Analyse zur Motorisierung in Österreichs Städten (Privat-PKW je 1.000 Einwohner). Vienna, 2025.

Veneri et al. (2025): Veneri, P., Burgalassi, D., Weingarden, A.: Midsize Settlements in Europe: Definition, Population Trends, and Contribution to Regional Development. In: Journal of Regional Science, Vol. 65, Issue 5, pp. 1338-1352. L'Aquila, 2025.

VVT (2024): Verkehrsverbund Tirol (VVT): Integration of On-Demand Services into Tyrolean Public Transport. Innsbruck, 2024.

W24 (2024): W24 / VCÖ: Mobilitätstrends in Wien – PKW-Dichte 2024. Vienna, 2024.

Zwick & Axhausen (2022): Zwick, F., Axhausen, K. W.: Ride-pooling demand prediction: A spatiotemporal assessment in Germany. In: Journal of Transport Geography, Vol. 100, p. 103307. Zürich, 2022.