D4.2: Karlsruhe Demonstrator

Date: **15/12/2025**

Author: Dr. Thomas Benz

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101069782

URBANE

CIVITAS

Sustainable and smart mobility for all

Project & Document Information

Grant Agreement No	101069782	**Acronym**	URBANE
Project Full Title	UPSCALING INNOVATIVE GREEN URBAN LOGISTICS SOLUTIONS THROUGH MULTI-ACTOR COLLABORATION AND PI-INSPIRED LAST MILE DELIVERIES		
Call	HORIZON-CL5-2021-D6-01		
Topic	HORIZON-CL5-2021-D6-01-08	**Type of action**	IA
Coordinator	INLECOM INNOVATION		
Start Date	01/09/2022	**Duration**	42 months
Deliverable	D4.2	**Work Package**	WP 4
Document Type	DEM	**Dissemination Level**	PU
Lead beneficiary	AENET		
Responsible author	Dr. Thomas Benz		
Contractual due date	31/12/2025	**Actual submission date**	Dd/mm/jjjj

Disclaimer and Acknowledgements

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101069782

Disclamer

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

While the information contained in the document is believed to be accurate, the authors or any other participant in the URBANE consortium make no warranty of any kind regarding this material including, but not limited to the implied warranties of merchantability and fitness for a particular purpose.

Neither the URBANE Consortium nor any of its members, their officers, employees, or agents shall be responsible or liable in negligence or otherwise howsoever in respect of any inaccuracy or omission herein.

Without derogating from the generality of the foregoing neither the URBANE Consortium nor any of its members, their officers, employees, or agents shall be liable for any direct or indirect or consequential loss or damage caused by or arising from any information advice or inaccuracy or omission herein.

Copyright message

Authoring, Revision & QA Information

Deliverable Contributors	
Contributor	Organisation (Acronym)
Dr. Thomas Benz	Automotive Engineering Network e.V. (AENET)
Dr. Christoph Rentschler	Albtal-Verkehrs-Gesellschaft mbH (AVG)
Dr.-Ing. Frank Schönung	SEW Eurodrive GmbH & Co. KG (SEW)
Sebastian Brack	SEW Eurodrive GmbH & Co. KG (SEW)
Valentin Hecht	Transport Technologie-Consult Karlsruhe GmbH (TTK)
Serena Veltz	Automotive Engineering Network e.V. (AENET)
Ralf Eichhorn	Wirtschaftsförderung Stadt Karlsruhe (KARL)
Aristea Zafeiropoulou	Konnecta
Önder Gürcan	NORCE
Larissa Lima	NORCE
Pierre Georges Van Wolleghem	NORCE
Markus Grendstad Rousseau	NORCE
Merve Cebeci	TUD/Panteia

Formatted: French (France)

Deliverable Contributors				
Version	Date	%	Changes	Author
0.1	01/03/2023	5%	ToC	Zisis Maleas
0.5	29/09/2025	50%	Added Text	All
0.8	31/10/2025	80%	Added Content	All
0.9	01/12/2025	100%	Final Draft	All
1.0	19/12/2025	100%	Final Version ready for submission	Dr. Thomas Benz and Serena Veltz

Quality Control (includes pear & quality reviewing)			
Date	Version	Name (Organisation)	Role & Scope
15/12/2025	0.9	Satu Reijonen (FVHI)	Peer Review
19/12/2025	1.0	John Limaxis (INLE) Efstathios Zavvos (VLTN)	PM & QM Review

Executive summary

This report presents the activities, results, and key findings of the Karlsruhe Twinning Living Lab within the URBANE project. The Living Lab investigates the integration of autonomous mobile robots (AMRs) and tram-based transport to enable sustainable, low-emission last-mile delivery in urban environments. The work aligns with the overall project objectives to assess, demonstrate, and evaluate innovative urban logistics solutions that reduce traffic congestion, lower environmental impact, and improve delivery efficiency.

The Karlsruhe Living Lab builds upon the city's strong tradition in public transport innovation, particularly through the TramTrain system, which combines tram and regional rail services. The unique concept tested in Karlsruhe involves using the available transport capacity of trams during off-peak times to transport goods and parcels. Autonomous robots handle the first and last mile of delivery, travelling independently between tram stops and customer locations. This approach aims to exploit existing public transport infrastructure while minimizing additional road traffic and emissions.

To support the design and evaluation of the Living Lab, a data collection and analysis framework was established. Data were gathered from publicly available sources such as municipal transparency portals, logistics company reports, and mapping platforms. The dataset included socioeconomic indicators, courier market shares, parcel volumes, and spatial information about delivery zones. These data formed the basis for modelling, simulation, and key performance indicator (KPI) assessment related to economic, environmental, and social impacts which are carried out in other work packages within the project.

The Living Lab setup was developed in close coordination with local authorities, transport operators, and industry. Particular attention was given to the governance and regulatory framework, as the combination of autonomous robots and passenger trams introduces new operational and legal challenges. A dialogue with approval bodies was established to explore pathways toward legal demonstration and potential temporary operation of mixed passenger–freight tram systems in the coming years.

Public engagement played an essential role in the project. A structured survey was conducted to assess citizen attitudes toward autonomous delivery robots and their operation in public spaces. The results indicated a generally positive perception of such technologies, reflecting the local population's familiarity with innovative public transport and openness toward sustainable mobility solutions.

Several use cases were defined and tested to explore different delivery scenarios, ranging from business-to-business (B2B) internal logistics to business-to-customer (B2C) deliveries. Exploration of these use cases provided valuable insights into operational feasibility, efficiency, and acceptance. Evaluation of these use cases using the developed KPIs and the Digital Twin framework confirmed the environmental benefits of electric, tram-based logistics and highlighted opportunities for integration with existing transport systems.

The experience gained from the Karlsruhe Living Lab demonstrates that technical challenges can be addressed with sufficient development time and resources, while non-technical barriers, such as regulatory approval, require engagement at the political and institutional level. The results also underline the potential of tram-based logistics to support local businesses and urban sustainability goals by providing environmentally friendly and reliable delivery services.

Overall, the work in Karlsruhe contributes to advancing the understanding of multimodal, automated urban logistics systems. It provides practical evidence for their environmental and social benefits, identifies key obstacles to large-scale implementation, and offers recommendations for future policy alignment, technology development, and urban integration.

Table of Content

List of figures

List of tables

Glossary of Abbreviations and Acronyms

ACRONYM	DECRIPTION
ADV	Autonomous Delivery Vehicle
AFGBV	Autonomous Vehicles Approval and Operation Regulation (Autonome-Fahrzeuge-Genehmigungs-und-Betriebs-Verordnung)
Agora Verkehrswende	Agora Verkehrswende is committed to climate neutrality in transport – evidence-based, non-partisan, non-profit and solution-orientated.
AMR	Autonomous Mobile Robot
BHG	Depot Gerwigstraße
BHO	Depot East
BHW	Depot West
BMDV	Federal Ministry for Digital and Transport (Bundesministerium für Digitales und Verkehr)
BMWK	Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie)
BOStrab	Regulations governing the construction and operation of tramways (Verordnung über den Bau und Betrieb der Straßenbahnen)
CTC	Centralised Traffic Control
DIN	German Institute for Standardisation (Deutsches Institut für Normung)
DT	Digital Twin
EBA	Federal Railway Authority (Eisenbahn Bundesamt)
EBO	Railway Construction and Operating Regulations (Eisenbahn Bau- und Betriebsordnung)
EN	European Standard
FZV	Vehicle Registration Regulation (Fahrzeug Zulassungsverordnung)
GPS	Global Positioning System
ICT	Information and Communication Technology
IMU	Inertial measurement unit
ISO	International Organisation for Standardization
KBA	Federal Motor Transport Authority (Kraftfahrt-Bundesamt)
Kombilösung	The Karlsruhe combined solution is a project that has further developed the tram and light rail systems in the city of Karlsruhe.

KPI	Key Performance Indicator
LED	Light-Emitting Diode
LL	Living Lab
LMD	Last Mile Delivery
LSP	Logistic Service Provider
NUFAM	Commercial Vehicle Exhibition (Nutzfahrzeugmesse)
NVBW	Baden-Württemberg Local Transport Company (Nahverkehrsgesellschaft Baden-Württemberg)
RGB	Red, Green and Blue
StVG	Road Traffic Act (Straßenverkehrsgesetz)
StVO	Road Traffic Regulations (Straßenverkehrsordnung)
StVZO	Road Traffic Licensing Regulations (Straßenverkehrs-Zulassungs-Ordnung)
SULP	Sustainable Urban Logistic Plan
TAB	Technical Supervisory Authority
TÜV	Technical Inspection Association (Technischer Überwachungsverein)
USP	Unique Selling Proposition

1. Introduction

This document presents the work conducted and the results achieved within the Twinning Living Lab Karlsruhe as part of Work Package 4 (Task 4.2). Similar to the Living Lab in Helsinki, the Karlsruhe Living Lab explores the use of Autonomous Mobile Robots (AMRs) for last-mile parcel delivery in urban environments. However, the Karlsruhe approach introduces a distinctive concept: rather than completing the entire journey autonomously on public roads, the robots cover the main transport segment by travelling inside trams.

The underlying idea is to make efficient use of the existing transport capacity available during off-peak hours. In this system, AMRs act as passengers, boarding and alighting at designated tram stops, just like humans, while autonomously navigating the first and last segments of their delivery routes between the tram stops and the final destinations. This hybrid concept combines public transport infrastructure with automated ground delivery, thereby creating a highly flexible and potentially low-emission logistics chain within the urban area.

The implementation of this approach, however, introduces a set of unique challenges and conditions. These challenges are not only of technical nature, such as the safe transfer of robots into and out of trams or the coordination of movement within public spaces, but also legal and societal. The integration of autonomous systems into a public transport environment requires careful consideration of regulatory frameworks, including both tram operation regulations and the legal provisions governing autonomous robotic systems. Furthermore, interactions between AMRs and other tram passengers, as well as with the general public, must be managed to ensure safety, acceptance, and compliance with existing public transport norms.

Accordingly, the focus of the Karlsruhe Living Lab lies on the regulatory and legal aspects of implementing such an integrated logistics system, as well as on the interaction between the autonomous delivery units and the public in real-world settings. Within this framework, three potential use cases have been defined to represent different applications of the concept. These use cases serve as the basis for the evaluation of Key Performance Indicators (KPIs), which will allow for comparative analysis with the corresponding results obtained in other Living Labs, particularly Helsinki.

1.1 URBANE Outputs Mapping to GA Commitments

TABLE 1: DELIVERABLE ADHERENCE TO GRANT AGREEMENT DELIVERABLE AND WORK DESCRIPTION

URBANE GA ITEM	URBANE GA ITEM DESCRIPTION	DOCUMENT CHAPTER(S)	JUSTIFICATION
	DELIVERABLE		
D4.2 Karlsruhe Demonstrator	*D4.2 consolidates the results of the implementation of the Karlsruhe demonstrator. It will include a feasibility study and implementation plan for the combined use of trams with delivery robots, covering technical, operational, and regulatory considerations. It will include the evaluation results of a small-scale pilot implementation, including user acceptance results and conclusions.*	*Chapters 3 - 8*	*This report describes the work of Task 4.2, the specification of requirements for the last mile delivery system involving autonomous mobile robots (AMR) together with the Karlsruhe tramtrains. It details the technical and legal issues and shows how they were solved during the project or what is needed for a future operation of this system. It also details the feasibility study undertaken and the surveys carried out to study the general public's opinion towards this system. It also explains the system's performance regarding major KPIs.* *Furthermore, it explains the collaboration with project partners' work on the models (CitiQore, Blockchain, HUMAT, MASS-GT and VRP module)*
	TASK		
T4.2 Karlsruhe Demonstrator	*ST.4.2.1. LLs Communities Setup. General planning and management of activities. Coordinate with other LLs, especially those involved in the first wave, such as Helsinki, to obtain first-hand knowledge on their activities and results and identify areas of innovation that can be adopted.* *ST.4.2.2 Development of feasibility study, for usage of trams and robots for delivery of goods: technical-operational concept as well as municipal regularities. Analysis of the logistics needs of the economic (especially retailers in city centre) and transport actors of the region through surveys and workshops. Analysis of the light rail stations for the selection of suitable logistics hubs and conception of transhipment and interim storage as well as identification of resulting synergy effects with other station-related economic activities. Analysis of residential areas for further implementation of tram-robot-delivery including acceptance.* *ST.4.2.3 Real-life piloting and analysis of travellers' acceptance for tram-robot-delivery model. Evaluation of small-scale pilot, identification of hardware and software required for fully functional operation for a tram-robot-delivery. Organization of a demonstration model, acceptance analysis, and dissemination of results.*	*Chapters 3 - 8*	*Chapter 3 explains the set-up of the living lab including the vision, the existing technical, infrastructure and regulatory frameworks. Chapter 4 describes the live demonstration and the surveys carried out. Chapter 5 describes the use cases defined for the system. Chapter 6 indicates the results in terms of KPI evaluation and the way forward for the regulatory issues found. Chapter 7 explains the application of the ABM framework to the Karlsruhe case. Chapter 8 gives an overview of the lessons learnt and recommendations.*

1.2 Deliverable overview and Report Structure

This deliverable provides a comprehensive overview of the activities, data collection, analysis, and results carried out within the scope of the URBANE project's Living Lab in Karlsruhe. It focuses on the development, testing, and assessment of innovative last-mile delivery concepts using autonomous delivery robots in combination with the city's tram infrastructure.

The document is structured into eight main chapters:

- **Chapter 1 – Introduction:** This section presents the background of the deliverable, its alignment with the Grant Agreement (GA) commitments, and an overview of the report structure.
- **Chapter 2 – Data Collection and Analysis for Task 2.1:** This chapter describes the data collection process and analytical approaches used to assess the sustainability impact of the URBANE Living Lab activities.
- **Chapter 3 – Living Lab Setup:** The Living Lab setup in Karlsruhe is presented in detail, including local context and strategic initiatives, governance structures, objectives, and the regulatory frameworks relevant to both tram and robot operations. It also outlines the key stakeholders involved and provides an overview of the existing physical and digital infrastructure supporting the pilot activities.
- **Chapter 4 – Events & Survey:** This chapter summarises the public engagement activities and surveys conducted to assess public perception of the URBANE concept. It includes the live demonstration and participation in relevant trade fairs and conferences. It further provides a detailed analysis of the public survey, including methodology, participant demographics, and key insights derived from the responses.
- **Chapter 5 – Application of the URBANE ABM framework:** This chapter explains the application of the ABM framework created in WP 3 to the Karlsruhe case, including variations of different parameters.
- **Chapter 6 – Use Cases:** The three main URBANE use cases are described here: (1) **Internal Transport (B2B)**, (2) **Shop to Customer (B2C)**, and (3) **Meals on Wheels (B2C)**. Each subsection provides a detailed description of the operational setup, objectives, and observed performance.
- **Chapter 7 – Results, Evaluation, and Impact Assessment:** This chapter presents the results and evaluation of the different use cases, including KPI calculations and the integration of the Digital Twin Platform. It also discusses regulatory coordination and approval processes relevant to the Living Lab.
- **Chapter 8 – Lessons Learnt & Recommendations:** The final chapter summarises the main findings from the Karlsruhe Living Lab, highlighting key

lessons learned and providing recommendations for the further deployment and scaling of autonomous, tram-based delivery systems in urban environments.

Overall, this deliverable provides an integrated overview of the technical, operational, regulatory, and social dimensions of the URBANE Living Lab in Karlsruhe, offering insights that support the project's wider European objectives for sustainable urban logistics and last-mile delivery innovation.

2. Data collection and analysis for Task 2.1.

2.1 Sustainability impact analysis

The data used in this study were compiled from a combination of publicly available geographic and statistical sources to characterize the courier market and urban logistics environment in Karlsruhe. Market shares of major courier companies were derived from openly accessible information published on the websites of the respective service providers, complemented by sectoral reports and press releases. Geographic data, including depot locations, travel times, and distances between origins and destination were extracted from freely available digital maps such as Google Maps[1] and OpenStreetMap[2]. These tools provided geospatial information that enabled the estimation of network connectivity and routing performance for urban parcel logistics.

Monthly parcel delivery volumes for the Karlsruhe area were estimated using publicly available datasets and industry statistics, combined with local data on delivery frequency and courier density. Data regarding unsuccessful deliveries could not be gathered in the required detail.

In addition, a wide range of socioeconomic data was collected to describe demographic and spatial heterogeneity within the city. Indicators such as employment per zone, households per zone, age distribution, income levels, and average household size were retrieved from the Transparency Portal of the City of Karlsruhe[3] and other municipal open data platforms ("Stadtteile im Überblick"). These datasets provided the foundation for spatially disaggregated analyses of logistics demand and accessibility. All compiled data were harmonized, standardized, and subsequently shared with other partners within the project consortium for further analysis and model integration.

[1] https://www.google.com/maps
[2] https://www.openstreetmap.org/
[3] https://transparenz.karlsruhe.de/

3. Living Lab setup

3.1 Context – Local plans – Key initiatives

3.1.1 Location/City and context

Karlsruhe is a medium-sized city located in the federal state of Baden-Württemberg in southwestern Germany, close to the Rhine River and the Franco-German border. With approximately 300,000 inhabitants, it is one of the ten largest cities in the state and serves as an important administrative, judicial, and educational centre. Karlsruhe is home to the Federal Constitutional Court[4] and the Federal Court of Justice[5], as well as the Karlsruhe Institute of Technology[6] (KIT), one of Germany's leading technical universities. In addition to these institutional functions, Karlsruhe has gained international recognition for its innovative approach to urban mobility, particularly through the so-called Karlsruhe Model of tram-train integration.

FIGURE 1: LOCATION OF KARLSRUHE WITHIN GERMANY

[4] https://www.bundesverfassungsgericht.de/EN/
[5] https://www.bundesgerichtshof.de/EN/
[6] https://www.kit.edu/index.php

The city was founded in 1715 as a planned baroque settlement with a radial street layout centred on the palace. This geometric design, resembling a fan, continues to shape Karlsruhe's urban morphology. The city expanded significantly during the 19th century due to industrialization and the arrival of railway infrastructure. After the Second World War, Karlsruhe, like many German cities, experienced automobile-oriented development, with the construction of major road axes and urban highways. In recent decades, however, transport planning in Karlsruhe has increasingly shifted toward sustainable mobility, with investments in public transport and cycling infrastructure.

FIGURE 2: KARLSRUHE CITY (© STADT KARLSRUHE, ROLAND FRÄNKLE)

Karlsruhe presents a complex multimodal transport system that integrates private vehicles, public transport, cycling, and pedestrian movement.

- **Road Traffic:** The city is intersected by major highways, including the A5 and A8 motorways, making it a regional transport hub. Inner-city road traffic, however, is constrained by the historical street pattern and limited urban space. Congestion is a recurring challenge, particularly during peak commuting periods.
- **Cycling:** With its relatively flat topography, Karlsruhe is well-suited for cycling. The city has invested in an expanding network of bicycle lanes and parking

facilities. Cycling accounts for a significant share of daily trips (around 25%), positioning Karlsruhe among Germany's leading cycling cities.

- **Public Transport:** The public transport system is dominated by the Karlsruhe Transport Association (Karlsruher Verkehrsverbund, KVV[7]), which coordinates buses, trams, and regional trains. The centerpiece of this network is the extensive tram system, complemented by buses in peripheral areas.

Despite these strengths, Karlsruhe has faced challenges related to capacity, punctuality, and urban congestion in the central area, particularly before the completion of the inner-city light rail tunnel in 2021. This project, known as the Kombilösung, relocated tram lines underground to reduce surface-level conflicts between road traffic and trams.

The most distinctive feature of Karlsruhe's mobility system is the Karlsruhe Model, developed in the late 20th century. The concept is based on the integration of urban tram networks with regional railway lines, allowing specially designed vehicles (tram-trains) to operate seamlessly across both systems.

Introduced in 1992, the model enabled passengers to travel directly from suburban and regional towns into Karlsruhe's city centre without changing modes of transport. For example, a commuter from the town of Bretten can board a tram-train that uses regional railway tracks before switching to the tram infrastructure within the city.

The advantages of the Karlsruhe Model include:

- **Seamless connectivity:** Reduction of transfer points between regional rail and urban tram.
- **Regional integration:** Improved accessibility for smaller towns in the metropolitan region.
- **Economic efficiency:** More cost-effective than constructing separate rail or metro systems.
- **Environmental benefits:** Encourages modal shift from private cars to public transport.

The success of the Karlsruhe Model has attracted international attention. It has been adopted or adapted in other German cities such as Saarbrücken and Kassel, and has influenced light-rail planning in France, the United Kingdom, and the United States. The model demonstrates how institutional cooperation, technical innovation, and political commitment can create sustainable transport solutions in medium-sized urban regions.

Karlsruhe exemplifies how a medium-sized European city can balance historical urban structures, modern mobility needs, and sustainable transport planning. While road congestion remains a challenge, the city's investment in cycling, tram infrastructure, and particularly the pioneering tram-train concept has transformed Karlsruhe into a reference point in international transport planning. The Karlsruhe Model continues to stand as an

[7] https://www.kvv.de/index.html

innovative best-practice example for integrating local and regional mobility, shaping both urban development and the broader discourse on sustainable transport.

3.1.2 Governance

Karlsruhe has made substantial progress in improving its air quality over the past decade. As a result of these sustained environmental improvements, the city officially lifted its low-emission zone on 1 March 2023. This decision reflects the successful reduction of air pollutants to levels that meet national and European standards, largely due to continuous modernization of the vehicle fleet, the expansion of public transport, and the promotion of sustainable mobility alternatives.

Despite the absence of a low-emission zone, Karlsruhe continues to pursue a strategic approach to sustainable urban transport. The city has developed a comprehensive Transport Development Plan (Verkehrsentwicklungsplan), which outlines long-term objectives and measures for mobility management, including initiatives related to city logistics. These measures address traffic flow optimization, the reduction of delivery-related congestion, and the integration of innovative urban logistics concepts.

However, Karlsruhe does not currently maintain a Sustainable Urban Logistics Plan (SULP) as a standalone or formalized strategic instrument. Instead, logistics-related actions are embedded within broader transport and sustainability frameworks. Likewise, there is no formal cooperation agreement between municipal authorities and logistics operators. While informal exchanges and pilot initiatives do occur, institutionalized collaboration mechanisms, such as public-private partnerships or coordinated governance structures, are not yet established.

In summary, Karlsruhe demonstrates a strong commitment to sustainable urban mobility and logistics through policy integration and planning instruments, even in the absence of a formal SULP. The city's experience highlights both the effectiveness of environmental policy in improving air quality and the potential for further advancement through structured cooperation with logistics stakeholders.

3.2 Vision and challenge to be addressed in URBANE

Freight logistics as well as passenger transport, requires a fundamental transformation in the light of climate change and sustainability goals. The shift to alternative propulsion systems represents only one aspect of the challenges involved. For this reason, Agora Verkehrswende[8] defined in 2017 both the energy transition in transport and the mobility transition as integral components of the transport transition.

[8] https://www.agora-verkehrswende.de/

The primary goal of the Karlsruhe Twinning Living Lab in URBANE therefore is to further develop combined passenger and freight transport with automated loading and unloading and to assess its feasibility by using a delivery robot. By enabling the usage of existing rail and vehicle infrastructure for passenger and freight transport, the project lays the foundation for a key element of the mobility transition. The combined transport of passengers and goods could possibly reduce energy consumption without restricting mobility, which is in line with the definition of the mobility transition.

The idea of the described concept is to address the rising pressures on logistics, mobility, and transport infrastructure in urban areas, where liveable housing is under pressure from urban growth and digital commerce trends.

The project's focus clearly distinguishes itself from previous rail freight initiatives through its combination of passenger and goods transport and its extended use of automation. Previous comparable projects, for example in Frankfurt, Dresden or Schwerin, involved dedicated freight trams, with loading, unloading, and securing of goods carried out by men without automation. While this approach is easier and quicker to implement under current technical, operational, and legal constraints, it does not generate synergy effects and is highly time-consuming. URBANE therefore investigates the feasibility of a new, efficient system using delivery robots that can achieve such synergies.

Commented [RC1]: Hier werden die rechtlichen Herausforderungen ergänzt.

3.2.1 LL Objectives

The overarching objectives of this work package focus on the comparative evaluation, performance assessment, and feasibility analysis of innovative last-mile delivery concepts within the framework of the Karlsruhe Living Lab (LL) and its twinning Living Lab in Helsinki. Three key objectives guide the research: (1) to compare the Karlsruhe Living Lab with the Helsinki Living Lab, emphasizing similarities and differences in use cases and target groups; (2) to define and apply suitable key performance indicators (KPIs) covering economic and environmental aspects; and (3) to identify potential obstacles in implementing a last-mile delivery service using TramTrains and autonomous delivery robots, including potential strategies to overcome them.

(1) Comparison to the Helsinki Living Lab

The Karlsruhe and Helsinki Living Labs share a common vision of developing sustainable, technology-driven urban logistics solutions that reduce emissions and traffic congestion while improving service efficiency. Both Living Labs are designed as real-world test environments, integrating research, industry, and municipal stakeholders to jointly develop, validate, and demonstrate new mobility solutions.

Despite this shared purpose, the contextual conditions and use cases differ considerably. The Karlsruhe Living Lab focuses on integrating freight transport into existing TramTrain systems, leveraging available transport capacity during off-peak hours. Its target groups primarily include urban logistics operators, municipal planners, and local retailers seeking efficient and low-emission distribution channels. In contrast, the Helsinki Living Lab emphasizes last-mile and neighbourhood-scale logistics, involving micro-hubs and automated robots in a dense urban setting. The target groups in Helsinki are more diverse, including delivery platform operators, residents, and service providers.

While both Living Labs employ automation and digitalization to optimize urban freight flows, Karlsruhe's use cases emphasize the integration of public transport infrastructure and the technical challenge of combining passenger and freight operations under a shared regulatory and operational framework. Helsinki, by comparison, places stronger emphasis on urban design, citizen acceptance, and service co-creation. The comparative analysis aims to extract transferable insights and identify context-dependent constraints that influence replicability across cities.

(2) Definition and Evaluation of KPIs

To ensure a consistent and quantifiable evaluation of results, a set of Key Performance Indicators (KPIs) will be defined and applied across both Living Labs. The KPIs are designed to assess economic viability and environmental performance, considering both operational efficiency and societal benefits.

Economic KPIs include indicators such as operational costs per parcel, cost per vehicle-kilometre, vehicle utilization rate, and total delivery time per trip. These metrics help assess the financial sustainability of integrating TramTrains and autonomous robots into urban logistics chains. Environmental KPIs focus on CO_2 emissions per parcel, energy consumption per delivery, and modal shift potential, quantifying the environmental benefits compared to conventional delivery vans.

The evaluation of these KPIs will be based on the simulation and optimization models developed in other work packages. These models integrate real-world data on traffic conditions, delivery demand, and network topology to generate scenarios for comparison. The outcome will provide evidence on whether the TramTrain-based last-mile delivery concept can achieve both economic competitiveness and ecological efficiency, and under which boundary conditions.

(3) Identification of Obstacles and Mitigation Strategies

The implementation of a last-mile delivery service using TramTrains and autonomous robots entails several technical, regulatory, and organizational challenges. One major obstacle lies in the regulatory framework, since TramTrain systems in Germany operate under two distinct sets of regulations (BOStrab and EBO), which complicates approval procedures for freight transport within passenger networks. Close cooperation with supervisory authorities, initiated through the approval steering group established in Karlsruhe, represents one effective strategy to mitigate this barrier.

From a technical perspective, challenges include ensuring the compatibility of autonomous robots with tram infrastructure, the safe loading and unloading of goods at tram stops and maintaining operational punctuality within mixed passenger-freight operations.

Furthermore, economic feasibility remains a critical issue. While the concept offers strong environmental advantages, the investment costs for automation, vehicle adaptation, and infrastructure upgrades can be considerable.

3.2.2 Regulatory framework (trams)

According to the actual regulatory framework and regulations in Germany, there are a lot of obstacles to tackle to achieve the permission of combined passenger and goods transport:

- Currently trams are used exclusively or predominantly for passenger transport, and it is likely necessary to assess whether passenger transport remains the primary function, as well as to apply for special approval.
- There are requirements regarding transport and operational obligations, under which the railway transport company is obliged to keep the planned schedule:
  - Regular service must be ensured
  - Passengers must not be turned away due to the transportation of delivery robots
  - Delays caused by loading and unloading must be avoided
  - Space for passengers must not be excessively restricted by robots).
- There are requirements concerning the design of the rail vehicle in relation to passenger transport, and therefore also regarding the transportation of delivery robots within the vehicle which must be complied with:
  - Fire safety regulations
  - Sufficient emergency exit options
  - Passenger safety
  - Smooth getting in and out of passengers
  - Symbols on the exterior and interior of the vehicle
- There are requirements for the securing of delivery robots within the rail vehicle.
- It is required that the rail vehicle must be approved for operation by the Technical Supervisory Authority (GER: Technische Aufsichtsbehörde; TAB) after implementing the necessary modifications for the transportation of delivery robots (a safe operation must be proved).
- There are requirements for areas at stops to allow for temporary storage or transhipment of the delivery robots.
- There are requirements concerning the safety and order of railway operations and infrastructure, which are fulfilled if the infrastructure and vehicles comply with the Railway Construction and Operating Regulations (GER: Eisenbahn Bau- und Betriebsordnung; EBO) and technical standards (EN and DIN norms).
- There are requirements regarding the safe operation of public transport and public safety, which must be achieved.

- There are requirements for the use of public roads (for loading and unloading the delivery robots and for last-mile distribution), which also require special permission in the context of use of delivery robots.

In line with the principles of the mobility transition, the dual use of existing rail and vehicle infrastructure additionally must not compromise the mobility of today's passengers. This also applies to accessibility, which means that the prioritised transport of wheelchair users, parents with prams, and other individuals with permanent or temporary mobility impairments must not be affected.

Thanks to the internationally acknowledged TramTrain model (GER: "Karlsruher Model"), the investigated combined passenger and freight transport could achieve inter-district goods flows and thereby providing over-regional impulses for sustainable, ecological, and regional economic development. In conclusion, the feasibility study conducted within URBANE creates an important foundation for a cross-regional sustainable logistics concept, even though the project itself focuses on urban loading and unloading.

The URBANE project is part of the broader RegioKArgo initiative, which was launched by numerous companies and institutions in the region of Karlsruhe. Through this initiative, the participating organisations aim to develop a sustainable and integrated logistics concept, which is being developed across various research projects. Therefore, URBANE builds upon the research project LogIKTram[9], which was funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK)[10].

The aim of LogIKTram was to develop and prototype essential foundations for combined passenger and freight transport. These are for example an information and communication technology (ICT) platform, efficient transhipment and transport processes and automated loading and unloading as well as securing technologies. In contrast to URBANE, the project focused on the use of an automated cargo bike trailer instead of a delivery robot. LogIKTram was successfully completed in June 2024.

In addition to that, research findings from the funded projects LieferBot-E[11] and efeuCampus Bruchsal[12] also serve as a knowledge base for the investigation of autonomous loading units.

3.2.3 Regulatory framework and regulations (robot)

There are currently no specific regulatory frameworks in Europe governing the approval and operation of autonomous delivery robots in public spaces. However, guidance can be drawn from the regulation concerning the approval and operation of motor vehicles with autonomous driving functions within defined operational areas. Nevertheless, several delivery robot applications have already received special permits for operation. The following sections therefore outline the key contents of the regulation on the approval and operation

[9] https://logiktram.de/
[10] https://www.bundeswirtschaftsministerium.de
[11] https://ikt-em-projekte.de/projekte/lieferbot-e/
[12] https://efeucampus-bruchsal.de/

of motor vehicles with autonomous driving functions in defined operational areas, a permit procedure for delivery robots already practiced by project partner SEW-EURODRIVE[13], and a preview of the approval process for Level 4 and 5 autonomy.

Additionally, SEW-EURODRIVE has had the opportunity, within the scope of other projects involving delivery robots, to submit requirements for a statutory regulation on the use of delivery robots to the German Ministry of Transport. These requirements are also listed.

3.2.3.1 Regulation on the Approval and Operation of Motor Vehicles with Autonomous Driving Functions in Defined Operational Areas

Regulation (EU) 2022/1426 does not contain specific provisions for the testing of autonomous vehicles. In German law, the testing of automated and autonomous vehicles is governed by §16 AFGBV and §1i StVG. This document therefore refers exclusively to national law and aims to limit the legal texts to content relevant to the project application.

General Information on Testing Permits (§16 AFGBV and §1i StVG)

Motor vehicles intended for testing autonomous driving functions may only be operated on public roads if:

- A testing permit has been issued by the Federal Motor Transport Authority (KBA)
- The motor vehicle is registered
  → *Not applicable*, as light four-wheeled vehicles (EU class L6e) do not require registration (§3, para. 3 FZV)
- The motor vehicle is used exclusively for testing purposes
- The vehicle is continuously monitored during operation by a reliable technical supervisor

A testing permit is issued by the Federal Motor Transport Authority[14] upon application by the vehicle owner.

The permit must be time-limited and should not exceed a validity period of four years as a rule. It may be extended for an additional two years if the conditions for approval continue to be met and the previous course of testing does not oppose an extension.

Requirements for Issuance of a Testing Permit:

- Availability of a type approval for the vehicle
  → *Not applicable*, as the delivery robot has a design-based maximum speed of 6 km/h (EU Regulation 168/2013, Article 2, Paragraph 2)
- The vehicle owner and all parties involved in the testing must be sufficiently

[13] https://www.sew-eurodrive.de/startseite.html
[14] https://www.kba.de/EN/Home/home_node.html

qualified and reliable
- Availability of a development concept for intended modifications and driving functions to be tested
- Compliance with the requirements of §1e section 2 StVG
- Assurance of continuous monitoring of operations by a locally present, technically reliable supervisor
- Provision of non-personal data and events
- The vehicle system must always be deactivatable and overrideable on-site

The testing permit must be carried during test drives.

*: It is possible that the Federal Motor Transport Authority may refuse to issue a testing permit if requirements are not met, regardless of the fact that registration and type approval for delivery robots are neither possible nor necessary.

Early consultation with the Federal Motor Transport Authority is therefore recommended.

Requirements in the Context of the Testing Permit

General Requirements (§1e section 2 StVG)

Motor vehicles with autonomous driving functions must be equipped with technical systems capable of independently performing driving tasks within a defined operational area in compliance with traffic regulations, without continuous monitoring by the technical supervisor.
Any impairment of functionality must be immediately reported to the technical supervisor. The requirement to activate an alternative driving manoeuvre, deactivate the system with sufficient time buffer, and signals indicating the system's status must be visually, acoustically, or otherwise perceptibly communicated to the technical supervisor.

A sufficiently stable and secure wireless connection, particularly to the technical supervisor, must be ensured.

Risk Assessment (§1e section 2 StVG)

The accident prevention system must be designed to avoid and reduce damage. In cases of unavoidable alternative harm to different legal interests, the significance of these interests must be considered, with the protection of human life taking the highest priority. In the event of unavoidable alternative endangerment of human life, no further weighting based on personal characteristics may be applied.

Minimal Risk Condition (§1e section 2 StVG)

The vehicle must be capable of independently transitioning into a minimal risk condition when:

- Continuation of the journey would require violation of traffic laws
- A driving manoeuvre specified by the technical supervisor would endanger persons

- A system limit is reached
- A technical malfunction occurs that impairs autonomous driving functions
- The boundaries of the defined operational area are reached
- The vehicle is deactivated by the technical supervisor
- The wireless connection to the technical supervisor is lost or accessed without authorization

Upon entering the minimal risk condition, the vehicle should autonomously propose possible driving manoeuvres to continue the journey and provide data to assess the situation, enabling the technical supervisor to decide on the approval of the proposed manoeuvre.

Data and Events in the Context of the Testing Permit (AFGBV §16 section 3, no. 4d):

- Number and duration of usage, as well as activation and deactivation of the automated or autonomous driving function
- Number and duration of approvals for alternative driving manoeuvres, error memory entries (start and end), including software version
- Respective environmental and weather conditions
- Identification of activated and deactivated passive and active safety systems, their status, and the entity that triggered the safety system
- Vehicle acceleration in longitudinal and lateral directions
- Speed

Data must be recorded under the following circumstances: (StVG §1g section 2):

- When interventions are made by the technical supervisor
- In conflict scenarios, particularly in accidents and near-accident situations
- In cases of unplanned lane changes or evasive manoeuvres
- In the event of operational disruptions

Suitability of the Operational Area (AFGBV §9 section 2):

An operational area is deemed suitable if:

- The vehicle is capable of independently performing the driving task within this area
- The ability of the technical supervisor to intervene for deactivation or approval of driving manoeuvres is ensured at all times
- The operation of the vehicle within this area does not impair the safety and fluidity of road traffic, nor endanger the life or physical integrity of individuals

3.2.3.2 Practiced Procedure for the Operation of Delivery Robots at Level 3

A procedure that has been successfully tested multiple times in Germany for obtaining approval to operate delivery robots up to Level 3 – highly automated driving – was also successfully implemented by SEW-EURODRIVE within the efeuCampus project. This approach consists of the following steps:

a) Expert Report for Obtaining an Individual Operating Permit pursuant to §21 StVZO

The expert report can be prepared, for example, by TÜV. Several proofs and documentation are required for the report:

- Vehicle description including maximum speed of 6 km/h, Permissible total weight, power output and dimensions
- Classification of the vehicle into an existing vehicle category
- Manufacturer
- Description of the intended use or project
- Description and location of the operational area
- To be provided by the manufacturer and reviewed by TÜV:
  - Hazard and risk analysis based on ISO 26262
  - Overall assessment of functional safety
  - Cybersecurity assessment based on ISO 21434
- Training materials for instructing a vehicle escort
- List of deviations from the regulations of the StVZO with justification for why the deviations are permissible

In the case of the delivery robot certified by SEW-EURODRIVE under this procedure, a safety escort must always be present in the vicinity of the mobile robot to ensure operational safety. The escort has the ability to bring the robot into a safe state at any time using a carried emergency stop switch.

b) Special Permit pursuant to §70 StVZO for the Test Vehicle

A Special Permit pursuant to §70 StVZO for the test vehicle is issued by the responsible regional administrative authority (Regierungspräsidium[15]). It is based on the expert report for obtaining an individual operating permit pursuant to §21 StVZO. A component of the special permit is the site plan of the operational area. This special permit confirms that the delivery robot is suitable for operation within the designated area.

c) Special Permit pursuant to §46 StVO

A Special Permit pursuant to §46 StVO for the test vehicle is issued by the responsible regional administrative authority (Ordnungsamt[16]). It is based on the expert report for obtaining an

[15] https://rp.baden-wuerttemberg.de/themen/
[16] https://www.karlsruhe.de/stadt-rathaus/verwaltung-stadtpolitik/aemter-dienststellen/detailseite/32-ordnungs-und-buergeramt

individual operating permit pursuant to §21 StVZO. This special permit confirms that the delivery robot is authorized to operate within the designated area.

3.2.3.3 Approval Procedure for the Operation of Delivery Robots at Level 4 and Level 5

Responsibility for the operation of delivery robots at autonomous driving level 4 – fully automated driving – or level 5 – autonomous driving – lies with the Federal Motor Transport Authority (KBA). Currently, there are no specific regulations for autonomous delivery robots. The procedure must therefore follow the regulation on the approval and operation of motor vehicles with autonomous driving functions in defined operational areas.

3.2.3.4 Requirements Submitted to the Ministry of Transport for a Regulatory Framework Governing the Operation of Autonomous Delivery Robots

SEW-EURODRIVE has had the opportunity, within the scope of further projects involving delivery robots, to submit requirements and suggestions for a statutory regulation on the use of delivery robots to the Ministry of Transport. The following are the proposals and requirements that were submitted to the Ministry of Transport.

Experiences and Challenges Regarding Approval:

Jurisdictional Ambiguity:

Currently, it remains unclear which authority is responsible for granting approval or issuing special permits (Federal Motor Transport Authority – KBA or regional administrative authority?).

The KBA issued the following statement on September 12, 2024:

At present, approval for autonomously operated delivery vehicles that are remotely controlled and travel at a maximum speed below 6 km/h is not possible under the existing specific regulations for autonomous vehicles. According to current legislation, such objects—commonly referred to as delivery robots—are classified as motor vehicles under §1 paragraph 2 of the German Road Traffic Act (StVG). However, due to the unique technical design, control mechanisms (autonomous and/or remote-controlled), maximum speed of 6 km/h, smaller dimensions, and behavioural requirements necessary for delivery (e.g., use of sidewalks), the approval of delivery robots requires a separate legal framework.

Additionally, questions regarding the necessity of liability insurance must be examined and clarified.

Current legal provisions only allow for pilot-like local deployment of remotely controlled delivery robots in public traffic, which can only be authorized through special permits issued by the respective state authorities. Neither the Federal Ministry for Digital and Transport (BMDV[17]) nor the KBA can issue such permits due to a lack of legal authority.

Unclear Assumptions Regarding Operational Areas:

The initial assumption was that approval for delivery robots operating on sidewalks would be easier to obtain than for street operation, given the lower safety risk associated with the maximum speed of 6 km/h.

This assumption may be incorrect, and street approval might involve fewer hurdles due to the existing comprehensive legislation for the automotive industry.

Previous Special Permit:

The special permit issued for the efeuCampus project in cooperation with the Karlsruhe regional authority was productive but involved considerable effort and was highly restrictive. No modifications to the approved vehicle are permitted, which hinders adjustments and further development of autonomous driving functions.

Operation beyond SAE Level 3 is currently not covered by the regional authority's jurisdiction, significantly limiting development opportunities.

Conclusion from Experience:

Due to the high regulatory burden associated with operating autonomous robots in public spaces, and the practical impossibility of obtaining full approval, SEW-EURODRIVE GmbH & Co. KG has decided to reduce its investments in the field of urban logistics.

Proposals and Recommendations for New Legislation:

Model: South Korea

In November 2023, South Korea classified delivery robots weighing up to 500 kg and traveling at speeds up to 15 km/h as pedestrians.

This approach could serve as a model to facilitate development of autonomous robots for public spaces by various manufacturers.

It would also require other road users (e.g., drivers) to exercise caution around these robots.

Source: South Korea: Mobile robots will be considered pedestrians in road traffic | heise online

Collaboration with Affected Industry Partners

[17] https://www.bmv.de/DE/Home/home.html

It is recommended that affected companies from the industry be involved in the development of regulations for mobile delivery robots in public spaces.

A clear distinction should be made from the legislation governing autonomous driving in the automotive sector.

The vehicles in question are significantly lighter, smaller, and slower than automated passenger cars and therefore pose a much lower safety risk.

Moreover, the extensive testing permit process currently required for Level 4 autonomous passenger cars is not economically viable for the low production volumes expected for delivery robots in the coming years.

A simplified special permit process is therefore desirable.

Facilitating Special Permits

As previously mentioned, a meaningful step would be to enable manufacturers to obtain simplified special permits for public operation.

This could include reducing requirements for data storage and documentation obligations for manufacturers, justified by the lower risk potential.

Such measures would allow new technologies to be tested in real-world environments and accelerate their market readiness.

3.3 Stakeholders and their role

TABLE 2: STAKEHOLDERS AND THEIR ROLE

Stakeholder	Role	Relation to project
City Authority	Enabling demo in real-life Provision of essential statistical data User of results Connection to local politics	Partner
AEN	Task Leader Organisation of work Carrying out surveys Dissemination	Partner

SEW-Eurodrive	Development of suitable AMR Operation of AMR during demo	Partner
AVG/TKK	Responsible for rail-related aspects (legal and others) Provision of tram and stop for demo	Partner (Subcontractor)
General public	Interaction with AMR within and outside of tram Providing information of public acceptance	Survey candidates

3.4 Existing infrastructure

3.4.1 Existing physical infrastructure - Railway

3.4.1.1 Railway Network

In the greater region of Karlsruhe, the public transport companies Albtal-Verkehrs-Gesellschaft mbH (AVG[18]) – which is part of the Karlsruhe Twinning Living Lab in URBANE – and the Verkehrsbetriebe Karlsruhe GmbH (VBK[19]) are operating together in a TramTrain model. Originally this operating system was invented in Karlsruhe and in 1992 already operated on a total network length of 140 km, in 2016 561 km. That is why it is also known as the "Karlsruher Modell".

The TramTrain model allows passengers to travel directly and without changing trains or trams from regional villages, towns, and cities into the city centre of Karlsruhe, without needing to transfer from a train to a tram at the main station. This is also a major opportunity for combined passenger and freight transport, as the railway lines run close to regional distribution centres and make it possible to shift much of today's freight transport distances onto the rail network.

However, the Karlsruhe model also requires several technical infrastructure solutions, as trains in Germany operate on 15 kV AC, while trams run on 750 V DC. To accommodate this, in addition to using specially designed TramTrains, voltage change points must be installed at

[18] https://www.avg.info/index.html
[19] https://www.vbk.info/index.html

the transitions between the regional railway network and the urban tram network. At these separation points, the TramTrain first disconnects from the 15 kV AC power supply from the overhead line, then coasts through a neutral section without power, and is subsequently reconnected to the 750 V DC supply via the overhead line.

A greater challenge for the combined passenger and freight transport analysed in URBANE however, is the difference in platform heights in Germany. Trains typically have an access height of 55 cm, while trams have an access height of 34 cm. Since both TramTrains with 55 cm access height and conventional trams with 34 cm access height stop at platforms within the Karlsruhe urban area, special platform structures are required. These platforms are designed similarly to camel humps, featuring one section at 34 cm height and another at 55 cm height. This ensures barrier-free access for both types of rail vehicles.

However, for TramTrains, this means that barrier-free boarding is mostly only possible at two doors. As a result, delivery robots can only be loaded and unloaded through these two doors. For this reason, a tram with a 34 cm access height was selected for the demonstration in URBANE to allow greater flexibility during testing and trials.

3.4.1.2 Stops and Railway Stations

Every station in the Karlsruhe city area, served by lines with low-floor vehicles (34 cm entrance height), was checked for its accessibility by the year 2030.

- Vehicle: barrier-free entry from the platform into the low-floor vehicle
- Station: barrier-free access from the public roads to the platforms
- Crossing: crossing between the platforms, across the tracks / street without a crowd barrier

There are seven lines using low entry vehicles, serving a total of 145 stations within the city area. Next to the criteria listed above, all underground Stations have been excluded, for now. This is due to regulatory restrictions.

All the stations are listed in the tables below, including their status of accessibility by the year 2030.

station	accessibility by 2030			total	tram lines							
	vehicle	station	crossing		1	2	3	4	5	S1 / S11	S2	sum
Albert-Braun-Straße								x				1
Albtalbahnhof										x		1
Altrheinbrücke							x					1
Ankerstraße							x					1
Arbeitsagentur						x						1
Auer Straße / Dr. Willmar Schwabe					x	x						2
Augartenstraße						x				x		2
August-Bebel-Straße										x		1
Badeniaplatz								x				1
Bannwaldallee								x				1
Barbarossaplatz						x						1
Dammerstock										x		1
Dornröschenweg											x	1
Duale Hochschule					x							1
Dunantstraße							x					1
Durlach Bahnhof									x			1
Durlacher Tor / KIT-Campus Süd (Karl-Wilhelm-Straße)							x	x				2
Durlacher Tor / KIT-Campus Süd (U)					x	x					x	3
Ebertstraße						x	x					2
Eckenerstraße							x			x		2
Egon-Eiermann-Allee						x						1
Elbinger Straße Ost								x				1
Ellmendinger Straße						x						1
Entenfang (Am Entenfang)							x			x		2
Entenfang (Lameystraße)									x			1
Essenweinstraße											x	1
Ettlinger Tor (Kriegsstraße)								x	x			2
Ettlinger Tor / Staatstheater (U)						x				x		2
Europahalle / Europabad								x				1
Europäische Schule								x				1
Europaplatz / Postgalerie (Kaiserstraße)						x	x	x				3
Europaplatz / PostGalerie (Karlstraße)						x	x	x				3
Europaplatz / Postgalerie (U)					x					x	x	3
Fächerbad								x				1
Feierabendweg						x						1
Forststraße							x					1
Friedrichschule					x							1
Geroldsäcker											x	1
Glogauer Straße								x				1
Gottesauer Platz / BGV					x	x					x	3
Gritznerstraße						x						1
Hagsfeld Bahnhof											x	1
Hagsfeld Bahnhof											x	1
Hagsfeld Süd											x	1
Hammweg							x					1
Händelstraße							x				x	2
Hardecksiedlung								x				1
Hauptfriedhof (Tullastraße)							x				x	2
Hauptfriedhof (Tullastraße)							x				x	2
Haus Bethlehem										x		1
Heidehof					x							1
Hertzstraße						x						1
Hirtenweg / Technologiepark								x			x	2
Hübschstraße									x			1
Im Eichbäumle								x				1
Jägerhaus								x				1
Jenaer Straße											x	1
Karl-Delisle-Straße											x	1
Karlsruhe Hbf Bahnhofsvorplatz						x	x			x		3
Karlstor/ Bundesgerichtshof (Karlstraße)						x	x		x			3
Karlstor/ Bundesgerichtshof (Kriegsstraße)								x	x			2
Karl-Weysser-Straße					x							1
Karl-Wilhelm-Platz							x	x				2
Killisfeldstraße						x						1
Kirchplatz							x					1
Knielingen Nord						x						1
Knielinger Allee / Städt. Klinikum										x		1
Kolpingplatz							x					1
Kongresszentrum (U)						x				x		2

FIGURE 3: TRAM STATIONS (PART 1)

Station	accessibility by 2030			total	tram lines							
	vehicle	station	crossing		1	2	3	4	5	S1 / S11	S2	sum
Kronenplatz (Fritz-Erler-Straße)							x					1
Kronenplatz (U)					x	x					x	3
Kühler Krug									x			1
Kunstakademie / Hochschule					x							1
Kurt-Schumacher-Straße										x		1
Kußmaulstraße / Städt. Klinikum						x						1
Lameyplatz									x			1
Landesbausparkasse								x				1
Lessingstraße									x			1
Lilienthalstraße					x							1
Marktplatz Kaiserstraße (U)					x					x	x	3
Marktplatz Pyramide (U)						x				x		2
Mathystraße (Karlstraße)							x					1
Mathystraße (Mathystraße)						x			x			2
Mauerweg							x					1
Mühlburger Feld									x			1
Mühlburger Tor (Kaiserallee)						x	x	x		x	x	5
Mühlburger Tor / Grashofstraße					x							1
Neureut Adolf-Ehrmann-Bad										x		1
Neureut Bärenweg										x		1
Neureut Welschneureuter Straße										x		1
Neureuter Straße						x						1
Neureut-Heide					x							1
Neureut-Kirchfeld										x		1
Nussbaumweg											x	1
Oberreut Zentrum								x				1
Ostendstraße									x			1
Osteroder Straße								x				1
Ostmarkstraße						x						1
Otto-Sachs-Straße						x			x			2
Philippstraße							x				x	2
Pionierstraße						x						1
Poststraße						x	x			x		3
Rappenwört							x					1
Reitschulschlag Wendeschleife											x	1
Reitschulschlag Wendeschleife											x	1
Rheinhafen									x			1
Rheinhafenstraße											x	1
Rintheim							x					1
Rüppurr Ostendorfplatz										x		1
Rüppurr Tulpenstraße										x		1
Rüppurrer Tor (Kriegsstraße)								x	x			2
Rüppurrer Tor (Rüppurrer Straße)							x					1
Schillerstraße								x				1
Schlesier Straße (West)						x						1
Schloss Gottesaue / Hochschule für Musik									x			1
Schloss Rüppurr										x		1
Schlossplatz (Durlach)					x							1
Siemensallee						x						1
Sinsheimer Straße								x			x	2
Sophienstraße								x				1
Städtisches Klinikum / Moltkestraße						x						1
Städtisches Klinikum / Moltkestraße						x						1
Stadtwerke							x					1
Steiermärker Straße						x						1
Sudetenstraße						x						1
Synagoge					x							1
Thomas-Mann-Straße											x	1
Tivoli							x					1
Tullastraße / Alter Schlachthof (Durlacher Allee)					x	x			x			3
TullaStraße / Alter Schlachthof (TullaStraße)											x	1
Turmberg					x							1
Untermühlstraße					x	x			x			3
Waidweg							x					1
Waldstadt Zentrum								x				1
Weinbrennerplatz (Kriegsstraße)									x			1
Weinbrennerplatz (Süd)								x				1
Weinweg					x	x			x			3
Welfenstraße						x						1
Werderstraße							x					1
Wilhelm-Leuschner-Straße								x				1
Wolfartsweier Nord						x						1
Wolfartsweierer Straße									x			1
Yorckstraße						x	x			x	x	4
ZKM						x						1
Zündhütle						x						1

FIGURE 4: TRAM STATIONS (PART2)

After examination of the listed criteria 99 of the 145 checked stations are or are going to be accessible barrier-free by the year 2030. Therefor they are, theoretically, usable for an autonomous delivery robot.

Disclaimer: The stations have not been checked for their availability of space, which is critical for the final evaluation. If there is not enough space for the robot at or right next to the station to wait for the train, the station would not be suitable.

The robot cannot be in the way / block platforms and walkways for regular passengers. They always have priority.

The check for availability of space was only done for all stations of tram line 5, within use case 2.

TABLE 3: RELEVANT CRITERIA, CURRENT AND FUTURE

Criteria	current		future	
	required	optional	required	optional
Barrier-free access (gap width & height difference <5 cm)	x		x	
No circulating railings and guardrails	x			x
Availability of space for a designated waiting area for the robot	x		x	
Connection to other modes of transport in the neighbourhood	x		x	
Free space in the vicinity of the stop for loading units	x		x	
Extended stopping possibility		x		x
No track crossing during (partially) automated loading and unloading	x			x
No tunnel stop	x			x
Stop close to regional distribution centre (no transfers)	x			x

In addition, the table below lists every relevant criterion, current and in the future.

The importance of the listed criteria (required / optional) was assessed qualitatively, according to the experts' experience.

3.4.1.3 Railway Vehicles

As described above the Karlsruher TramTrain model requires special trains. There are classical tram vehicles (as shown below) and special dual system trains, which can drive inside the city and on regional rail network.

FIGURE 5: TRAMTRAIN VEHICULE KARLSRUHE

For this feasibility study classical tram vehicles have been chosen. They always have low-entry doors und multiple multi-functional areas, where the robot could stand.

3.4.2 Additional equipment/infrastructure needed for URBANE

3.4.2.1 Requirements for robot

The integration of autonomous delivery robots into urban logistics systems requires a robust and modular hardware architecture capable of meeting diverse operational, environmental, and user-centric demands. Requirements arise from the urban deployment scenarios, as well as from movement within trams and on platforms.

Modular and Scalable Architecture

To enable flexibility and scalability, delivery robots must be designed with a modular structure. The system should consist of interoperable modules. Those modules can be grouped in modules for movement, navigation, energy supply, communication and safety. Standardized interfaces for data and power exchange between modules are essential to ensure compatibility and future upgrades.

Mobility and Suspension System

High maneuverability is critical in dense urban environments and especially in narrow aisles and multipurpose spaces in trams. Robots should feature an omnidirectional drive system.

Given the variety of urban surfaces, such as pavements, cobblestones, ramps, and curbs, the robot must be moderately all-terrain capable to ensure reliable navigation in diverse environments. A system to ensure consistent ground contact of all wheels and stability across uneven terrain is needed.

Energy Supply and Charging

Robots must be equipped with an energy storage solution. It should be scalable to accommodate different operational scenarios resulting in various robot sizes, payloads and operational durations. Depending on the scenario different technologies can be chosen including different types of lithium-ion batteries or hybrid systems (battery + supercapacitor).

Inductive charging capabilities are necessary to allow autonomous recharging in public spaces.

Navigation and Sensor Systems

Reliable autonomous navigation requires a combination of sensors, such as laser scanners for 360° obstacle detection, GPS modules for geolocation, IMUs for orientation and motion tracking and Cameras for environmental perception and object recognition.

Communication Infrastructure

Reliable, continuous connectivity with the central fleet management system must be ensured, allowing the robot to receive routing updates and report its status in real time. Available technologies are Wi-Fi, LTE and 5G.

Safety and Compliance

Robots must comply with common standards (e.g., BOStrab, DIN EN ISO 12100), including emergency stop mechanisms and safe signal processing for critical functions.

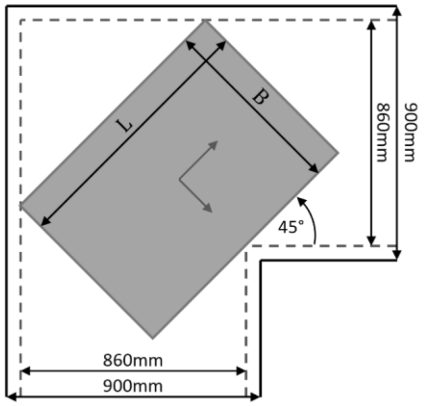
Robot Dimensions

Dimensions must allow passage through elevators, tram doors, and narrow sidewalks, with width and length calculated to include safety margins.

The standard DIN 18040-3 serves as a guideline for the barrier-free design of public spaces. It stipulates a usable minimum sidewalk width of 1.80 m, a usable minimum width of 0.90 m at narrow points, and a minimum clear height of 2.25 m above the sidewalk width.

According to BOStrab §31 (5), a usable platform width of at least 2 m is required, and at least 1.5 m in public street traffic. §43 (2) specifies that passenger doors must be at least 0.65 m wide, with at least one door having a minimum width of 0.8 m.

Taking these requirements into account and adding a safety margin of 20 cm, the following maximum vehicle width can be derived:



$$\sin 45^\circ * \frac{L}{2} + \cos 45^\circ * B = 860mm$$

$$\frac{\sqrt{2}}{2} * \frac{L}{2} + \frac{\sqrt{2}}{2} * B = 860mm$$

$$\frac{L}{2} + B = \frac{2*860mm}{\sqrt{2}}$$

$$B = \sqrt{2} * 860mm - \frac{L}{2}$$

FIGURE 6: DETERMINATION OF MAXIMUM ROBOT DIMENSIONS

The height of delivery robots varies depending on their specific application. Given their intended use on sidewalks and their planned transport via trams over longer distances, frequent encounters with pedestrians are expected. It is therefore essential that the presence of these robots does not cause disruption or unease among pedestrians. The size of the delivery robot could evoke feelings of threat or insecurity, particularly among smaller individuals. For this reason, it is assumed that the robot will not be perceived as threatening if pedestrians can see over it. This implies that the vehicle height should remain below eye level. The 5th percentile for women in Germany is 1430 mm, which is used here as the reference for the maximum vehicle height. In other European markets, the maximum vehicle height may need to be further reduced.

3.4.2.2 Description of the delivery robot used in the URBANE project

The objective in URBANE's Karlsruhe twinning living lab was to test an omnidirectional robot in tramway settings, evaluating its mobility and suitability within complex public transport infrastructures.

We used a delivery robot from SEW-EURODRIVE, which was designed to meet the requirements listed in the previous chapter. The modular robotic system was designed to offer the highest possible adaptability to various applications. Based on existing delivery robots, a decomposition of the functional structure was carried out, followed by a functional analysis and subsequent module definition (Figure 7Figure 7).

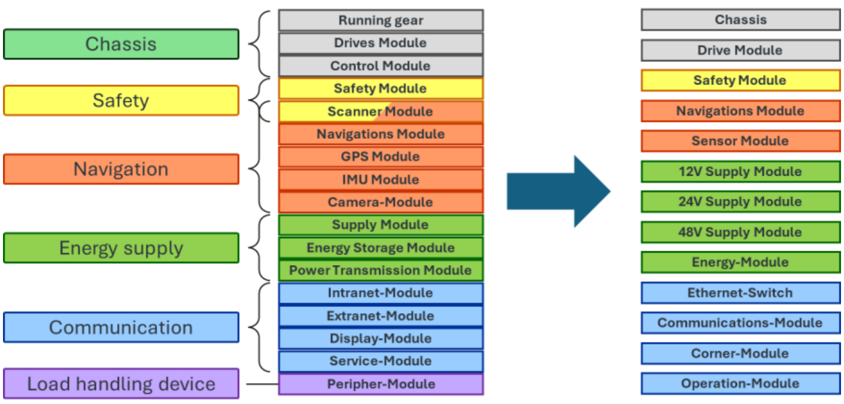


FIGURE 7: MODULARIZATION OF DELIVERY ROBOT

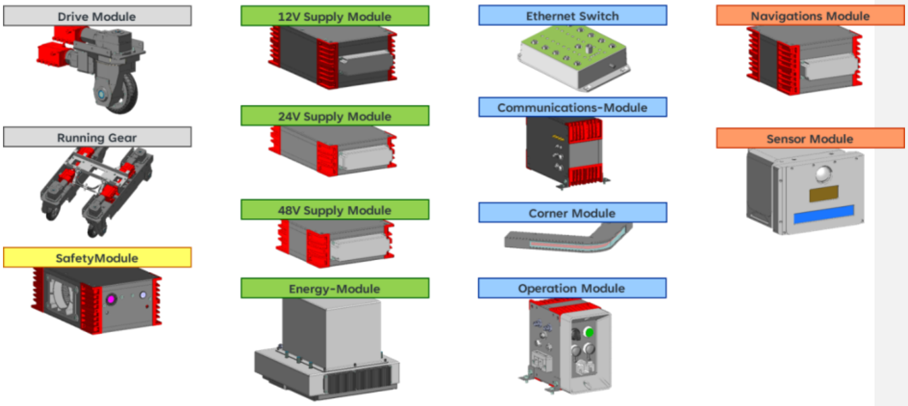


FIGURE 8: MODULES OF THE DELIVERY ROBOT USED FOR URBANE ACCEPTANCE STUDY AND FEASABILITY PROOF

Chassis / omnidirectional driving

An omnidirectional drive system was required. To meet this, a chassis concept was developed based on four drive modules specifically designed for the modular robot system. This concept enables a wide range of driving maneuvers, including straight-ahead driving, double Ackermann cornering, on-the-spot rotation, and lateral/diagonal movement.

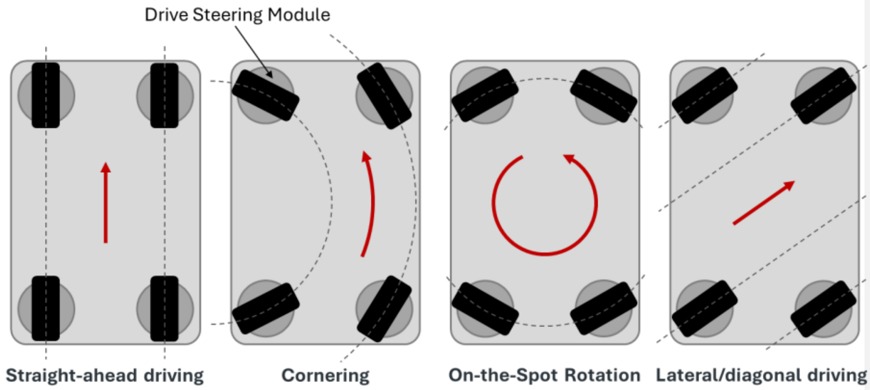


FIGURE 9: POSSIBLE DRIVING MANEUVERS OF AN OMNIDIRECTIONAL CHASSIS

The developed drive module is designed to integrate propulsion and steering into a single unit, allowing for continuous 360-degree steering movements. Additionally, the module is suitable for both indoor and outdoor use and enables ground clearance of up to 50 mm. Various chassis configurations can be derived from this module.

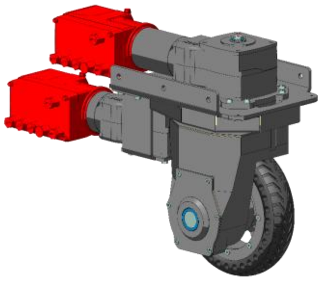


FIGURE 10: DRIVE MODULE

The requirement also included consistent ground contact of all wheels and stability across uneven terrain. To achieve this, the chassis was equipped with a hydraulic rocker differential.

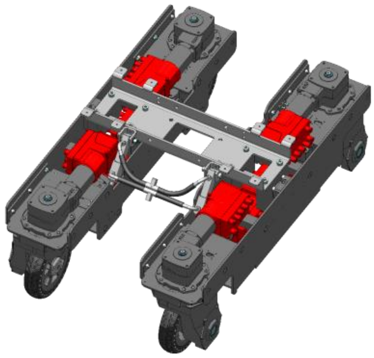


FIGURE 11: OMNIDIRECTIONAL CHASSIS

In Figure 12~~Figure 12~~ (left), the support polygon of a rocker-bogie wheel suspension is shown in red. If the vehicle's centre of gravity lies outside this support polygon or moves beyond it, the vehicle will tip over. The robot is assumed to have a central centre of gravity. However, if the vehicle is loaded asymmetrically or positioned on a slope, the centre of gravity shifts. To ensure robustness against tipping due to uneven loading or inclined surfaces, it is crucial that the minimum distance from the symmetrical centre of gravity to the edge of the support polygon (R_{RB}) is as large as possible. In this regard, the rocker chassis, with its symmetrical, diamond-shaped contact area, offers a distinct advantage over a pendulum chassis (Figure 12~~Figure 12~~, right).

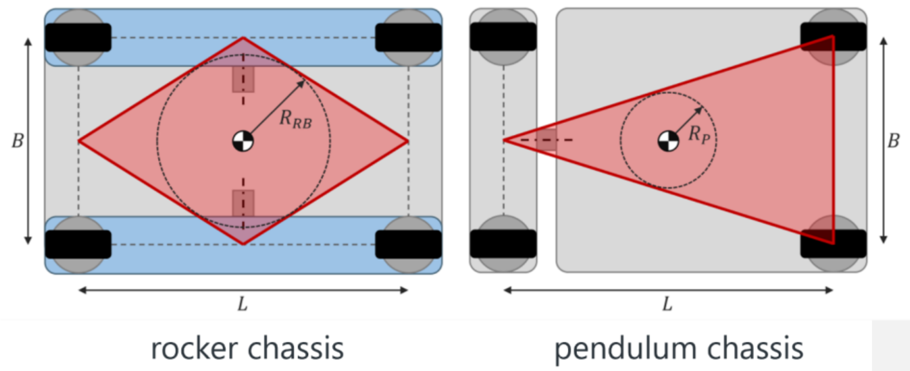


FIGURE 12: SUPPORT POLYGON OF ROCKER AND PENDULUM CHASSIS

Energy Module

The energy module (Figure 13~~Figure 13~~) comprises a battery storage system with an associated charge controller and double-layer capacitors designed to buffer power peaks. Engineered for reliable operation and weather-independent energy supply, the module supports contactless inductive charging. The energy module provides all low-voltage levels required within the vehicle.

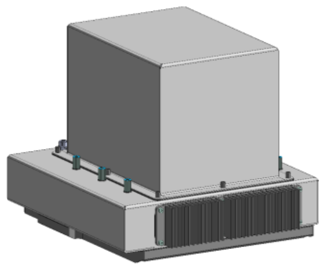


FIGURE 13: ENERGY MODULE

Safety Module

The developed safety module (Figure 14Figure 14) primarily consists of an RGB camera fused with a thermal imaging camera for object detection and classification. Unlike conventional safety sensors, this module enables the specific identification of humans and objects closely associated with human activity. The objective of the module is to allow the system to safely traverse obstacles that do not pose a threat to people, such as thin branches on the path or curbs, thereby enhancing the robustness and availability of the system.

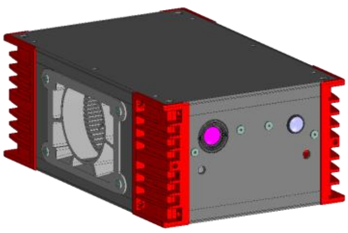


FIGURE 14: SAFETY MODULE

3.4.2.3 Delivery robot used for proof of feasibility of the mobile robot concept

For the feasibility proof of the requirements and the defined delivery robot concept the SEW delivery robot with two parcel compartments was used as shown in Figure 15Figure 15, Figure 16Figure 16 and Figure 17Figure 17.

The main specifications of the robot are:

- omnidirectional rocker chassis
- two compartments for parcels/goods of the size of 500x390x330mm
- contactless energy charging system
- hybrid energy storage system (Lithium-Ion battery + energy buffer based on double layer capacitors)
- Navigation module
- Safety module
- Communications module
- Dimensions: width 670mm, length 1020mm, height 1040mm

With this configuration, the robot essentially meets the requirements for Use Case 2, enabling a validation of the robot concept based on this scenario. The validation primarily focused on its suitability for deployment in AVG tram environments, its operation on AVG platforms, and the interaction between users, namely retailers and end customers, and the delivery robot.

FIGURE 15: DELIVERY ROBOT ENTERING TRAM OVERCOMING STEPS AND GAPS

FIGURE 16: DELIVERY ROBOT IN MULTIPURPOSE SPACE WITHIN TRAM – HIGH MANEUVERABILITY BY OMNIDIRECTIONAL CHASSIS (HERE: LATERAL DRIVING)

FIGURE 17: TWO COMPARTMENTS ACCORDING TO REQUIREMENTS OF USE CASE 2

On the demo day the following validations were performed:

- Validations on demo day for operation in tram environment and on platforms
- Suitable size for use in multifunctional areas
- The delivery robot's compact dimensions support use on the platform
- Sufficient manoeuvrability within trams and on the platform
- The robot is capable of entering and exiting trams and crossing tramway tracks without difficulty
- Adequate torque to overcome steps and gaps
- Sufficient ground clearance
- Entry and exit within the transfer times specified by AVG is conditionally possible, provided there are no path conflicts with passengers.

FIGURE 18: SEW ROBOT ON TRAMWAY TRACKS

3.4.2.4 Conclusion and outlook

(1) Human-Robot Interaction

To ensure public acceptance and usability, robots should be equipped with:

- Displays for text-based communication
- Sound signals or speech synthesis for auditory interaction
- LED indicators for visual signalling
- App connectivity for user control and tracking

(2) Delivery robot concept

The delivery robot used for validation, in its current configuration, is highly suitable for deployment in Use Case 2. For Use Case 3, "Meals on Wheels", a customized delivery robot configuration should be deployed, featuring multiple compartments specifically designed for meal trays. A modular design, as implemented in the deployed vehicle, supports this approach by allowing the use of different load carriers or load-handling devices.

The hydraulic rocker chassis exceeds the specified requirements while a chassis with the less complex pendulum axle might suffice.

The perception system intended for use in confined spaces requires further research and validation

3.4.3 Existing digital infrastructure

As part of the regular railway operations at AVG, a Centralised Traffic Control System (CTC) is currently in use and enables following functions and opportunities:

- It serves as the central production control system for AVG's railway operations and enables a GPS-based tracking of all rail vehicles in the fleet, regardless of whether they are currently assigned to a scheduled service or not.
- For services supplied with data by CTC, the driver of the train can log in on board.
- CTC provides forecasts about delays and occupancy levels in the TramTrain. Therefore, it is integrated with a passenger counting system within the rail vehicles.
- CTC allows data to be stored for statistical purposes, particularly data on traffic volume, deviations compared to the planned schedule, causes of deviations, and passenger numbers. The associated statistics system can be operated either separately or as an integrated component.
- CTC allows the central control station to manage current services, which makes CTC a central tool for the staff in the central control station.
- Any changes in services within the CTC are immediately reflected in passenger information systems and are visible to all operational staff, especially drivers and conductors.
- CTC also functions as a reporting system, feeding textual passenger information and enabling direct reporting to, for example, the public transport authority.
- CTC can also supply peripheral devices in the vehicle with data and information, for example destination tables, automated announcements, interior displays, and other inboard information systems.
- Additionally, the CTC can be connected to a depot management system.
- In addition, driver assistance systems within the rail vehicles can be linked to the CTC.
- Shift schedules (ensuring compliance with collective agreements and working time accounting) as well as maintenance intervals for vehicles (workshop scheduling, operational restrictions) can be managed either separately or integrated within the CTC. Vehicle diagnostic systems can be integrated in this context.

All these CTC-functions must not be limited by the combined passenger and freight transport system, analysed in URBANE. They must be automatically synchronised with the logistics data and data streams of the delivery robot. To achieve this, suitable data exchange interfaces must be developed. The most appropriate solution is an ICT platform. Such a platform was already fundamentally developed in the project LogIKTram.

3.5 Impact Assessment Radar

As part of the project activities, an Impact Assessment Radar had been developed to evaluate the overall maturity, potential, and readiness of the Living Labs. This online questionnaire was designed to systematically assess various dimensions such as innovation potential, governance structure, and scalability. For the Karlsruhe Living Lab, the questionnaire was jointly reviewed and completed in collaboration with the Karlsruhe City Planning Department (Stadtplanungsamt[20]) to ensure that local conditions and perspectives were accurately reflected.

The results of this assessment are illustrated in the Figure 19: Impact Assessment Radar. Interestingly, the calculated value for Innovation Readiness in Karlsruhe reached 49%, which is remarkably close to the results obtained for the other Living Labs especially Helsinki (48%) but also Valladolid (44%). This indicates a comparable level of development and preparedness across all three sites, despite their differing local contexts, institutional frameworks, and technological approaches. The result also suggests that Karlsruhe's innovative logistics concept, combining autonomous mobile robots and tram-based delivery, is already approaching a promising level of readiness from the city side.

Commented [SR2]: Ensure the text fully explains *why* Karlsruhe scored 49% and what that implies for future readiness.

[20] https://www.karlsruhe.de/stadt-rathaus/verwaltung-stadtpolitik/aemter-dienststellen/detailseite/39-stadtplanungsamt

What your responses show

▲ The strongest element of your ecosystem is **SMART ACTORS**

▲ The responses show that **Interoperability of operations** & **Citizen perception** are strong points of the system.

▲ Finally, it can be seen that city's main advantages are regarding **Q6** and **Q7**

▼ According to your responses, the weakest element of your ecosystem is the **SMART & EASILY ACCESSIBLE CITY LOGISTICS NETWORKS**

▼ More analytically, the city is not performing well in **Service Quality** and **Multimodal logistics**

▼ In a more detail, lowest scores were identified considering the **Q20** and **Q19**

Compared to other cities

▲ The city is really strong in **SMART & INNOVATIVE RESOURCES & INFRASTRUCTURE.**

▲ Your city was found to outperform the other cities in **PlanningMultimodal logistics** point(s).

▲ Related to the other cities, your city is strong in **Q2, Q9, Q10, Q19.**

▼ Following a comparatory approach, your city was found to be very weak in **none** element(s).

▼ Looking in a lower level, city underperforms in **Digitization of sector, Citizen perception** point(s).

▼ Related to the other cities, your city is weak in **Q7, Q8, Q12, Q15, Q17.**

FIGURE 19: IMPACT ASSESSMENT RADAR

4. Events and Survey

4.1 Events for demonstration and dissemination

4.1.1 Live Demonstration and Public Survey – March 6, 2025

To test the interaction between the delivery robot and the tram system, a live demonstration event was held on March 6, 2025, in Karlsruhe. The main objective was to present the innovative concept of parcel delivery using a delivery robot in combination with the tram network to the citizens of Karlsruhe and to gather public feedback through an on-site acceptance survey.

Selection of the Location

The demonstration site had to fulfil several important criteria. The chosen tram stop needed to be free from regular tram traffic to allow the test vehicle to remain stationary for an extended period. This made it possible to carry out the tests safely and to engage with a sufficient number of people from the general public. Furthermore, the station had to be barrier-free and have spacious platforms to accommodate the testing team, survey staff, and participants comfortably.

After reviewing several options, Philipp-Reis-Straße station was selected as the most suitable location. The site offered ideal conditions for demonstrating the robot's motion capabilities – particularly crossing the tracks and entering the tram vehicle via the step, which provided valuable insights into the robot's running gear and navigation system. Using a BOStrab-compliant low-floor tram ensured that the results could be transferred to other stops within the Karlsruhe network.

Timing of the Event

The date in early March was chosen strategically. Holding the event shortly after the carnival season ensured that both regular tram operations and commuter traffic had returned to normal. Additionally, this timing avoided conflicts with scheduled track maintenance during that period. Consequently, Thursday, March 6, 2025, proved to be the optimal day for conducting the live test and public survey.

Execution and Survey

During the event, the delivery robot performed multiple test runs between the platform and the tram vehicle, demonstrating the process of parcel transfer via the tram system. The robot's movement across the tracks and into the vehicle attracted considerable attention from passers-by, many of whom stopped to observe and engage with the project team.

An on-site public survey was conducted to collect citizens' opinions on the concept. Participants were asked about their awareness of automated delivery systems, their perception of integrating such systems into public transport, and their willingness to use or accept delivery robots in their daily environment. Despite the short notice of the invitation, numerous spontaneous visitors participated, resulting in a diverse set of responses that provided valuable feedback on public acceptance and perceived benefits of the project.

Technical Performance and Expert Feedback

From a technical perspective, the robot successfully entered and exited the AVG tram from the northern platform without any issues. Its smooth operation demonstrated the feasibility of automated delivery movements in an urban tram environment.

The event was also attended by the VBK's BOStrab operations manager and a representative of TAB Baden-Württemberg, who used the opportunity to observe the robot's movement sequences and discuss potential next steps for technical validation and further development.

FIGURE 20: KA DEMONSTRATION OF PACKAGE IN DELIVERY ROBOT

4.1.2 Additional Public Engagement Event – May 11, 2025

As part of the continued dissemination and stakeholder engagement activities within the URBANE project, a second public event was held on May 11, 2025, during the Open Day at the Alte Schlachthof[21] area in Karlsruhe. This event provided another valuable opportunity to present the delivery robot to the public and to collect additional feedback through a follow-up survey.

[21] https://alterschlachthof-karlsruhe.de/

A large exhibition stand was installed in the foyer of the FUX – Festigungs- und Expansionszentrum[22] Karlsruhe, serving as the central point of interaction. Throughout the day, the delivery robot was displayed and demonstrated, allowing visitors to experience its design and functionality firsthand. Representatives from SEW were present to explain the robot's operation, discuss the objectives and benefits of the URBANE concept, and answer questions from interested attendees.

The event attracted a diverse audience, including families, children, students, professionals, and senior citizens. Many visitors stopped by out of curiosity and took the opportunity to learn more about the integration of automated delivery robots with the tram network. In addition to these interactions, further surveys were conducted, enabling the project team to gather valuable insights into public acceptance, perceived usefulness, and potential concerns regarding the technology.

Overall, the participation in the Open Day significantly contributed to raising awareness of the URBANE project, enhancing public engagement, and collecting complementary feedback that supports the refinement and user-oriented development of the delivery robot and service concept.

FIGURE 21: OPEN DAY AT ALTER SCHLACHTHOF AREAL (KARLSRUHE)

[22] https://alterschlachthof-karlsruhe.de/FUX/

4.1.3 Participation in Trade Fairs and Conferences

In addition to the live demonstration and public events, the URBANE project was also presented at several trade fairs and professional conferences, providing opportunities to reach a broader audience, engage with experts, and raise awareness of the project's objectives.

On November 27th and 28th 2024, the project team participated in the POLIS Conference[23], where a dedicated exhibition stand was set up to introduce the URBANE concept to urban mobility professionals, city representatives, and researchers. Although no public survey was conducted during this event, the focus was on promoting the project and informing attendees about the upcoming live demonstration, where citizens would be able to experience parcel delivery using a robot and the tram system in real-life conditions.

Later, from September 25th to 28th 2025, URBANE was showcased at the NUFAM[24] commercial vehicle trade fair in Karlsruhe, one of the region's key industry events. The project team operated an interactive stand, displaying the delivery robot and engaging with numerous visitors from both the logistics and transport sectors as well as the general public. During this event, targeted surveys were conducted to gather visitors' opinions, expectations, and acceptance levels regarding automated parcel delivery systems linked to public transport.

Both events significantly contributed to enhancing the project's visibility, fostering dialogue with industry stakeholders, and collecting valuable feedback to support the further development and implementation of the URBANE concept.

FIGURE 22: EXHIBITION STAND AT POLIS CONFERENCE (NOVEMBER 2024)

[23] https://www.polisnetwork.eu/2024-annual-polis-conference/
[24] https://www.nufam.de/de/

FIGURE 23: EXHIBITION STAND & SURVEYS AT NUFAM (SEPTEMBER 2025)

4.2 Survey

4.2.1 About the survey

An important component of the URBANE project's public outreach activities was a comprehensive survey designed to gather the opinions and perceptions of citizens regarding the concept of parcel delivery using a combination of trams and autonomous delivery robots. The goal of the survey was to better understand how the general public perceives this innovative approach, how familiar people already are with parcel logistics, and which factors influence acceptance and trust in such a system.

The survey consisted of 31 questions across eight pages and included a variety of question types – such as rating scales, yes/no questions, and knowledge-based items – to obtain both qualitative and quantitative insights. The structure of the questionnaire was designed to assess respondents' general awareness of parcel delivery processes, their attitudes toward automation and sustainability, and their openness to new technologies in urban logistics.

The survey was conducted during several public events in Karlsruhe, including the live demonstration day on March 6, 2025, the Open Day at the Alte Schlachthof area on May 11, 2025, and the NUFAM commercial vehicle trade fair in September 2025. This approach ensured that a broad and diverse audience was reached – from local residents and daily tram users to industry experts and professionals in logistics and mobility.

The collected responses provide valuable insights into public awareness, acceptance, and expectations regarding the integration of automated parcel delivery systems into the public transport network. These results will serve as a foundation for further refinement of the service concept and support the development of user-oriented, sustainable logistics solutions within the URBANE project.

FIGURE 24: CITIZENS PARTICIPATING IN THE URBANE SURVEY ON PUBLIC PERCEPTION OF PARCEL DELIVERY USING TRAMS AND AUTONOMOUS ROBOTS

Survey Participants and Demographic Profile

A total of 182 individuals participated in the public survey. The respondents represented a diverse cross-section of the population in terms of age, gender, education, household composition, and employment status.

Gender and Age Distribution

Of all respondents, 50.0% identified as female, 46.7% as male, and 0.5% as diverse. The participants were born between 1936 and 2011, reflecting a broad age spectrum ranging from younger adults to senior citizens. This diversity in age and background helped capture a wide range of perspectives regarding parcel delivery and public transport usage.

Education Level

In terms of educational attainment, 59.3% of participants reported having a higher education degree (Bachelor's, Master's, or Doctorate). An additional 9.9% indicated having a technical or vocational qualification, while 29.1% held a secondary school diploma. This composition shows that the majority of respondents had a strong educational background, which likely contributed to an informed evaluation of the URBANE concept.

Household Composition

Regarding household size, 45.5% of respondents reported living in households of up to two people, while 46.5% lived in households with up to five members. Only 3.2% lived in households with more than five people. These figures suggest that most participants reside in small to medium-sized households, which aligns with typical urban living conditions.

Employment Status

The majority of respondents were employed (53.3%), followed by students (25.8%). The remaining share consisted of retirees, self-employed individuals, and others not actively employed. This distribution reflects a balanced representation of the working population and younger adults, two key target groups for future urban delivery services.

Tram Usage Patterns

The frequency of tram use among respondents varied considerably. 29.7% reported using the tram daily, 24.1% used it once per week, and 17.1% several times per month. In contrast, 13.3% stated that they never use the tram. These results highlight the importance of public transport in everyday mobility for a large portion of respondents – an important factor when considering the integration of parcel delivery into tram operations.

Daily Routines and Mobility

When asked about their daily routines, 36.8% indicated that they are frequently away from home and work irregular hours, 35.2% are typically away between 9:00 and 17:00, and 19.8% reported spending most of their time at home. These findings provide useful context for understanding delivery preferences and availability, as they influence how and when residents might interact with a delivery robot.

Overall Observations

During the evaluation of the survey results, no significant differences were observed between the demographic groups. Responses were evenly distributed across age, gender, education level, and occupation, without any clear patterns indicating that one particular group held distinctly different views. This suggests that the opinions expressed in the survey were broadly shared across the population, and that the level of acceptance and perception of the URBANE concept was consistent and balanced among all respondent groups.

Overall, the demographic data demonstrate a diverse and well-balanced participant group, ensuring that the survey results reflect a wide range of lifestyles, mobility habits, and socio-economic backgrounds relevant to the future design of the URBANE parcel delivery service.

4.2.2 Survey insights

Comparative Evaluation of Delivery Options

In addition to the general assessment of delivery preferences, respondents were also asked to evaluate three specific delivery options – Home Delivery, Collection Point Delivery, and Autonomous Vehicle Delivery – according to six key criteria: Delivery to a Convenient Location, Delivery at a Convenient Time, Low Environmental Impact, Good Working Conditions for Couriers, Low Delivery Costs, and Confidentiality of Parcel Data. Each criterion was rated on a numerical scale from 1 to 10, allowing for a detailed comparison of the perceived strengths and weaknesses of the different delivery concepts.

In the subsequent analysis, the distribution of responses for each delivery option was compared to identify relative advantages or disadvantages. The results are summarized in the following table, where the symbols "=", "–", and "+" denote the comparative outcome: "=" indicates that the respective delivery options were rated as equal or very similar, "–" denotes a lower evaluation, and "+" signifies a higher evaluation relative to the other options.

TABLE 4: COMPARATIVE EVALUATION OF DELIVERY OPTIONS

	Traditional home delivery	Collection point	Autonomous vehicle
Parcel delivery to a convenient location	=	-	=
Parcel delivery at a convenient time	=	=	=
Low environmental impact	-	=	=
Good working conditions for couriers	-	=	=
Low delivery costs	=	=	=
Confidentiality of parcel data	=	=	=

Overall, the analysis revealed big differences between the three options. Most ratings are clustered closely together, indicating that participants perceived the alternatives as largely comparable in terms of convenience, cost, and service quality. However, two notable exceptions emerged. In the categories *Low Environmental Impact* and *Good Working Conditions for Couriers*, the *Home Delivery* option received a slightly lower evaluation. This result suggests that participants associate conventional home delivery with higher emissions and greater physical strain on couriers.

Interestingly, *Collection Point Delivery* was rated better in these two categories, though the underlying reasons for this perception remain unclear. It could be speculated that respondents view consolidated parcel handling at collection points as more energy-efficient and logistically optimized, yet this assumption would require further investigation. Conversely, *Collection Point Delivery* received lower ratings in the category *Delivery to a Convenient Location*, which aligns with the practical inconvenience of having to travel to a pick-up location.

In summary, while the differences among the three delivery models were generally small, the results provide useful insights into public perceptions of sustainability and service quality in last-mile logistics. The findings indicate a nuanced balance between environmental awareness, convenience, and social aspects of delivery work – elements that will play a key role in shaping future urban delivery systems.

Perceived Advantages of Autonomous Robot Deliveries

Participants were asked to identify what they consider to be the most important potential advantages of autonomous delivery robots in urban environments. The responses provide valuable insights into public expectations and perceived benefits of this emerging technology.

The most frequently selected answer was *flexibility regarding time and place of collection*, chosen by 123 respondents. This indicates that adaptability and convenience are seen as the most valuable benefits of robot-based parcel delivery. People appreciate the potential to collect parcels according to their own schedules and at locations that best suit their daily routines.

The second most common response was *faster and more punctual delivery* (95 participants), followed by a *reduction in the number of delivery vehicles in the area* (78 participants). These results reflect a strong public expectation that robot delivery could enhance efficiency and reduce urban congestion, contributing to smoother logistics operations and less traffic in residential areas.

Sustainability was also a major factor, with 75 respondents indicating that they see autonomous delivery robots as a step toward more environmentally friendly urban logistics. Cheaper deliveries, mentioned by 52 participants, were of lesser, but still notable, importance, suggesting that while cost matters, reliability and flexibility take precedence for most users.

In the open-ended "other" responses, participants offered a variety of thoughtful perspectives, such as:

- "No labor exploitation of couriers"
- "Six medium robots are much smaller than six Sprinter vans"
- "Transporting large parts"
- "With many parcels, there is no need to feel uncomfortable, as they are delivered by a robot."
- "None"
- "Sustainability, quality of life, less congested roads"
- "Reduced delivery charges for parcel couriers"
- "Environmentally friendly"
- "Practical, also possible at night, no working hours"
- "Not possible, too far away from the tram stop."

These qualitative comments highlight a diverse range of expectations, including social and environmental benefits, operational efficiency, and ethical considerations such as reducing courier workload. Several participants also mentioned nighttime operation and improved urban livability, suggesting that citizens see autonomous delivery not only as a convenience but also as a potential contribution to sustainability and social well-being.

Overall, the results demonstrate that the public perceives flexibility, punctuality, and sustainability as the main advantages of autonomous robot delivery systems. These findings support the idea that the URBANE concept aligns well with citizens' priorities for efficient, green, and people-friendly urban logistics.

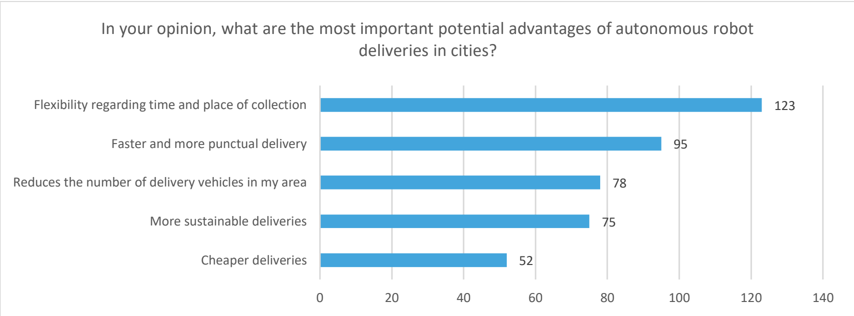


FIGURE 25: PERCEIVED ADVANTAGES OF AUTONOMOUS ROBOT DELIVERIES

Perceived Concerns Regarding Autonomous Delivery Robots in Urban Areas

This multiple-choice question explored participants' potential concerns related to the introduction of autonomous delivery robots in cities. The responses provide valuable insights into public attitudes toward safety, practicality, and social implications of this emerging delivery technology.

The most frequently mentioned issue, selected by 117 respondents, was *safety issues, such as robot malfunctions or loss of control*. This dominant result highlights that technical reliability and operational safety are the primary public concerns. Many citizens fear that malfunctions could lead to accidents or unsafe situations in busy urban environments.

The second most common concern was *loss of parcels due to a malfunction of the robot* (74 respondents), closely followed by *security risk for the parcels* (61 respondents). These results suggest that participants are worried about parcel security and delivery reliability, emphasizing the need for robust fail-safe mechanisms and traceability systems to build user trust.

A further 42 respondents identified *negative impact on delivery orders*, indicating that some participants believe robot-based systems could disrupt established logistics processes or reduce service quality. Additionally, 33 respondents expressed concern that robots take up too much space on the road, pointing to possible conflicts in shared urban spaces, especially on sidewalks and in pedestrian areas.

In the "other" category, several additional comments were provided, reflecting a range of social, technical, and ethical considerations:

- Employment loss (4)
- Manipulation by others (hacking, attacking, run over, etc.) (2)
- High costs for robot production (resources, etc.)
- Who will take the parcel?
- Additional surveillance in public spaces, albeit indirect
- No concerns (2)
- Theft
- Competition for space on public footpaths – more than roads
- Wheelchairs, etc. cannot move out of the way quickly.
- Expensive, only a few parcels fit into a robot compared to a delivery van.
- Too far from the station.
- Damage to the parcel – is immediate return or non-acceptance possible?

These open-ended responses reinforce recurring themes of safety, accessibility, cost, and ethical implications. Several participants raised inclusion concerns, noting that delivery robots might pose challenges for people with mobility impairments. Others questioned the economic efficiency and resource intensity of large-scale robot deployment.

Overall, the results indicate that while the concept of autonomous robot delivery is widely recognized as innovative, it is also accompanied by significant trust, safety, and societal concerns. Ensuring transparency, reliability, and accessibility will therefore be key to increasing public acceptance of robot-assisted last-mile delivery systems.

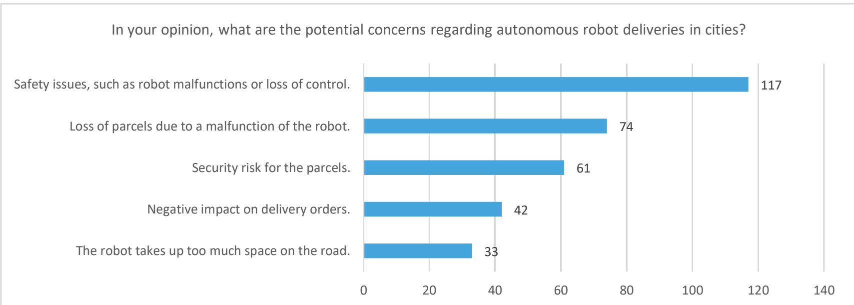


FIGURE 26: PERCEIVED CONCERNS REGARDING AUTONOMOUS DELIVERY ROBOTS IN URBAN AREAS

Public Perception of Autonomous Delivery Robots

The survey results provide a clear indication of a generally positive attitude toward autonomous delivery robots among respondents. A majority of 60.4% of participants expressed that they would like to see more delivery robots operating in their city, while only 7.7% disagreed, and 31.9% remained neutral. This finding suggests a broad level of acceptance and curiosity regarding the integration of robotic delivery systems into urban environments. The relatively high share of neutral responses may indicate that many individuals have not yet formed a strong opinion due to limited exposure or practical experience with such technologies.

The willingness to actively use these services is even higher. 74.7% of respondents stated that they would use a delivery robot if such an option were available in their area. This result highlights the perceived practical value and convenience of robotic delivery solutions, particularly for last-mile logistics. Only a small proportion of 9.9% expressed unwillingness to use such services, implying that acceptance barriers are relatively low from a user perspective.

Regarding safety perceptions, the data reveal a somewhat more cautious attitude. While a majority of 61.5% reported feeling safe when an autonomous robot operates in their neighbourhood, 13.2% did not share this confidence, and 25.3% provided no clear opinion. This pattern reflects an underlying trust in the technology but also points to a need for continued public communication and transparent demonstration of safety standards and operational reliability.

When asked specifically about pedestrian safety, the responses were slightly less affirmative: 54.9% indicated that they would feel safe if delivery robots were moving along footpaths, 16.5% disagreed, and 28.6% expressed no opinion. These figures suggest that while more than half of the respondents view co-existence with robots in pedestrian zones as acceptable, a notable fraction still has concerns about shared space, potential obstructions, or collision risks.

Overall, the results demonstrate a very strong potential for public acceptance of autonomous delivery robots, particularly if their deployment is accompanied by clear communication, visible safety measures, and user-oriented design. The findings also underscore the importance of continued field testing and citizen engagement to ensure that technological innovation aligns with societal expectations and urban liveability.

TABLE 5: PUBLIC PERCEPTION OF AUTONOMOUS DELIVERY ROBOTS

	Yes	No	No opinion
I would like to see more delivery robots in my city.	**60,40%**	7,70%	31,90%
I would use the delivery robot if there were a delivery option in my area.	**74,70%**	9,90%	15,40%
I feel safe when an autonomous robot is operating in my neighbourhood.	**61,50%**	13,20%	25,30%
As a pedestrian, I would feel safe if delivery robots were moving along the footpaths.	**54,90%**	16,50%	28,60%

Evaluation of Key Factors Influencing Acceptance

One of the survey questions focused on identifying the main factors that would convince respondents to opt for parcel delivery using a robot. The question allowed for multiple selections and included several predefined options, as well as the possibility to provide individual responses.

Out of all participants, the most frequently selected factor was the flexibility of the delivery schedule, chosen by 132 respondents. This indicates that convenience and time flexibility play a central role in users' willingness to adopt robot-based delivery services.

The availability and proximity of delivery points was the second most common factor, selected by 97 participants. This highlights the importance of ensuring that service accessibility is well integrated into citizens' daily routines and local environments.

A significant number of respondents (73 participants) also stated that the fact that the delivery service is emission-free would positively influence their decision. This result underlines the relevance of sustainability and environmental awareness among the surveyed population.

Furthermore, 68 respondents indicated that they enjoy testing new service options, reflecting a notable degree of technological curiosity and openness to innovation within the group.

In addition to these predefined answers, several individual responses were provided, offering further qualitative insights. These included:

- “I love research / gadgets”
- “Interesting technology”
- “Cheaper”
- “Well tested and safe”
- “No factors would be convincing.”

These open responses reinforce that, while most participants value flexibility, accessibility, and sustainability, a smaller subset is particularly motivated by curiosity and innovation, whereas a few remain sceptical or price sensitive.

Overall, the results suggest that user convenience, service availability, and environmental benefits are the key drivers of public acceptance for robot-based parcel delivery. Ensuring these factors in future implementations could therefore play a crucial role in encouraging adoption and building trust in the URBANE delivery concept.

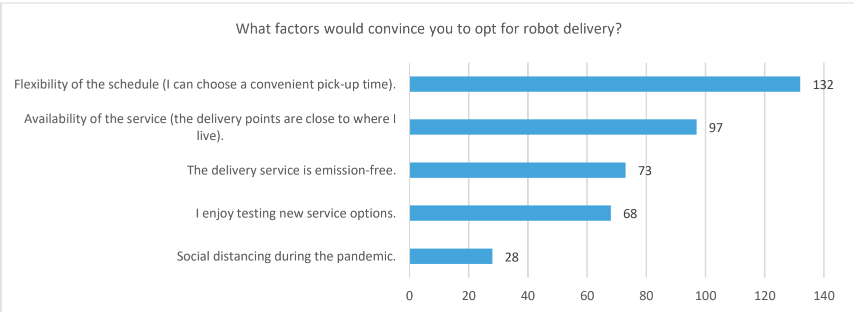


FIGURE 27: EVALUATION OF KEY FACTORS INFLUENCING ACCEPTANCE

Evaluation of Concerns and Barriers to Adoption

The survey also explored potential barriers and concerns that might prevent citizens from choosing parcel delivery via a robot. As with the previous question, respondents could select multiple predefined options and provide additional open comments.

Among the predefined answers, the two most frequently selected factors were:

- “I have no confidence in the delivery of my parcel” chosen by 50 respondents, and
- “I consider the current delivery options to be sufficient” also selected by 50 respondents.

These results indicate that trust in reliable delivery and satisfaction with existing services are the most significant barriers to the adoption of robot-assisted parcel delivery.

A further 45 participants stated that they do not feel confident using the robot, reflecting a degree of technological hesitation or uncertainty among some respondents. In addition, 35 respondents mentioned that they prefer collecting their parcel from a conventional parcel box or another pick-up point, suggesting that familiarity and established routines remain important factors in delivery preferences.

In the open-answer section, 40 respondents explicitly wrote “nothing,” indicating that they had no objections or no specific concerns about robot delivery. This demonstrates that a substantial portion of the population is open-minded or neutral toward the concept.

Other individual comments provided deeper qualitative insights, including:

- “Fewer jobs” (2 respondents)
- “Environmental pollution caused by data storage devices, electronic waste, etc.”
- “Comfort, flexibility”
- “Robot gets stolen”
- “Safety of humans and animals”
- “If it were expensive”
- “I am neutral on this as long as the legal approval conditions are met.”
- “Only shifting last mile services from road to footpath.”
- “Data protection – who receives my data? Confidentiality.”

These responses highlight a range of nuanced concerns, including environmental sustainability, personal and public safety, data protection, and socio-economic implications (e.g. potential job loss).

Overall, the findings suggest that while many citizens are open to innovative delivery solutions, trust, perceived safety, and familiarity remain critical factors influencing acceptance. Clear communication regarding security, reliability, and data protection, alongside transparent legal frameworks and user-friendly design, will be essential in addressing these concerns and fostering confidence in robot-based parcel delivery systems.

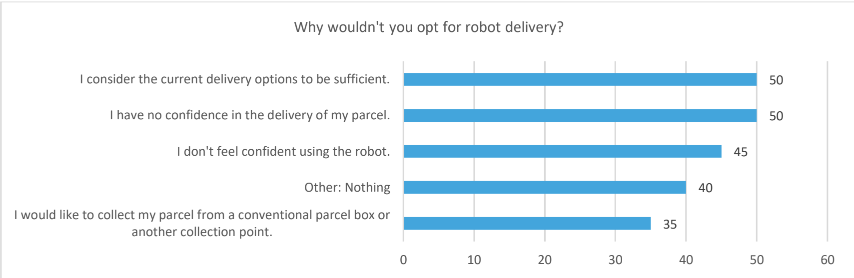


FIGURE 28: EVALUATION OF CONCERNS AND BARRIERS TO ADOPTION

Preferred Delivery Methods

Another multiple-choice question aimed to identify which delivery methods participants would prefer when using an autonomous delivery robot. The responses provide clear insights into user expectations and comfort levels regarding the delivery process and interaction with the robot.

The majority of respondents (124 participants) indicated that they would prefer the delivery robot to bring parcels directly to their front door or another private area near their flat. This strong preference demonstrates a desire for maximum convenience, privacy, and minimal effort on the part of the user. It suggests that citizens are most receptive to robot delivery when it integrates seamlessly into their existing, familiar delivery routines.

A smaller yet significant group (71 respondents) stated that they would prefer the delivery robot to bring parcels to a public place near their home, such as a neighbourhood delivery point or shared access area. This option appeals particularly to those who value flexibility and accessibility but may not require direct home delivery.

Meanwhile, 20 respondents explicitly answered that they do not want parcels to be delivered by delivery robots in their area. This minority reflects a certain level of resistance or scepticism toward the use of autonomous systems in residential environments, possibly linked to concerns over noise, safety, or privacy.

One additional participant suggested “work” as a preferred delivery location, indicating openness to alternative, workplace-based delivery solutions. This comment highlights the potential for expanding the concept beyond residential areas, offering delivery options that align with people’s daily mobility patterns.

Overall, the responses show a clear preference for private, doorstep delivery, followed by public nearby access points as a secondary choice. The findings underline the importance of user-centred design, emphasizing convenience, security, and integration into personal routines as key factors for the successful implementation of robot-based delivery systems within the URBANE framework.

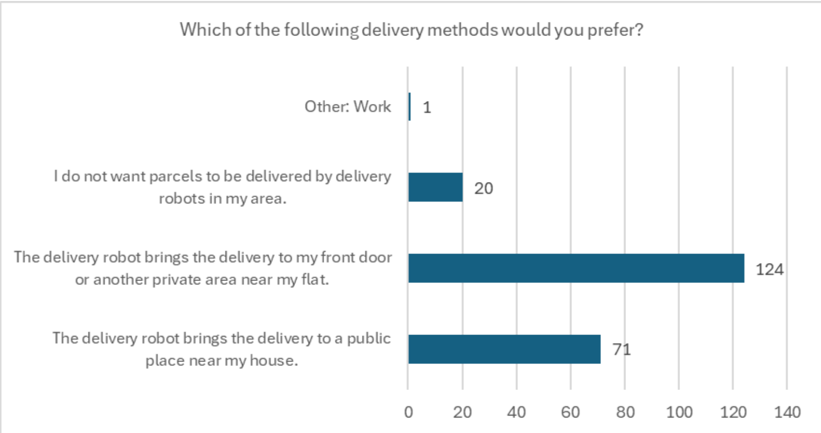


FIGURE 29: PREFERRED DELIVERY METHODS

Key Delivery Priorities

In this single-choice question, participants were asked to select the most important factor for them when considering parcel delivery options. The results highlight the core priorities that shape user expectations for delivery services.

The responses were almost evenly split between two dominant preferences:

- 37.9% of respondents indicated that it is important for them to determine the delivery schedule themselves, and
- 37.4% stated that it is important for them that the parcel is delivered directly to their front door.

These two results clearly show that flexibility and convenience are the primary drivers of user satisfaction in parcel delivery. People want to have control over when and where deliveries occur, and they value the comfort of home delivery above other factors.

A smaller proportion of respondents emphasized sustainability (10.4%) and accessibility for people with disabilities (5.5%) as relevant considerations, showing that while these aspects are appreciated, they are secondary to convenience-related factors for most users.

Other options, such as the availability of parcel collection points (4.9%) and simplified local collection (3.8%), received only minor attention, suggesting that existing infrastructure already meets users' expectations in this regard.

Overall, these findings reinforce that for broad public acceptance of robot-based delivery, the system must prioritize user flexibility, time autonomy, and direct home delivery, as these are perceived as the most valuable features by potential users.

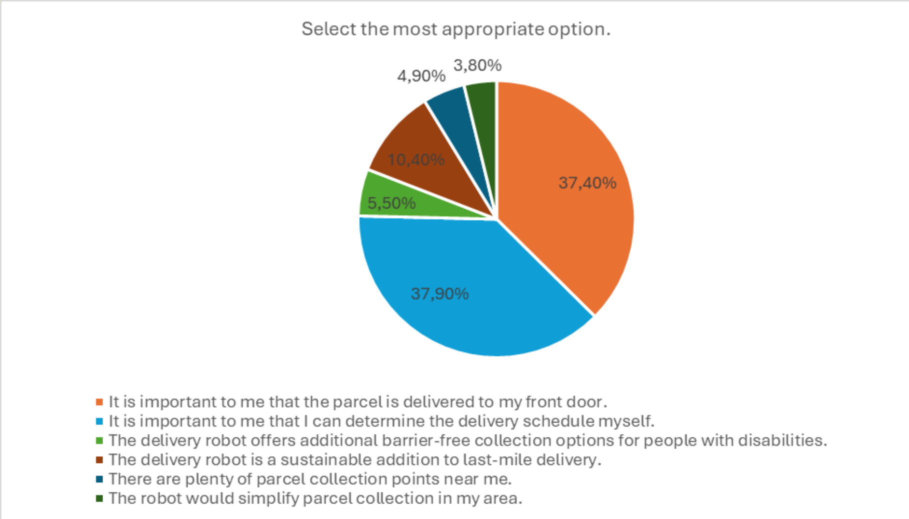


FIGURE 30: KEY DELIVERY PRIORITIES

Preferred Technologies for Interaction with Delivery Robots

Participants were also asked which technologies they could imagine using to interact with delivery robots. This multiple-choice question provides valuable insight into user expectations for accessibility and interface design.

The most frequently selected option was the smartphone application, chosen by 132 respondents. This strong preference highlights that mobile-based interaction is perceived as the most natural and convenient channel, aligning with current habits in digital service use. Respondents appear to expect a user-friendly, app-based interface that allows them to track, schedule, and confirm deliveries seamlessly.

The second most common answer was the display directly on the delivery robot, selected by 82 participants. This reflects an appreciation for on-device interaction, particularly for users who may prefer direct, tangible communication with the robot, for example when collecting a parcel or confirming receipt.

63 respondents mentioned a website as an acceptable interaction method, showing that while web-based access remains relevant, it is less favoured than mobile-first solutions.

In the open-ended "other" responses, participants contributed several interesting ideas and reflections, including:

- "Voice input/output" (2 respondents)
- "Display only when activated manually (protected, identity confirmation)"
- "Identify receiver, so receiver can walk up to the robot around the corner"
- "Terminal / large display (for people without technical knowledge / with visual impairments / without resources)"
- "No additional data servers would be great"
- "Friendly emoji"
- "Voice command, display with face"
- "None" and "no matter."

These qualitative comments provide useful insights for inclusive and privacy-conscious design considerations. Some participants emphasized data protection and minimal data processing, while others focused on accessibility and ease of use for non-technical users. The mention of voice interaction and emotional cues (e.g. emojis, "display with face") suggests an interest in more natural and human-like communication modes.

In summary, the results demonstrate a strong public preference for mobile app-based interaction, complemented by on-device interfaces for flexibility. Future development within the URBANE project should therefore focus on mobile integration, privacy protection, and accessibility features, ensuring that interaction with delivery robots is both intuitive and inclusive.

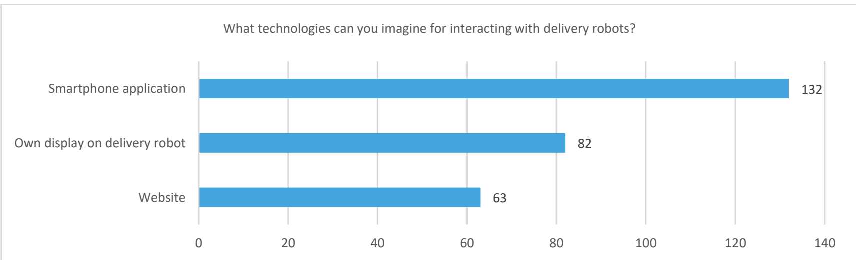


FIGURE 31: PREFERRED TECHNOLOGIES FOR INTERACTION WITH DELIVERY ROBOTS

Expected Information Displayed on the Delivery Robot

This multiple-choice question investigated what type of information citizens would like to see displayed on a delivery robot. The results provide valuable guidance for designing the communication and transparency features of such systems.

The most frequently selected response was battery status, chosen by 73 participants. This finding suggests that respondents are interested in understanding the operational state and reliability of the robot during its delivery route. The display of such technical information appears to build trust and confidence in the system's functionality.

The second most common responses were project information (65) and CO_2 reduction (58), showing that many participants appreciate informational and educational content. These selections indicate that the public is not only curious about the technology itself but also values transparency regarding its environmental benefits and project background.

Other popular answers included the date and temperature (50), the destination of the robot (47), and the number of parcels delivered (46). These preferences suggest that users are interested in both contextual and performance-related data, which could make the robot appear more interactive and engaging to passers-by.

Less frequently, 32 respondents wanted to see the number of parcels currently contained in the robot, possibly reflecting a lower perceived relevance for general observers but potential interest from recipients awaiting deliveries.

In the open-ended comments, several additional insights were shared. These included:

- "Nothing" (5 respondents), indicating a desire for minimal or no display content.
- "Not too much, so no one is tempted to break in" (3 respondents).
- "Data protection" (2 respondents).
- "Compare how many normal parcel delivery to robot delivery."
- "Driving route."
- "When it comes to your own parcels."
- "As little as possible."
- "Weather forecast, latest news, cinema listings, concerts, tram timetables."
- "Contact details – Maintenance / Parcel Centre."

These qualitative answers reveal two contrasting perspectives: while some participants support informative and educational displays, others emphasize the need for privacy, data minimization, and security. Concerns about potential misuse or theft were also mentioned, underlining the importance of careful content selection and display design.

Overall, the findings show that citizens value transparency, environmental awareness, and operational clarity, but also expect the display to balance information with privacy and safety considerations. For the URBANE project, this means that the robot's information interface should be designed to communicate essential and educational data, while avoiding excessive or sensitive information that could raise security concerns.

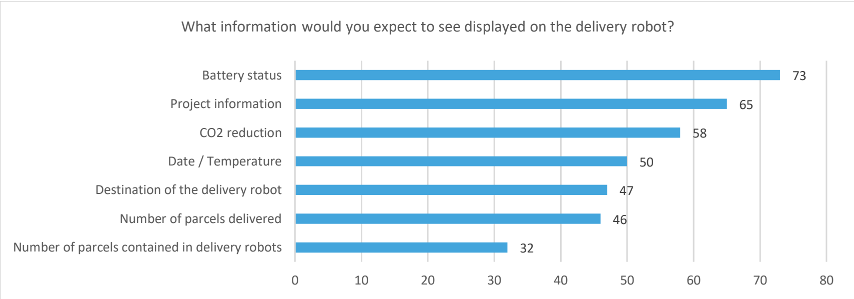


FIGURE 32: EXPECTED INFORMATION DISPLAYED ON THE DELIVERY ROBOT

Expected Technologies for Robot-to-Human Communication

The survey also asked participants which technologies they would expect delivery robots to use to communicate their status to humans. Respondents could select multiple options, providing insight into preferred interaction modes and information channels.

The most frequently selected option was text, chosen by 127 respondents. This indicates that participants expect clear, readable, and direct information, likely displayed on the robot or via connected devices. Sound was the second most popular option (110 respondents), highlighting the importance of auditory signals to attract attention or indicate specific robot actions.

Light signals were selected by 94 participants, suggesting that visual cues, such as coloured lights or blinking indicators, are also valued for conveying robot status at a glance, especially in public spaces. Haptics was chosen by a smaller group (46 respondents), pointing to interest in tactile feedback, though this is less critical than visual or auditory modes for the majority.

In the "other" responses, participants added:

- "Display" (2 respondents)
- "App" (4 respondents)
- "No matter" (3 respondents)
- "Talk to me"

These comments reinforce that flexibility in communication channels is appreciated, with some users open to app-based notifications or interactive audio communication, while a few indicated that the exact technology is less relevant.

Overall, the results suggest that a combination of text, sound, and light signals would be most effective for communicating delivery robot status to humans, providing clear, immediate, and easily interpretable information. Supplementary channels such as mobile apps or interactive speech could further enhance usability and accessibility for different user groups.

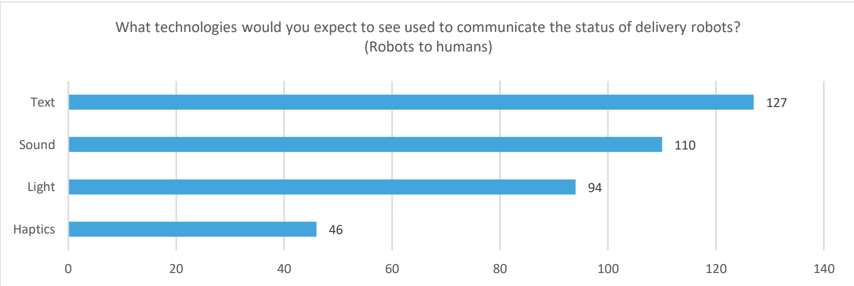


FIGURE 33: EXPECTED TECHNOLOGIES FOR ROBOT-TO-HUMAN COMMUNICATION

Expected Communication Technologies During Robot Operation

Participants were asked which technologies they would expect to see for communication during the autonomous operation of delivery robots (robot-to-human interaction). This multiple-choice question provides insights into preferred real-time communication methods while the robot is moving or performing tasks.

The most frequently selected option was sound, chosen by 131 respondents, indicating that auditory signals are considered the most intuitive method to alert humans of the robot's actions or status during operation. Light signals were selected by 125 participants, showing that visual cues, such as coloured lights or blinking indicators, are also highly valued for conveying information quickly and clearly in a dynamic environment.

Text was chosen by 84 respondents, suggesting that while readable textual information is useful, it may be less practical for communicating with passers-by during active delivery operations compared to immediate auditory or visual signals. Haptics received fewer responses (34 participants), highlighting that tactile feedback is seen as a secondary mode of communication in this context.

Additional suggestions provided in the "other" category included:

- "App" (2 respondents)
- "No communication" (2 respondents)
- "Sound like an electric car"
- "Face on the display"

These responses highlight a desire for flexible, user-friendly, and even playful interaction methods. Some participants suggested mobile app notifications, while others emphasized minimal or realistic auditory signals that reflect modern vehicle sounds or anthropomorphized displays.

Overall, the findings indicate that sound and light should form the primary communication channels during autonomous delivery operations, ensuring that humans can reliably perceive the robot's status and actions. Textual information can supplement these signals, and optional app integration or display features may enhance usability for specific user groups.

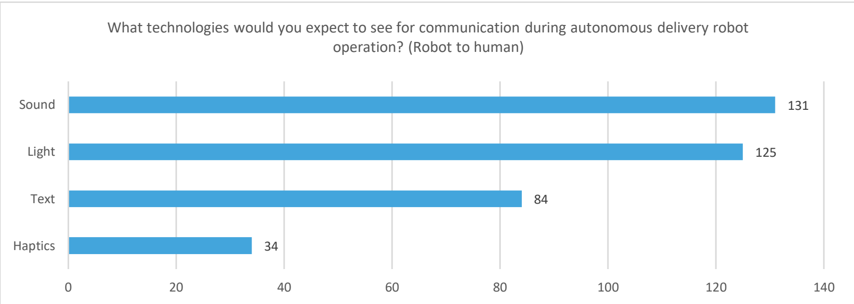


FIGURE 34: EXPECTED COMMUNICATION TECHNOLOGIES DURING ROBOT OPERATION

Expected Frequency of Use for Different Parcel Collection Methods

Participants were asked to rank four different parcel collection options according to their expected frequency of use, with 1 being the most preferred and 4 the least preferred. The results provide insight into user preferences for different delivery scenarios.

The highest-ranked option was collection of parcels at the front door, which was chosen as the first preference 18 times. This indicates that participants clearly value maximum convenience and direct home delivery, making it the most attractive option among the choices.

The second preference was collection of parcels at the stop, selected 17 times for the second rank. This suggests that users also see value in integrating delivery with public transport stops, likely for convenience during daily commuting.

Collection at a pop-up packing station received mixed preferences: it was ranked first 9 times, second 13 times, third 10 times, and fourth 11 times. This distribution indicates that while some participants appreciate flexible, temporary collection points, others view them as less convenient compared to home or stop delivery.

Collection of parcels on the train during the journey was generally the least preferred option, with 18 respondents ranking it fourth. While 14 participants ranked it third, and 8 ranked it first, the overall pattern shows limited enthusiasm for receiving parcels directly on the tram, suggesting that users may perceive logistical or practical challenges with this option.

Overall, the ranking results highlight that home delivery remains the most desirable method, followed by collection at tram stops, while pop-up stations and on-train collection are less favoured. These findings provide clear guidance for prioritizing delivery modes in the implementation of the URBANE project, emphasizing convenience and ease of access for users.

Please rank the following options according to the expected frequency of use, with 1 being the most important and 4 being the least important:

a) Collection of parcels on the train (during the train journey)

b) Collection of parcels at the stop

c) Collection of parcels at the front door

d) Collection of parcels at a pop-up packing station

TABLE 6: EXPECTED FREQUENCY OF USE FOR DIFFERENT PARCEL COLLECTION METHODS

	Rank 1	Rank 1-2	Rank 1-3	Rank 1-4
A – Collection on the train	8	11	25	**43**
B – Collection at the tram stop	8	**25**	37	43
C – Collection at the front door	**18**	28	35	43
D – Collection at pop-up packing stations	9	22	**32**	43

Concerns Regarding the Introduction of Delivery Robots

This multiple-choice question explored participants' main concerns and worries about the introduction of autonomous delivery robots, providing important insights into perceived risks and potential barriers to acceptance.

The most frequently mentioned issue was delivery robot malfunction, selected by 89 respondents. This highlights a widespread concern about the technical reliability of such systems and the fear that operational failures could lead to service disruptions or safety risks.

Closely following were concerns related to accidents:

- 87 participants mentioned accidents involving other vehicles,
- 79 cited accidents involving passengers, and

- 78 referred to accidents involving trams.

These results underline that safety in shared public spaces is one of the key concerns among citizens. The findings suggest that for successful implementation, delivery robots must demonstrate high levels of situational awareness, safety certification, and integration with urban traffic systems.

Falling into the track bed was mentioned by 39 respondents, indicating a specific worry related to the tram-based operation of the URBANE concept. Additionally, 40 participants expressed concern about the collection, use, and protection of data, while 33 highlighted liability and responsibility for potential damage as important issues. These results show that legal clarity and data security are also essential for building public trust.

Open-ended responses provided additional insights:

- "Drives people over"
- "Hindrance to passengers"
- "Perceive acoustic and tactile signals"
- "No concerns" (3 respondents)
- "Development costs"
- "Theft of parcels from robots"
- "Job losses"

These comments reveal both safety-related and societal concerns, including potential obstruction of pedestrian traffic, parcel theft, and employment impacts. The fact that several participants explicitly stated "no concerns" also indicates a growing openness or neutrality toward the technology among some citizens.

In summary, the results show that while there is general interest in and curiosity about autonomous delivery, the public's primary concerns revolve around safety, reliability, and data protection. Addressing these issues through robust technical design, transparent communication, and clear regulatory frameworks will be crucial for achieving social acceptance of delivery robots in the URBANE context.

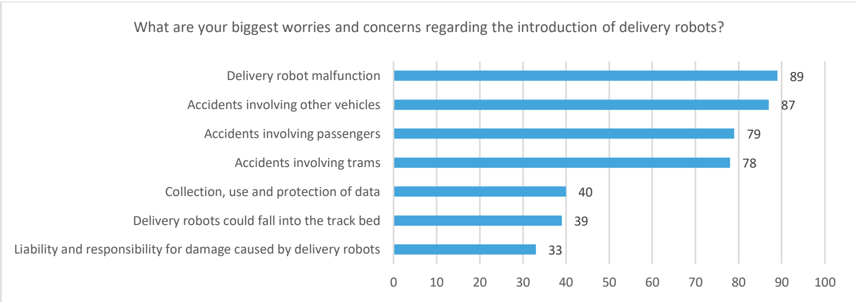


FIGURE 35: CONCERNS REGARDING THE INTRODUCTION OF DELIVERY ROBOTS

5. Application of the URBANE Agent-Based Modelling Framework

5.1 Introduction

This document complements Deliverable D3.2: Modelling Framework and Agent-Based Models (M24) of the URBANE project by providing a detailed description of the Karlsruhe Living Lab case study and its implementation within the integrated HUMAT–MASS-GT–VRP modelling framework. The URBANE project develops a modular agent-based modelling (ABM) framework to analyze how consumers choose among last-mile delivery (LMD) options and how logistics operations respond to those choices. The framework links a socio-cognitive model of consumer behavior (HUMAT) with a freight transport model (MASS-GT) and, where needed, a vehicle routing problem (VRP) module for detailed routing of innovative delivery services such as autonomous delivery vehicles.

Deliverable D3.2 defines this generic modelling framework and demonstrates its calibration for two Wave 1 Living Labs: parcel locker services in Thessaloniki and autonomous delivery vehicles in Helsinki. In those case studies, the integrated HUMAT–MASS-GT–VRP architecture is used to estimate consumer acceptance, logistics performance, and environmental impacts under multiple what-if scenarios.

The present document applies the same framework to the Karlsruhe Living Lab (LL), focusing on a case study in which small businesses act as local depots for autonomous delivery robots. Consumers can either request a robot delivery from the business to their doorstep or collect their parcel in person at the business location (self-pickup). The simulation model is used to quantify the interplay between consumer preferences and the operational characteristics of the robot service.

5.1.1 Purpose and scope

The purpose of this document is to describe the Karlsruhe LL case study from a modelling perspective. It covers: (i) the system overview and motivations for the use case, (ii) the adaptation of the generic URBANE ABM framework to the Karlsruhe context, (iii) data preparation and calibration steps for HUMAT, MASS-GT and the VRP module, and (iv) the design of what-if simulation scenarios that vary consumer satisfaction with robot deliveries and the capacity of delivery robots.

The document is intended to be read alongside Deliverable D3.2. Detailed theoretical and technical descriptions of HUMAT, MASS-GT and the VRP module are therefore only summarized here to the extent needed to understand the Karlsruhe implementation.

5.1.1.1 Relation to Deliverable D3.2

Deliverable D3.2 introduces the integrated modelling framework, the generic data structures and interfaces between HUMAT, MASS-GT and the VRP module, and its calibration for Thessaloniki and Helsinki. The Karlsruhe case study uses the same architecture, data formats, and model components. Where possible, default parameter settings, distributions and calibration procedures from D3.2 are reused to ensure comparability across Living Labs. This document therefore focuses on Karlsruhe-specific aspects, while referring to D3.2 for generic methods, algorithms, and software implementation details.

5.2 System overview and motivations for the Karlsruhe Living Lab

5.2.1 Local context and Living Lab objectives

The Karlsruhe Living Lab investigates innovative LMD solutions that can reduce congestion and emissions while maintaining or improving service quality for residents and businesses. A key idea is to leverage existing small businesses as micro-depots, decoupling inbound parcel flows from the final distribution to households. The Living Lab aims to understand under which conditions autonomous delivery robots can support or replace traditional last-mile services, and how citizens perceive and adopt such services.

Commented [m.3]: LMD already mentioned in section 1 and abbreviation is also provided earlier. No need to add it here

5.2.2 Use Case

In this use case, a set of local shops act both as micro-depots and collection points. Parcels destined for nearby residents are consolidated at these shops. When a parcel arrives at a micro-depot, the consumer faces a delivery choice:

- **Autonomous Robot Delivery:** A small autonomous delivery robot (ADR) transports the parcel from the shop to the consumer's doorstep.
- **Self-pickup:** The consumer is notified that the parcel has arrived and collects it personally at the collection-point.

The main objective of this use case is to measure consumer preference and acceptance of autonomous robot-based deliveries relative to traditional self-pickup, and to assess how these preferences interact with the technical capabilities and constraints of the robot fleet (e.g. capacity). The Living Lab thus provides a context for analysing both the behavioural and operational dimensions of the new service.

5.2.3 Research questions

The Karlsruhe case study addresses the following main research questions:

- What is the average daily demand in the study area?
- How willing are consumers to adopt autonomous robot delivery instead of self-pickup under different levels of satisfaction with the robot service?
- How does the capacity of autonomous delivery robots, measured as the number of compartments per robot, constrain or enable higher adoption of robot deliveries?
- What are the implications of autonomous delivery robot adoption for parcel flows, robot utilization, delivery times and travel distances in the Living Lab area?
- How robust are these effects when social influence between consumers and variability in parcel demand are considered?

5.3 Modelling frameworks for the Karlsruhe case study

5.3.1 Overview of the URBANE ABM framework

The URBANE modelling framework integrates three main components:

- **HUMAT** – a socio-cognitive ABM that represents individual consumers (HUMAT agents), their socio-demographic attributes, motives, satisfaction with different fulfilment types, and their social networks.
- **MASS-GT** – a freight transport ABM used to generate parcel demand.
- **VRP module** – a vehicle routing problem solver that generates optimized routes for vehicles or robots given capacity, time-window and travel time constraints.

HUMAT captures why and how consumers choose among fulfilment options (robot delivery versus self-pickup), MASS-GT provides spatially and temporally distributed parcel demand, and the VRP module models how robots serve the parcels assigned to them. The overall architecture and data interfaces follow the design described in Deliverable D3.2.

5.3.2 Functional integration in the Karlsruhe use case

For the Karlsruhe LL, the generic framework is instantiated as follows:

(1) MASS-GT generates daily parcel demand between micro-depots (small businesses) and households in the Living Lab area. For each parcel, the destination household is identified, while the origin is the assigned micro-depot.

(2) Each household is represented by one or more humat agents in HUMAT. Given a parcel order, the agent evaluates the available fulfilment options (robot delivery, self-pickup) based

on its motives, current satisfaction levels and information from its social network, and selects a preferred option.

(3) Parcels for which robot delivery is chosen are grouped by micro-depot and passed to the VRP module. The VRP module plans robot tours starting from the micro-depots, constrained by robot capacity (number of compartments), service times and any time-window assumptions. Parcels not assigned to robots are treated as self-pickup, implying that the consumer travels to the micro-depot.

(4) After each simulated day, HUMAT updates agents' satisfaction with each fulfilment type based on experienced outcomes (e.g. successful or failed robot delivery, waiting time, walking distance for self-pickup). These updated satisfaction levels influence choices on subsequent days, allowing social and experiential feedback loops to be represented.

This integration allows the model to capture both demand-driven and supply-driven constraints: if robots run out of capacity, some parcels must revert to self-pickup, which in turn affects consumer satisfaction and future choices.

5.3.3 Key performance indicators (KPIs)

The Karlsruhe case study uses a set of KPIs that extend those defined in D3.2 for the Thessaloniki and Helsinki cases. They include:

- **Total number of parcels –** number of parcels being generated on an average day
- **Share of parcels by fulfilment type** – percentage of parcels served by robot delivery versus self-pickup, per day and over the full simulation.
- **Average consumer satisfaction** – average and distribution of humat agents' satisfaction with robot delivery and self-pickup.
- **Robot utilization** – number of parcels carried per robot tour, number of tours, fraction of used capacity, and idle time.
- **Operational performance** – total distance travelled by robots, average delivery time per parcel, and number of failed or delayed robot deliveries.
- **System-wide impacts** – change in private travel for self-pickup, total distance and emissions in the LMD system compared with a counterfactual without robots.

5.4 Data preparation for the Karlsruhe Living Lab

5.4.1 MASS-GT data

The MASS-GT configuration for Karlsruhe follows the input data structure already used for Thessaloniki and Helsinki, adapted to the network and parcel market characteristics of the LL area. Two categories of data are required:

- Network data – zones of the study area, locations of depots (parcel nodes), and matrices of travel times and distances between zones.
- Demand data - Sociodemographic characteristics, including population characteristics in the study area, market shares of the courier companies in the network

5.4.2 HUMAT data

HUMAT requires four types of input data in the Karlsruhe case study:

- Population – a list of agents representing individuals in the Living Lab area, with attributes such as age group, gender, employment status, education level, income bracket and home zone.
- Social network data – a multi-layer network structure that specifies which agents are connected as friends, neighbours or colleagues, enabling information diffusion about delivery experiences.
- Consumer motives data – parameters describing how strongly different motives (e.g. convenience, cost, environmental impact, reliability, privacy) influence each socio-demographic segment when evaluating robot delivery and self-pickup.
- Choice satisfaction data – initial satisfaction levels for each fulfilment type and motive, derived from survey responses collected in Karlsruhe. These values define the baseline from which the "what-if" scenarios with different satisfaction levels are constructed.

5.4.3 VRP and robot data

The VRP module for Karlsruhe uses the following inputs:

- Cost matrix – distances and/or travel times between micro-depots and consumer locations, consistent with the MASS-GT zoning system.
- Time-window and service time parameters – for each micro-depot and, if relevant, for consumer locations, indicating when robots may operate and how long each delivery or pickup takes.
- Robot characteristics – technical specifications of the robots, including speed, number of compartments (capacity), battery range and any operational limits that need to be respected in routing.

These inputs enable the VRP module to compute feasible and efficient routes for the robot fleet under the capacity settings investigated in the "what-if" scenarios.

5.5 Calibrated agent-based model for the Karlsruhe Living Lab

Calibration refers to fine-tuning software components to achieve desired output levels of the selected use case. This might involve setting parameters, fine-tuning inputs and outputs, adjusting algorithms, or optimizing configurations to meet specific criteria. This process ensures that the model accurately represents the use case being studied.

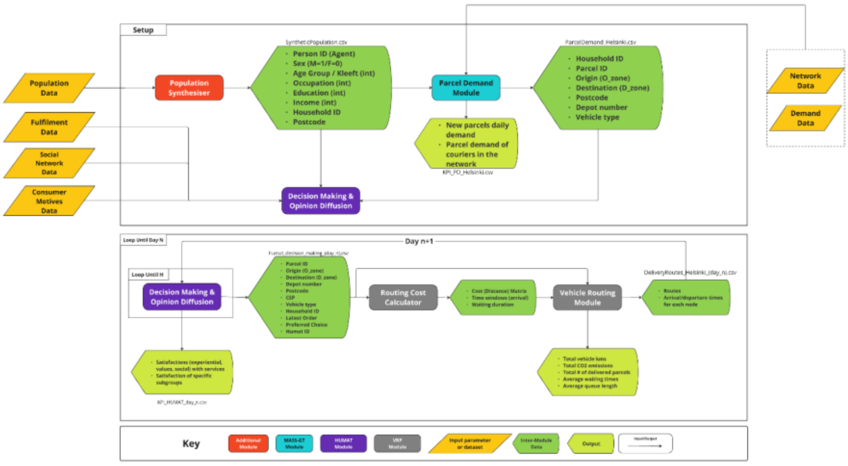


FIGURE 36: *MODELING FRAMEWORK CALIBRATED FOR THE KARLSRUHE LL*

The integrated high-level modelling framework (given in Section 5.2 of Deliverable D3.2) has been calibrated as shown in Figure 36~~Figure 36~~. The HUMAT module is used to model the acceptance of ADRs, the MASS-GT module is used only in the generation of parcel demand, and the VRP module is used to generate the optimal route of ADRs.

5.5.1 Population and parcel demand

The population for Karlsruhe is constructed using sample data (which is provided by the Karlsruhe LL but not representative of the actual population) to inform the attributes of agents (e.g., age, household size, income (purchasing power)). Karlsruhe census data are used to allocate people based on the percentage of people in each area of the city and the proportion of people in the survey. MASS-GT uses this population together with parcel market data to generate daily parcel demand per household and zone.

Calibration ensures that the simulated parcel volumes per day, per carrier and per zone are consistent with available statistics and, where possible, operator data for the Karlsruhe area.

This step mirrors the procedures applied in D3.2 for Thessaloniki and Helsinki, adapted to the local context.

5.5.2 Behavioural calibration of HUMAT

HUMAT agents' motives and initial satisfaction levels are calibrated using survey data collected in Karlsruhe on attitudes toward autonomous delivery robots and self-pickup at collection points. Survey results inform the relative importance of motives such as convenience ("receiving a parcel in convenient location", "receiving a parcel at a convenient time"), cost ("low delivery costs") and privacy ("confidentiality of parcel data").

The calibration process adjusts motive weights and satisfaction parameters so that, under baseline conditions, the simulated adoption rates of robot delivery are aligned with the stated preferences from the survey. This provides a realistic starting point for exploring the "what-if" scenarios that change satisfaction levels and robot capacity.

5.6 Simulation design and what-if scenarios

This section reports the simulation scenarios of the Karlsruhe use case. We define a simulation scenario as a combination of input parameter values defined at the stage of model initialization. For each use case, a baseline scenario and various what-if scenarios are defined.

Simulations of the URBANE ABM are carried out through implementing what-if scenarios in a DT of Helsinki with the population scaled 1:10. A what-if scenario is defined as a combination of 5 parameter values communicated to the model at the initialization. Table 7~~Table 15~~, summarizing the ABM simulation parameters and their settings, is followed by a description of parameter values. Next, a table of the simulated scenarios is provided in Table 8~~Table 8~~.

TABLE 7: *ABM SIMULATION PARAMETERS AND THEIR SETTINGS*

Parameter	Settings
1. Motives Type	A. Low environmental impact
	B. Low delivery cost
	C. Privacy
	D. Convenient time
2. Satisfaction Change	A. Increase by 50% of the standard deviation
3. ADR Capacity	A. 5
	B. 10
	C. 15

5.6.1 Motive with robot delivery and satisfaction variation

The first what-if dimension concerns overall satisfaction of motives with robot deliveries relative to self-pickup. In HUMAT, satisfaction of each motive type is represented by numerical values that influence decision-making. To explore the sensitivity of adoption to these values, their satisfaction levels are increased by 50% of the standard deviation in the "what-if" scenarios.

In all cases, satisfaction with self-pickup can either remain at its calibrated baseline level or be scaled in parallel, depending on the analysis needs. The relative difference between robot and self-pickup satisfaction is what ultimately shapes adoption patterns.

5.6.2 ADR compartment capacity

The second what-if dimension is the payload capacity of the robots, expressed as the number of usable compartments per robot tour. Four capacity settings are defined to reflect the range of currently available or plausible designs:

- C5 – small robot with 5 compartments, representing a conservative pilot configuration.
- C10 – medium-size robot with 10 compartments, suitable for moderate demand densities.
- C15 – larger robot with approximately 15 compartments, representing the upper bound considered in the Karlsruhe Living Lab.

These values determine how many parcels can be assigned to a robot tour in the VRP module before capacity is reached and additional demand must be shifted to self-pickup or additional tours.

5.6.3 Scenario matrix and experimental protocol

Combining the parameters yields a matrix of 15 what-if scenarios (Table 8~~Table 8~~). Each scenario is simulated over a multi-day horizon, allowing social influence and learning in HUMAT to stabilize. To account for stochasticity (e.g. in social network interactions), each scenario is replicated multiple times with different random seeds, and results are summarized using averages and confidence intervals.

TABLE 8. *SIMULATION SCENARIOS OF KARLSRUHE ABM*

Scenario	1 Motive Type	2 Satisfaction Change	3 ADR Capacity
Scenario 1	-	-	3A
Scenario 2	-	-	3B
Scenario 3	-	-	3C
Scenario 4	1A	2A	3A
Scenario 5	1A	2A	3B
Scenario 6	1A	2A	3C
Scenario 7	1B	2A	3A
Scenario 8	1B	2A	3B
Scenario 9	1B	2A	3C
Scenario 10	1C	2A	3A
Scenario 11	1C	2A	3B
Scenario 12	1C	2A	3C
Scenario 13	1D	2A	3A
Scenario 14	1D	2A	3B
Scenario 15	1D	2A	3C

5.7 Results and discussion

This section reports the results obtained by executing the simulation scenarios given in Section 6.

5.7.1 Demand generation

The parcel demand in Karlsruhe was generated following the same procedure applied to the Thessaloniki and Helsinki LLs as described in Deliverable D3.2. Given the data gathered from Karlsruhe LL, we have generated the demand per household in the study area. The main parameters are provided in the Table 9~~Table 9~~.

TABLE 9: *MAIN DEMAND PARAMETERS FOR THE KARLSUHE LL*

Number of parcels (year)	830000
Number of households	62868
Number of working days	250
Parcel success rate	0.85
Income per zone	4.421e-05
Employment per zone	0.0000

Although the market shares of the LSPs were available, no zonal network was available for all the LSPs and hence we have only used the LSP depot locations which are in the study area. Like the case in Helsinki LL, the data availability resulted in a smaller scale application.

Parcels per household, number of parcels per day on an average day and income level (buying power) has been provided by Karlsruhe LL. Additionally, Karlsruhe LL provided information on the household structure for the use case area. Like the previous use cases (Thessaloniki and Helsinki LL, we considered the number of working days and parcel success rates as 250 and 0.85, respectively. Lastly, the parameter "INCOME_PER_ZONE," showing the regression coefficient, is calculated as 4.421e-05 and was established via a linear regression model. To this end, sample demand is the dependent variable, while people and income level (purchasing power) are independent variables. The coefficient for income per zone is numerically small because income is expressed in euros; however, for realistic income differences between zones (in the order of thousands of euros), it translates into meaningful differences in parcel volumes. The full specification of the regression model is provided in Annex I: Input Data Preparation for MASS-GT for Karlsruhe LL.

The parameter "PARCELS_PER_EMPL," representing the number of parcels based on employment characteristics, is set at 0.000 and is included for generalization purposes due to the fact that we lack empirical information on parcels generated per employed person and the use case focuses on B2C household deliveries for which income is a more direct determinant than employment status. The network, including the parcel node (depot location) of UPS, is presented in Figure 37Figure 37.

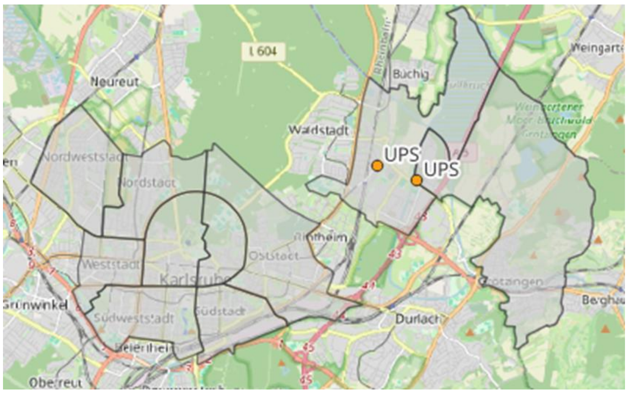


FIGURE 37: *ZONES OF THE KARLSRUHE LL*

Following the same procedure as applied in Thessaloniki and Helsinki LLs, we have generated the demand per household in the study area. The main parameters are provided in Table 9~~Table 9~~.

The Parcel Demand module generated 521 parcels for the study area. The distribution of the parcels is presented in Figure 38~~Figure 38~~.

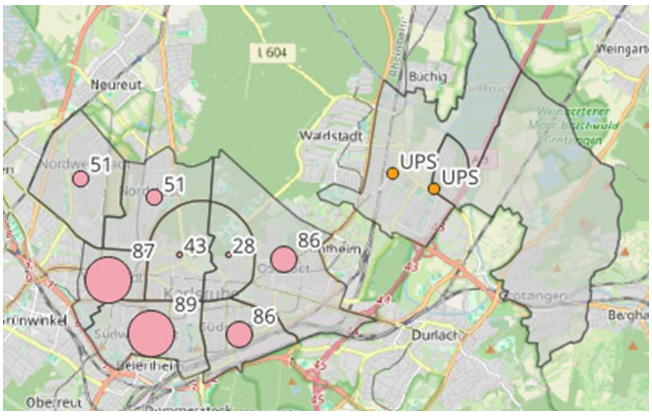


FIGURE 38: *DEMAND DISTRIBUTION OF THE KARLSRUHE LL*

5.7.2 Satisfaction outcomes for the collection-point option

Figure 39~~Figure 39~~ and Table 10~~Table 10~~ summarize the HUMAT outcomes for the collection-point alternative over 150 replications of each of the 15 simulation scenarios. Overall evaluation scores for the collection-point option remain concentrated between 0.036

and 0.059, with very small standard deviations (below 0.0013), which indicates that perceptions of the collection-point service are stable across changes in autonomous delivery robot (ADR) compartment capacity and in the tested motive-specific satisfaction variations. Average satisfaction values range from 0.055 to 0.094 across scenarios, suggesting that the collection-point option is perceived as a mildly positive choice in all simulated conditions.

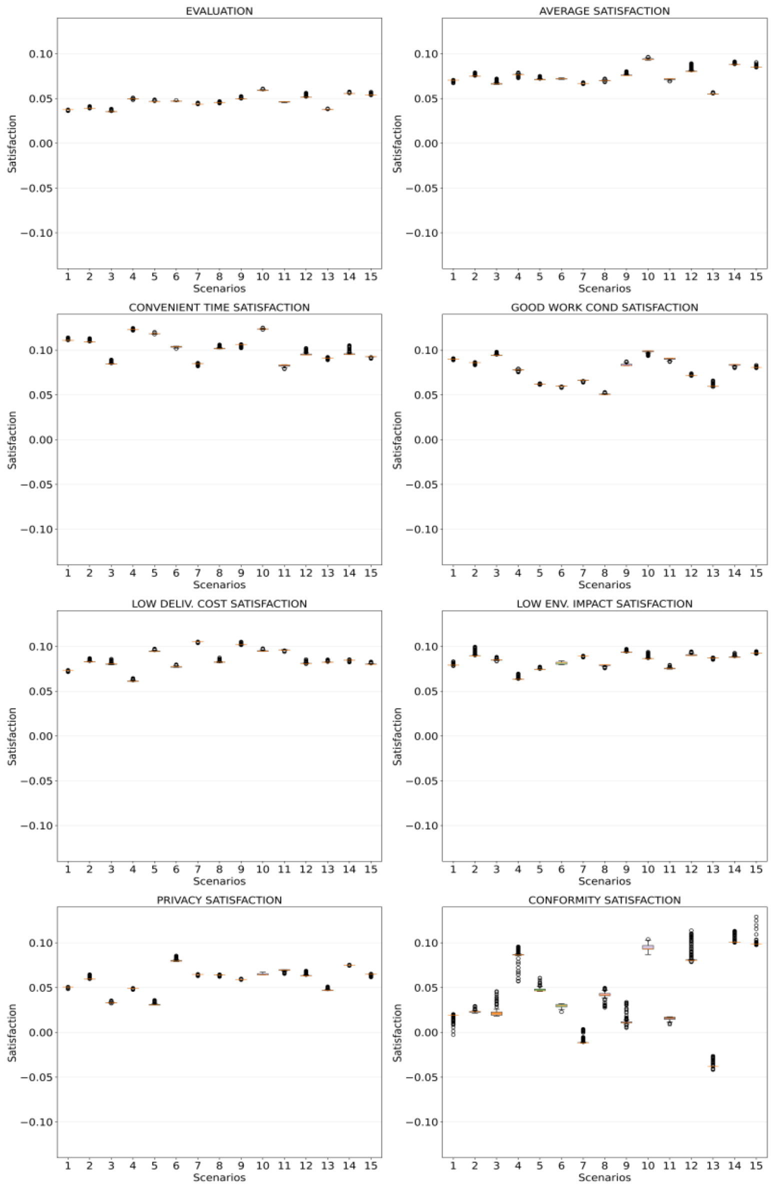


FIGURE 39: *RESULTS IN SATISFACTIONS REGARDING COLLECTION-POINT OPTION – 150 RUNS*

Across individual motives, "convenient time" and "low delivery costs" are the most highly rated attributes of the collection-point alternative, with mean satisfaction levels typically between about 0.08 and 0.12 for convenient time and between about 0.06 and 0.10 for low delivery costs (Table 4). Satisfaction with environmental impact and privacy is more moderate, generally in the 0.03–0.09 range, while the "conformity" indicator shows the largest variability, ranging from slightly negative values around −0.04 in some scenarios to approximately 0.10 where the collection-point service is perceived as well aligned with social norms. Standard deviations for all motive-specific indicators remain on the order of 10^{-3} (with a maximum of about 0.009 for conformity), confirming that the averages are robust with respect to stochastic variation between Monte-Carlo replications.

TABLE 10: *RESULTS OF MEAN AND STANDARD DEVIATION FOR COLLECTION-POINT OPTION – 150 RUNS*

Scenario	Evaluation	Average satisfaction	Convenient time satisfaction	Good work condition Satisfaction	Low delivery costs satisfaction	Low environment impact satisfaction	Privacy satisfaction	Conformity satisfaction
1	0.037±0.0002	0.07±0.0005	0.111±0.0005	0.09±0.0004	0.073±0.0005	0.079±0.0008	0.051±0.0003	0.018±0.0035
2	0.039±0.0006	0.075±0.0009	0.109±0.0009	0.086±0.0006	0.083±0.0011	0.09±0.002	0.06±0.0013	0.023±0.0012
3	0.036±0.0008	0.067±0.0015	0.085±0.0011	0.094±0.001	0.081±0.0012	0.085±0.0007	0.033±0.0004	0.023±0.0054
4	0.05±0.0004	0.077±0.0008	0.123±0.0004	0.078±0.0007	0.061±0.0009	0.064±0.0014	0.049±0.0003	0.086±0.0056
5	0.047±0.0004	0.071±0.0008	0.118±0.0003	0.062±0.0003	0.095±0.0008	0.075±0.0006	0.031±0.0011	0.048±0.0026
6	0.047±0.0002	0.072±0.0003	0.104±0.0005	0.06±0.0005	0.077±0.0006	0.081±0.0011	0.08±0.0015	0.03±0.0016
7	0.044±0.0003	0.067±0.0003	0.085±0.0006	0.066±0.0008	0.105±0.0004	0.089±0.0003	0.065±0.0003	-0.01±0.0033
8	0.046±0.0003	0.07±0.0006	0.102±0.0011	0.051±0.0007	0.083±0.0008	0.079±0.0011	0.064±0.0005	0.042±0.0039
9	0.05±0.0007	0.076±0.0011	0.106±0.0011	0.084±0.0013	0.102±0.0006	0.094±0.001	0.059±0.0002	0.013±0.0055
10	0.059±0.0004	0.094±0.0006	0.124±0.0003	0.098±0.0015	0.095±0.0009	0.087±0.0016	0.065±0.001	0.095±0.0027
11	0.046±0.0004	0.072±0.0008	0.083±0.0012	0.09±0.0011	0.096±0.0003	0.076±0.0007	0.069±0.0011	0.015±0.0018
12	0.052±0.0013	0.081±0.0024	0.096±0.0018	0.072±0.0004	0.081±0.0008	0.091±0.0011	0.064±0.0014	0.085±0.0092
13	0.038±0.0004	0.055±0.0006	0.091±0.0005	0.06±0.0011	0.083±0.0006	0.087±0.0004	0.047±0.0009	-0.037±0.0033
14	0.056±0.0005	0.088±0.0008	0.096±0.0021	0.083±0.0011	0.085±0.0005	0.088±0.0009	0.075±0.0002	0.102±0.0033
15	0.054±0.0004	0.085±0.0007	0.092±0.0005	0.081±0.0003	0.08±0.0008	0.092±0.0004	0.065±0.0007	0.1±0.004

5.7.3 Satisfaction outcomes for the autonomous delivery robot (ADR) option

Figure 40Figure 40 and Table 11Table 11 report the corresponding satisfaction outcomes for the ADR delivery option. Overall evaluation values for ADR lie between 0.024 and 0.043, with standard deviations again well below 0.001, and average satisfaction scores range from 0.033 to 0.065. These values are consistently below those of the collection-point option (Table 4), indicating that, under the current model assumptions, ADR delivery is perceived as slightly less attractive on average. The only exception is Scenario 13, where emphasizing the "convenient time" motive while keeping ADR capacity at five compartments leads to an average satisfaction for ADR (0.061) that marginally exceeds that of the collection-point alternative (0.055).

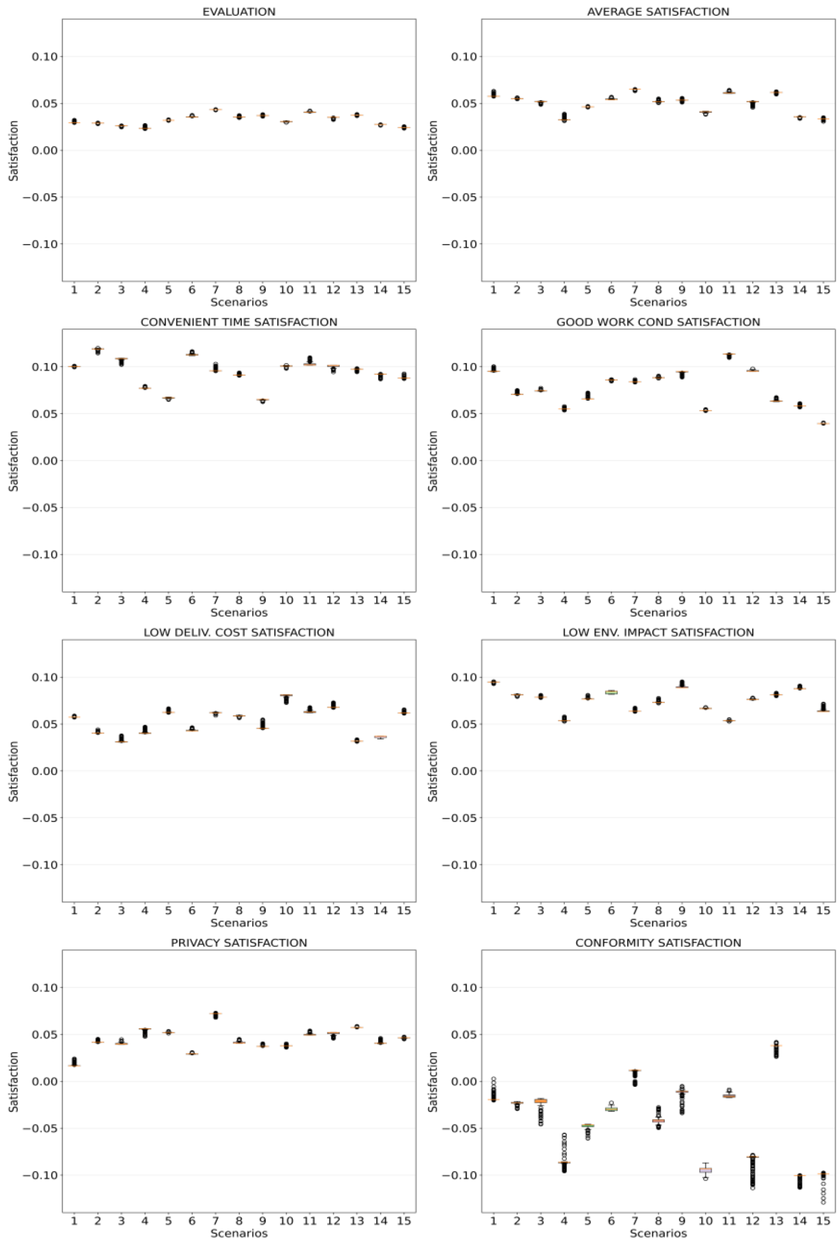

EVALUATION
AVERAGE SATISFACTION
CONVENIENT TIME SATISFACTION
GOOD WORK COND SATISFACTION
LOW DELIV. COST SATISFACTION
LOW ENV. IMPACT SATISFACTION
PRIVACY SATISFACTION
CONFORMITY SATISFACTION
Satisfaction
Scenarios

FIGURE 40: RESULTS IN SATISFACTIONS REGARDING ADR OPTION – 150 RUNS

Motive-specific indicators show a pattern broadly consistent with the collection-point results but with lower absolute levels for ADR. Satisfaction with convenient delivery time and good working conditions is relatively high (between roughly 0.07 and 0.12 and between 0.04 and 0.11 respectively), whereas satisfaction with low delivery costs and privacy remains more modest (approximately 0.03–0.08 and 0.02–0.07). In contrast to the collection-point alternative, the "conformity" indicator for ADR is negative in most scenarios and can reach values below –0.10, reflecting that many agents still perceive ADR deliveries as less aligned with the behaviour of their social contacts. Together, these results suggest that, while ADR is operationally feasible, additional efforts are needed to improve its social acceptance and to close the satisfaction gap with the established collection-point option.

TABLE 11: RESULTS OF MEAN AND STANDARD DEVIATION FOR ADR OPTION – 150 RUNS

Scenario	Evaluation	Average satisfaction	Convenient time satisfaction	Good work condition Satisfaction	Low delivery costs satisfaction	Low environment impact satisfaction	Privacy satisfaction	Conformity satisfaction
1	0.03±0.0005	0.058±0.001	0.1±0.0002	0.095±0.0009	0.057±0.0003	0.095±0.0004	0.017±0.0016	-0.018±0.0035
2	0.029±0.0002	0.055±0.0003	0.119±0.0007	0.071±0.0011	0.041±0.0006	0.081±0.0004	0.042±0.0008	-0.023±0.0012
3	0.026±0.0003	0.052±0.0007	0.108±0.0011	0.075±0.0006	0.031±0.0014	0.079±0.0003	0.04±0.0008	-0.023±0.0054
4	0.024±0.0006	0.033±0.0011	0.077±0.0006	0.055±0.0004	0.041±0.0015	0.054±0.0008	0.056±0.0015	-0.086±0.0056
5	0.032±0.0002	0.046±0.0002	0.067±0.0006	0.066±0.0014	0.063±0.0008	0.077±0.0007	0.052±0.0005	-0.048±0.0026
6	0.036±0.0004	0.054±0.0005	0.113±0.001	0.086±0.0002	0.043±0.0008	0.084±0.0014	0.029±0.0004	-0.03±0.0016
7	0.043±0.0001	0.065±0.0004	0.096±0.0014	0.084±0.0004	0.062±0.0004	0.064±0.0009	0.072±0.0009	0.01±0.0033
8	0.035±0.0005	0.052±0.0008	0.091±0.0004	0.088±0.0003	0.059±0.0005	0.073±0.0008	0.041±0.001	-0.042±0.0039
9	0.037±0.0003	0.053±0.0007	0.065±0.0005	0.094±0.0015	0.046±0.0022	0.09±0.0017	0.038±0.0009	-0.013±0.0055
10	0.03±0.0003	0.041±0.0006	0.101±0.0005	0.053±0.0004	0.08±0.0018	0.067±0.0004	0.038±0.0006	-0.095±0.0027
11	0.041±0.0004	0.061±0.0008	0.103±0.0018	0.113±0.0011	0.063±0.0015	0.054±0.0004	0.05±0.0011	-0.015±0.0018
12	0.035±0.0007	0.051±0.0017	0.101±0.0013	0.096±0.0007	0.068±0.0013	0.076±0.0004	0.051±0.0019	-0.085±0.0092
13	0.037±0.0003	0.061±0.0005	0.097±0.0007	0.063±0.0008	0.032±0.0002	0.081±0.0004	0.058±0.0003	0.037±0.0033
14	0.027±0.0003	0.036±0.0005	0.092±0.001	0.058±0.0006	0.036±0.0008	0.088±0.0006	0.041±0.0011	-0.102±0.0033
15	0.024±0.0003	0.033±0.0004	0.088±0.0006	0.039±0.0002	0.062±0.0007	0.064±0.0021	0.046±0.0003	-0.1±0.004

5.7.4 System-level impacts on distance and emissions

Table 12Table 12 summarizes the percentage of parcels delivered by the ADR fleet in each scenario as computed by the VRP module. Service reliability is very high across all 15 scenarios: average completion rates range from 97.95% to 100.0%, with standard deviations below about 2.7 percentage points. For robots with five compartments (capacity setting 3A), all parcels assigned to ADRs are delivered in every replication. For the ten-compartment configuration (3B), completion rates remain above 99.8% on average, while the largest robots considered (15 compartments, capacity setting 3C) still deliver around 98.1% of parcels on average, albeit with somewhat higher variability between replications.

TABLE 12: PERCENTAGE OF PARCELS DELIVERED IN EACH SCENARIO (MEAN AND STD OVER 150 RUNS)

Scenario	Percentage of parcels delivered
1	100±0
2	99.876±0.5455
3	98.106±2.5458
4	100±0
5	99.952±0.3049
6	98.164±2.5416
7	100±0
8	99.849±0.8515
9	98.062±2.4021
10	100±0
11	99.873±0.5083
12	98.21±2.4047
13	100±0
14	99.929±0.4047
15	97.954±2.6661

Given the demand levels generated for the Karlsruhe study area (521 parcels in the Parcel Demand module), these results indicate that even relatively small robots are sufficient to provide a highly reliable service under the tested operating assumptions. Increasing compartment capacity mainly changes how tours are structured rather than whether parcels can be delivered at all; the modest reduction in completion rates for the highest capacity setting suggests that tighter time-window or range constraints may occasionally prevent a small number of parcels from being served within a single tour. Although detailed distance and emission indicators are not explicitly reported here, the combination of high completion rates and the observed differences in satisfaction and acceptance between ADR and collection-point options implies that appropriately designed ADR services have the potential to replace a substantial share of individual collection trips and thereby reduce person-kilometres and emissions in the local last-mile system.

5.8 Conclusion and next steps

This case study applied the integrated HUMAT–MASS-GT–VRP framework of URBANE to the Karlsruhe LL. The calibrated model reproduces parcel demand in the study area and simulates how consumers evaluate and choose between the two fulfilment options under different motive-specific satisfaction and robot-capacity settings.

The simulation results indicate that, in all tested scenarios, the collection-point alternative is still perceived as slightly more attractive than ADR delivery on average. Evaluation and satisfaction scores for the collection point are consistently higher or very close to those for ADR (Sections 7.2 and 7.3), with only one scenario – where the convenient-time motive is emphasized and ADR capacity is kept low – in which ADR marginally outperforms the collection-point option. Motive-specific indicators highlight that consumers value convenience of time, low delivery costs and good working conditions for both alternatives, whereas privacy, environmental impact and especially social conformity remain more critical for ADR.

From an operational perspective, the VRP module shows that all three robot-capacity configurations considered (5, 10 and 15 compartments) can deliver almost all parcels assigned to ADRs, with completion rates above 97.9% in every scenario and 100% for the smallest robots (Section 7.4). This suggests that, for the current demand density in the Karlsruhe use case, relatively small robots are sufficient to provide a reliable service. The slight decrease in completion rates and increase in variability for the largest capacity setting underline that increasing payload alone does not guarantee better performance if time-window or range constraints become binding.

- Taken together, these findings imply that further deployment of ADRs in Karlsruhe will require both technically robust routing solutions and service designs that directly address the motives where ADR currently lags behind, in particular perceptions of privacy and social acceptance. Improving communication about data protection, showcasing positive experiences through social networks and bundling ADR with attractive delivery-time and cost options are potential levers to narrow the gap with the established collection-point alternative.

Next steps for the Karlsruhe case study include:

- Refining behavioural calibration using the full Karlsruhe survey dataset and, where available, revealed-preference data from Living Lab pilots, with a particular focus on privacy and conformity perceptions.
- Extending the MASS-GT module by adding more LSPs to the network in order to represent a more realistic parcel market.
- Extending the VRP components to produce explicit distance and emission indicators for the Karlsruhe scenarios, enabling a quantitative assessment of environmental impacts.

- Exploring additional what-if scenarios, including alternative pricing strategies, differentiated service levels for ADR versus collection point, and changes in ADR operating windows or speed.

The Karlsruhe Living Lab thus provides both a realistic test bed for robot-assisted last-mile delivery and a proof of concept for transferring the URBANE modelling framework to new urban contexts. The current results offer a first, quantitatively grounded picture of how citizens might react to ADR services and how these services could be operated, which can be progressively refined as additional empirical data from pilots and operator feedback become available.

6. Use cases

6.1 Use case 1 – Internal transport (B2B)

6.1.1 Description

Use case 1 is an internal AVG application of an autonomous delivery robot. For that, two locations are relevant (see map below):

- **Location A:** Depot East (BHO), Depot Gerwigstraße (BHG) and AVG post office
- **Location B:** Depot West (BHW) incl. workshop and central warehouse

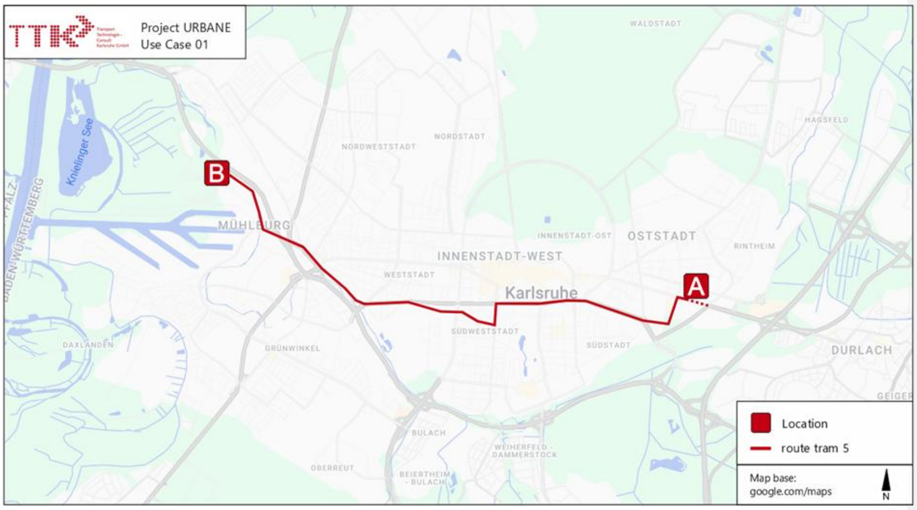


FIGURE 41: USE CASE 1 – ROUTE BETWEEN LOCATION A & LOCATION B

AVG letters and parcel post between the two sites are currently transported once a day, by car. Spare parts and tools are also transported once a day in a separate car journey. In total, one person commutes between the sites with a car, twice a day.

The idea of use case 1 is the use of an autonomous delivery vehicle for the transport of suitable shipments. Conveniently tram line 5 commutes between BHW and BHG a few times a day (see journey analysis). In theory, the delivery robot could use those journeys. The following graphic shows the intended process of use case 1.

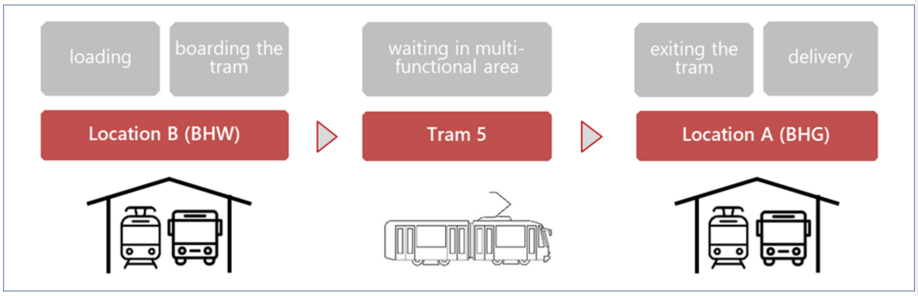


FIGURE 42: USE CASE 1 PROCESS

As both locations A and B are private properties of AVG, the robot does not have to drive on public sidewalks or cross public streets. Therefore, the implementation of use case one, regarding regulations, is rated as easier as the other use cases. It could be a suitable first step.

In a further stage, when the robot has been granted approval to drive on public sidewalks, it could travel between location A2 (BHG) and neighbouring AVG offices (A1) (see illustration below).

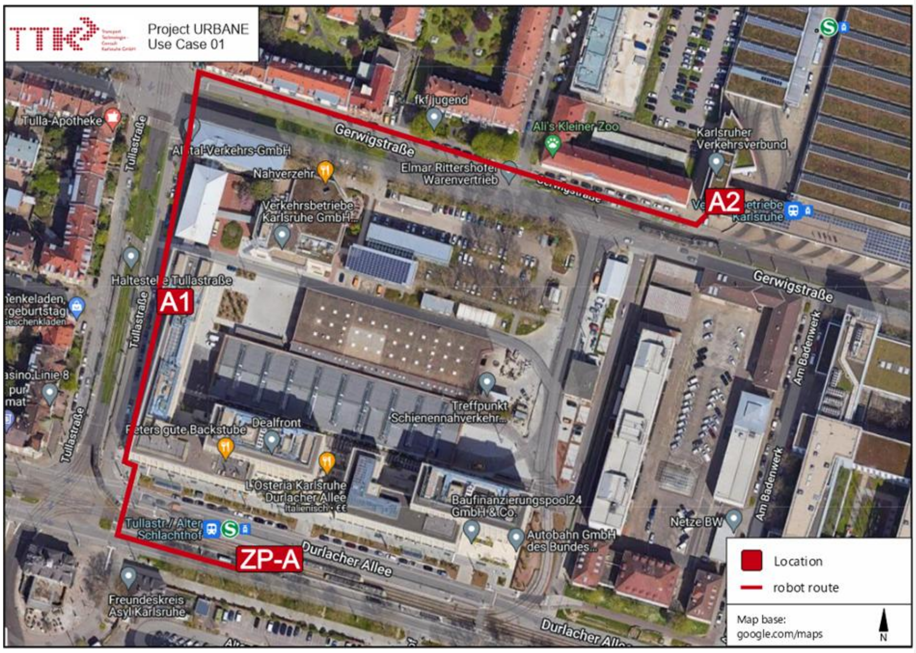


FIGURE 43: USE CASE 1 ROUTE A

The authorisation to drive on public sidewalks would expand the number of possible tram journeys, as only a few per day start/end in BHO, but a lot more stop at the station "Tullastraße/Alter Schlachthof" (ZP-A) nearby. The process diagram, as shown before, would change as follows.

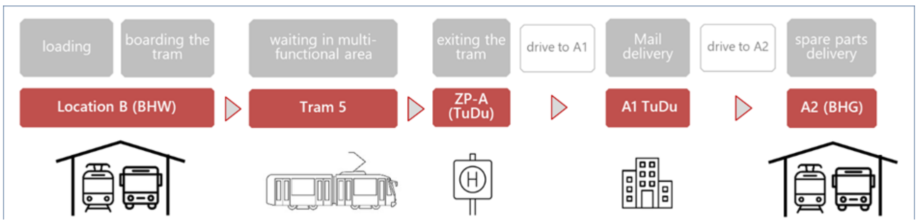


FIGURE 44: USE CASE 1 WHOLE PROCESS

A similar expansion of use case 1, under the same requirements, would be possible at location B (BHW). As shown in the illustration below, the robot could travel from location B to C, an AVG bus depot.

FIGURE 45: USE CASE 1 ROUTE B

As mentioned before, not every journey of tram line 5 can be used, because of two reasons:

- Not every journey starts/ends at location B (BHO)
- Not every journey starts/ends at location A2 (BHG)
- The utilisation during the journeys, especially of the multifunctional areas, must stay below a certain percentage (see following table) during the whole journey

TABLE 13: SELECTION CRITERIA

Criteria for selection (analogue to LogIKTram) [maximum values in the evaluation period]	Threshold value	
	Conservative	optimistic
Seat utilisation at the loading stop	30%	50%
Seat utilisation during the journey	50%	80%
Seat utilisation at the final stop	40%	60%
Passenger flows at the loading stop	8	15
Passenger flows at the final stop	8	15

Only if a journey fulfils all five criteria it is considered usable for the robot from a conservative or optimistic point of view. The analysis is done with the following general conditions:

- Data basis: NVBW[25] count data for line 5 in the period 12/12/2022 to 09/12/2023
- The maximum utilization of a journey in the evaluation period is used for the evaluation
- Only journeys starting or ending at BHW are analysed, as it is too far away from the final stop of tram line 5 for the robot to drive
- Vehicle in usage: DUEWAG GT6 70 D/N
  - 86 seats plus 89 standing = 175 total passenger capacity
  - 2 mfa. -> 1 mfa. can be used

The table below lists the prefiltered journeys, combined with the mentioned criteria. The departure times framed in black mark the journeys that start / end in location A2 (BHG).

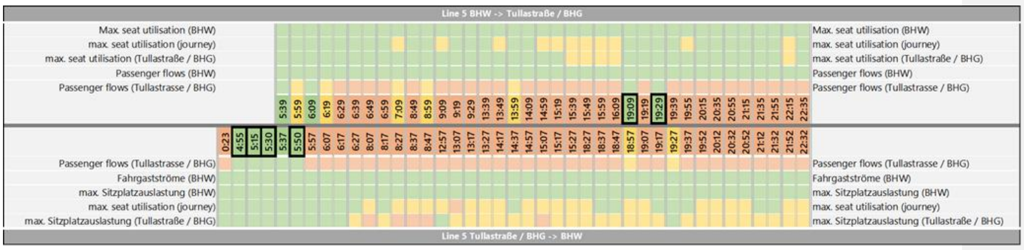


FIGURE 46: PREFILTERED JOURNEYS

[25] https://www.nvbw.de/

Conveniently, all the journeys ending / starting in BHG have low utilisation and are therefore best suited for use case 1. If approval is granted to drive in public areas, three (conservative) to ten (optimistic) more journeys could be usable.

In total, up to 15 journeys can be done by robot, daily on line 5. Of these, 6 start and end at the two depots, BHW and BHG.

6.2 Use case 2 – Shop to Customer (B2C)

6.2.1 Description

The delivery process involves several key stakeholders: the customer, who makes a purchase and expects a delivery; the local retailer, who sells the goods and initiates the delivery; a centralized logistics platform, which manages transport resources and coordinates the entire process; the autonomous mobile robot (AMR), which handles the first and last mile of delivery; and the tram, which transports the AMR between city centre and suburbs. Additionally, the URBANE blockchain is used to record key events throughout the delivery process, ensuring transparency and traceability.

The following Figure 47~~Figure 47~~ shows this process detailed in graphical form. It displays which process step is linked with which process actor and also the link to the blockchain (via REST-API). The following text explains the individual steps in detail.

Sending

The process begins when a customer shops at a local retailer and chooses the autonomous delivery option. Upon checkout, the retailer initiates a delivery request through the logistics platform. The platform then assigns an AMR to pick up the goods. At this point, the shipment is registered on the URBANE blockchain, and the event “delivery order received” is recorded.

The AMR navigates autonomously to the retailer’s location. Upon arrival, the retailer must authenticate themselves to unlock the robot’s compartment. Once the goods are placed inside and the compartment is closed, the system logs the event “parcel in compartment of AMR” on the blockchain, confirming that the robot is loaded and ready for transport.

Shipping

Next, the logistics platform coordinates the shipping phase. It reserves a designated space for the AMR in the multifunctional area of a suitable tram and informs the customer of the estimated delivery time. While the tram is en route, the AMR drives to the assigned tram stop and waits in a designated area.

When the tram arrives, it verifies that the reserved space is available. If confirmed, the tram opens its door, allowing the AMR to board and secure itself in place. This action triggers the blockchain event "parcel in tram", marking the transition to the intermodal transport phase.

The tram then travels to the stop nearest to the customer's address. Upon arrival, the AMR disembarks and the event "parcel left train" is recorded. The customer receives an updated estimated time of arrival as the AMR begins the final leg of the journey.

Upon reaching the customer's location, the AMR notifies them of its arrival. The customer authenticates themselves to unlock the compartment and retrieve their goods. Once the compartment is closed, the final event "parcel delivered" is written to the blockchain, completing the delivery process.

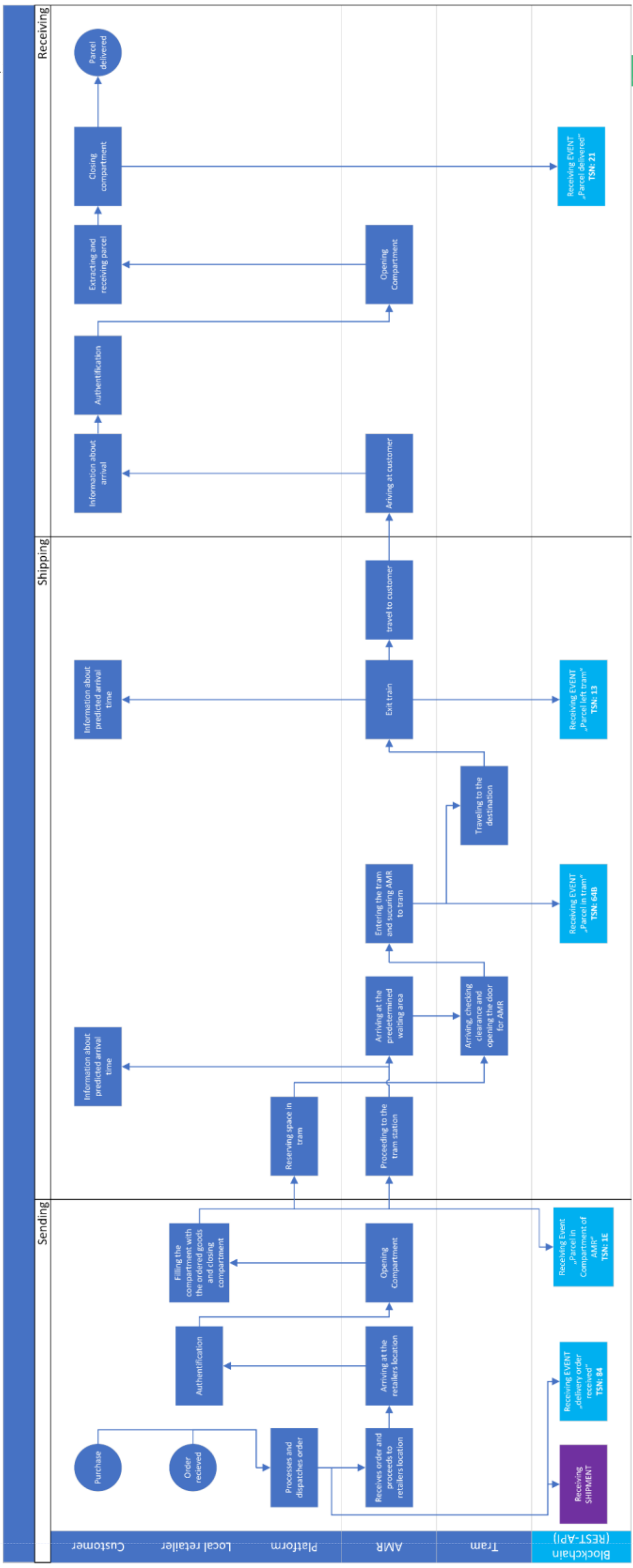


FIGURE 47: PROCESS DIAGRAM USE CASE 2

Commented [SR4]: Cross-reference this and check the titles and table of contents link

As the autonomous delivery robot cannot block walkways and waiting areas for passengers in any way, a designated waiting area is needed at every station the robot needs to use. Therefore, there must be space available at or right next to the station. Also, the platforms must be wide enough to accommodate a safe driving path for the robot, as wheelchairs etc. must be able to get past it.

All the stations of tram line 5, as listed below, have been checked for their availability of space for a designated waiting area:

- Green: space already available, just has to be marked
- Yellow: space available to build a designated waiting area
- Red: no space available

Also, the accessibility check is displayed to complete the overview.

TABLE 14: KARLSRUHE STATIONS TRAM LINE 5

Station	accessibility for delivery robot	availability of space	suitability
Durlach Bf	platform west only		
Untermühlstraße			
Weinweg			
Tullastraße/Alter Schlachthof (Durlacher Allee)			
Schloss Gottesaue / Hochschule für Musik			
Wolfartsweierer Straße			
Ostendstraße			
Rüppurrer Tor (Kriegsstraße)			
Ettlinger Tor/Staatstheater (oben)			
Karlstor/Bundesgerichtshof (Kriegsstraße)			
Karlstor/Bundesgerichtshof (Karlstraße)			
Mathystraße (Mathystraße)		not analysed	
Otto-Sachs-Straße			
Lessingstraße			
Weinbrennerplatz (Kriegsstraße)			
Hübschstraße			
Kühler Krug			
Mühlburger Feld			

Entenfang (Lameystraße)			
Lameyplatz		not analysed	
Rheinhafen			

In conclusion, four stations are already suitable for the robot to exit and enter the tram. Ten other stations could be used, if a waiting area for the robot would be built. At the remaining seven stations, there is no space available for a designated waiting area and/or there are no plans for creating barrier-free accessibility until 2030.

Disclaimer: The stations have been checked for their theoretical availability of space by the consultants. Environmental and regulatory aspects where not part of this check. Also, the city did not participate in this check and therefor hasn´t approved or denied the suitability of the listed stations.

Based on the assumption that the robot is allowed to deliver within a 500-meter radius around the station, the following areas of the city would be covered by the suitable stations of tram line 5 – assuming at all 10 yellow marked stations, a designated waiting area for the robot would be built.

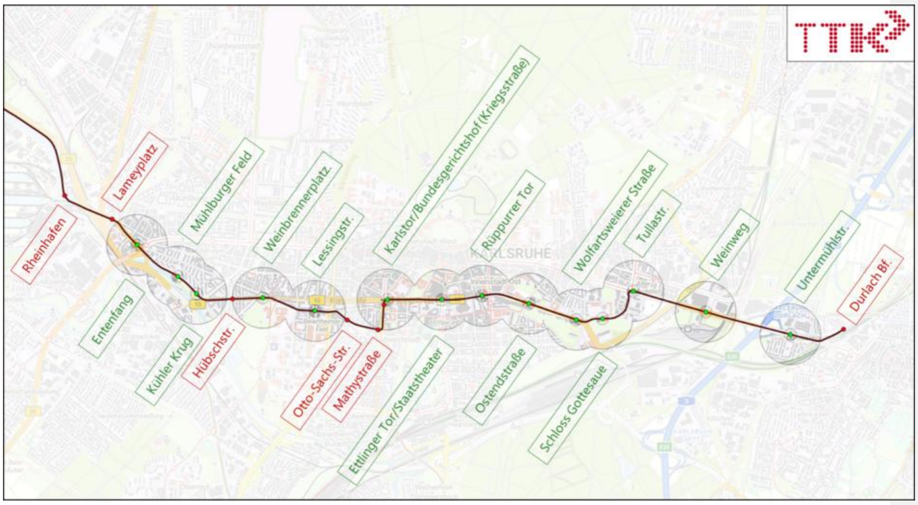


FIGURE 48: RADIUS OF SUITABLE STATIONS

6.3 Use Case 3 – Meals on wheels (B2C)

6.3.1 Description

In the city of Karlsruhe, as well as in selected areas of the surrounding region, several service providers are engaged in the preparation and distribution of warm meals to private households. Among the most prominent organizations involved is the Red Cross, which operates such services on a regular basis. The central objective of these initiatives is to ensure reliable access to daily meals for elderly citizens who, due to age-related limitations or health conditions, are no longer able to cook for themselves.

The meals are prepared in a centralized kitchen facility, where standardized processes guarantee both nutritional quality and compliance with hygiene regulations. Following preparation, the meals are packaged for distribution and loaded into passenger cars operated by the service providers. The delivery staff then transport the meals directly to the homes of registered clients, where they are handed over personally.

This delivery model represents a crucial element of social support infrastructure in Karlsruhe, ensuring that vulnerable population groups are able to maintain a degree of independence and well-being in their everyday lives. At the same time, the reliance on conventional passenger vehicles as the primary mode of distribution reflects both the logistical organization of the service and its dependence on individual motorized transport within the urban environment.

1. Pick-Up of Meals by the Autonomous Robot

At scheduled intervals, an autonomous robot arrives at the dispatch area of the central kitchen. The robot is equipped with a storage unit that allows for the safe transport of multiple meal containers simultaneously. Upon arrival, the robot positions itself precisely at the designated loading station. Kitchen staff or automated loading equipment transfer the packed meal boxes into the robot’s compartment. Once the storage is secured and verified, the robot begins its journey toward the nearest tram stop.

2. Robot Movement to the Tram Stop

The robot follows a predefined route from the central kitchen to the tram stop. This route is selected for accessibility and efficiency, ensuring that sidewalks, crossings, and entry points are compatible with autonomous movement. The robot travels at a steady speed, maintaining a safe distance from pedestrians and other urban traffic participants. Upon reaching the tram stop, the robot navigates to a designated waiting area adjacent to the boarding zone, where it pauses until the appropriate tram arrives.

3. Transfer into the Tram and Onboard Transport

When the scheduled tram arrives, the robot approaches the boarding point and enters the tram compartment reserved for logistics operations. Inside the tram, the robot positions itself in a dedicated space where it remains stable and secured for the duration of the journey. During transit, the meals are transported along the tram line from the origin stop to the destination stop. The use of the tram provides a reliable and consistent means of covering the main segment of the journey, ensuring that the meals progress rapidly toward the recipients' neighbourhood.

4. Disembarkation at the Destination Tram Stop

Upon arrival at the designated destination stop, the robot automatically disembarks from the tram. This process mirrors the entry sequence, with the robot leaving the vehicle safely and returning to the pedestrian area of the stop. Once outside, the robot reorients itself using its navigation system and prepares to begin the final leg of the delivery process.

5. Final Delivery to Recipients

From the destination tram stop, the robot travels autonomously to the homes or facilities of the intended recipients. This last segment of the journey involves navigating through local streets and walkways, with each robot programmed to follow an efficient delivery sequence. Upon reaching each recipient's address, the robot halts at the drop-off point and opens its storage compartment. The meal container is then handed over, either directly to the recipient or into a secure reception box. Once the delivery is completed, the robot continues to the next address on its route until all meals are distributed.

6. Return to Base

After completing the assigned deliveries, the robot returns either to the nearest tram stop for transport back to the central kitchen or directly to the kitchen via its designated route. At the central facility, the robot undergoes unloading (if required), charging, and preparation for the next delivery cycle.

7. Results, evaluation, impact assessment

In general, for all three use cases the following risks must be addressed / considered:

- Dealing with hazardous substances / dangerous items
- In several German cities, it is forbidden to transport e-scooters in public transport vehicles, because of the risk of battery fires.
    - Would that apply to a delivery robot?
    - this regulation is currently not existent in Karlsruhe
- Approval to transport the autonomous robot in a tram vehicle
- Only in use case 2 and 3: approval to use the robot in public areas and to cross streets and rails

7.1 Use Case 1

7.1.1 Calculation

The implementation of use case 1 would have several effects:

- Eliminated transport journeys (car)
    - Staff can be deployed elsewhere
    - Increased efficiency
- Less car kilometres / hours
    - Wear and tear / operating costs
    - Reduction in CO_2 and particulate matter
    - Reduction of noise emissions

In total ~87% of all car journeys currently made, could be replaced by the robot. That translates to 325 car journeys with ~3.090 kilometres and 68 hours of driving time per year.

As there are currently three cars in usage at AVG for internal deliveries, it can be assumed, that one of them is no longer needed.

For the calculation of the monetary effects the following assumptions and calculations are made:

TABLE 15: POSSIBLE SAVINGS

Possible business savings	
• operation of the car	personnel
• total operating time = 8 years • acquisition costs = 35.000 € • amortisation per year = 4.375 € • operating cost per year = 2.000 € • **total per year = 6.375 €**	• cost per hour = 39 € (as of 2016, from a German guideline "Standardisierte Bewertung 2016+") • savings= 2.652 € / year • **savings extrapolated to 2024 = 3.406 € / year**
Total possible business savings at AVG, extrapolated to 2024 = **9.700 € per year**	
possible savings in external costs	
• (as of 2016, from a German guideline "Standardisierte Bewertung 2016+")	
• 0,22 € / km cost rate for car operation • 0,085 € / km accident cost rate	• 0,004 € / km emission cost rate for pollutants • 127 g / km CO_2 emitted
Total possible savings in external costs, extrapolated to 2024 = **1.562 € per year**	

In total, use case 1 has the potential to save up to 0,39 tons of CO_2 and 11.262 € per year. This is offset by the anticipated costs of the robot, which is estimated to range between 40.000 and 60.000 €, including investment an operational cost for an operating time between 5 and 10 years.

TABLE 16: BALANCE OF COSTS AND SAVINGS USE CASE 1

Balance of costs and savings use case 1			
total cost [€] / operating time [a]	40.000	50.000	60.000
5	**+ 3.262 € / a**	**+ 1.262 € / a**	**- 738 € / a**
8	**+ 6.262 € / a**	**+ 5.012 € / a**	**+ 3.762 € / a**
10	**+ 7.262 € / a**	**+ 6.262 € / a**	**+ 5.262 € / a**

With the assumptions made, use case 1 would make a net profit, as long as the total cost and operating time ranges within the criteria shown above.

7.1.2 Transferability

Use Case 1 is transferable to every city, where there are multiple depots / locations with the need of transporting anything between them. The requirements for the stations shown above have to be fulfilled, the vehicles must have a barrier-free entry and enough room inside to accommodate the robot safely and without affecting passengers in any way.

If the requirements are met, the use case is not limited to tram vehicles. It is also possible with any other type of public transport, for example (underground) railway, busses, boats and cable cars.

7.2 Use Case 2

7.2.1 KPI calculation with digital twin platform

The URBANE Digital Twin Platform (DT) simulates different delivery scenarios aspiring to answer different "what-if" questions. This allows the LL to test new strategies, such as changing delivery vehicles, and see how they impact efficiency and the environment before implementing them in the real world. In the case of the Karlsruhe LL, it aspires to promote more sustainable modes of delivery but also gather robust data on how the employment of autonomous delivery vehicles (AMRs) for urban freight transport may affect the functioning of the city.

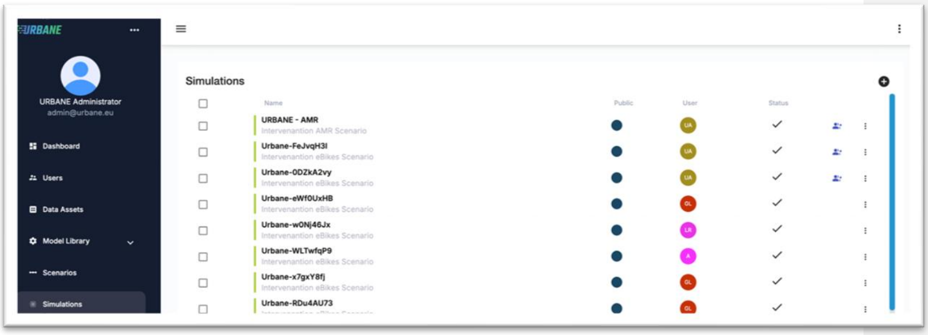


FIGURE 49: URBANE DIGITAL TWIN (DT) PORTAL

The Digital Twin makes use of a series of models developed in the project and presented in *D3.4 URBANE Innovation Transferability Platform* that seek to explore the Living Lab's operational performance. All models have been integrated into the DT following a meticulous integration process and are available for exploration and testing through the Portal of the DT, as shown in *Figure 1*. Through the Portal users can use the models to define *scenarios* (i.e., a sequence of models) and test these scenarios using different inputs, which in turn allows them to explore different "what-if" questions.

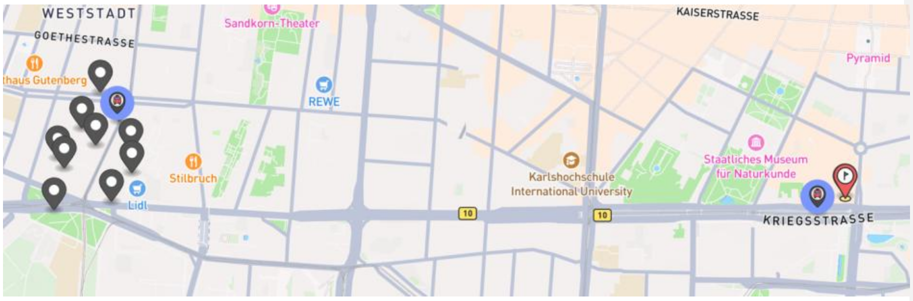


FIGURE 50: MAP DISPLAYING DELIVERY START AND DESTINATIONS

In the case of Karlsruhe, which is a Twinning Lab in the URBANE project, emphasis has been placed on the reusability of models already developed and integrated in the URBANE DT. Therefore, the 2-echelon, EVCO2 and copert models, which are all already part of the URBANE DT offering, were put together as a sequence of models and executed through the DT Platform.

TABLE 17: KEY INPUTS

Starting Point		Accessing the tram stop		Disembarking from the tram	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
49,00586488	8,403137681	49,005514880	8,402253775	49,00750028	8,379021793

TABLE 18: PARCEL DELIVERIES LOCATIONS

Delivery Points	
Latitude	Longitude
49,00733377	8,377790151
49,00669607	8,376974801
49,00686064	8,379420851
49,00556465	8,376880722
49,00636693	8,379452211
49,00574979	8,378762299
49,00813602	8,378417343
49,00698406	8,378260545
49,00646979	8,377194318

In this LL, the focus has been on the city centre of Karlsruhe, and two scenarios have been examined. In both scenarios we have explored the delivery of parcels starting from the ECE-Centre to be delivered in various locations near the Sophienstrasse tram stop, as shown in Figure 50~~Figure 45~~. In the first scenario an AMR is used for the delivery of the parcels, embarking the tram on the Ettlinger Tor tram stop and disembarking at Sophienstrasse and then delivering the parcels one by one. In the second scenario a Diesel light truck is used to pick up the parcels from ECE-Centre and deliver them to the same delivery destinations as in the first scenario.

The EVCO2 is used to calculate CO2 emissions for the AMR, while a geodesic calculation computes the distances. In the case of the Diesel light truck the 2-echelon is employed to calculate the distance covered and the Copert model to calculate the emissions for the light truck. The inputs used in the model sequence are presented in Table 17~~Table 17~~, specifying the exact geolocation of each major point on the map, while Table 18~~Table 18~~ contains all the deliveries used in the scenario.

TABLE 19: MODEL OUTPUTS

Vehicle Type	Model Sequence	Distance (km)	CO2 (g)
AMR	1. Compute distances (geodesic) 2. EVCO2 Model	3.91	111.35
Light Truck	1. Echelon Model 2. COPERT Model	6.09	1096.2

The model sequence and the outputs of the model executions for both tested scenarios are presented in Table 19~~Table 19~~.

7.2.2 More KPIs

Additional Transport Scenarios for Use Case 2

In addition to the previously described case, seven further transport scenarios were developed for Use Case 2, representing a range of delivery operations within the urban area of Karlsruhe. These scenarios were designed to cover different parts of the city, reflecting realistic delivery routes that autonomous mobile robots could perform in combination with tram-based transport.

For each of these cases, the transport times were calculated using the current timetable of the Albtal-Verkehrs-Gesellschaft (AVG) as of summer 2025. The travel time calculations considered the individual segments of the transport chain, including both the tram journeys and the autonomous movements of the robot between the tram stops and the delivery locations. A mean travel speed of 3 km/h was assumed for the robot during its autonomous operation on pedestrian pathways.

The resulting travel times provide a realistic estimation of the total delivery duration for each transport scenario. As an example, the table below presents the calculated times for Transport Scenario 1, illustrating the sequence and duration of each transport segment. In this scenario a parcel is transported from a local shopping mall (ECE Center) to a home in a residential area. All other transport scenarios are documented in the Annex, where they can serve as a reference framework for further analysis. In particular, these scenarios can be applied to model specific delivery demands per district once more detailed spatial demand data become available.

FIGURE 51: ADDITIONAL TRANSPORT SCENARIOS FOR USE CASE 2

TABLE 20: ADDITIONAL TRANSPORT SCENARIOS FOR USE CASE 2

Time		Event	Duration	
14:45:13	ECE-Center	Delivery Order received	10:00	Assumption: 10 min from Order to loading
14:55:13	ECE-Center	in ECE-Center	3:00	Loading
14:58:13		Start of ride to tram stop	2:52	Distance (143m) covered at 3 km/h
15:01:05	Arriving at tram stop	Waiting on tram line 4	3:55	Assumption: Tram arrives as scheduled
15:05:00		Tram arrives		
15:05:22		Getting in .	0:22	
		Drive to destination tram stop	10:00	Duration of Tram ride from schedule
15:15:21	Arriving at tram stop	Getting out	0:18	
15:15:40	Tram stop Sophienstr.	Ride Tram to "Sophienstr."		
15:17:43	Arriving at destination	Drive to Schillerstr. 50	2:02	Distance (135m) covered with 4 km/h
15:20:43	Receiver opens Compartment		3:00	Assumption: he needs 3 min from arrival
15:20:47	Receiver closes the compartment		0:05	Assumption: he needs 5sec to deload

7.3 Use Case 3

For *Use Case 3: Meals on Wheels*, no KPI calculation was conducted. This decision was based on several interrelated factors that highlight the unsuitability of the use case for the intended delivery system.

A central aspect concerns the geographical location of the production site. The Meals on Wheels service operates from a central kitchen located in an industrial area of Karlsruhe.

FIGURE 52: LOCATION OF CENTRAL KITCHEN (K) AND TRAM STOP (TS)

While this location is connected to the public transportation system via a bus line, the integration of autonomous delivery robots into buses is not technically feasible. Consequently, the robots would be required to travel independently from the central kitchen to the nearest tram stop. This transfer alone would take approximately 30 minutes, which is clearly excessive in the context of delivering warm meals that must reach recipients in a timely manner.

Furthermore, the 30-minute transfer time represents only one component of the overall journey. Additional time would be required for the tram ride itself, as well as for the final leg of delivery from the destination tram stop to the recipients. Taken together, these factors render the process inefficient and incompatible with the primary service goal of ensuring that meals are delivered hot and within a reasonable timeframe.

Beyond the temporal inefficiencies, further considerations (discussed in a later chapter) demonstrate that the Meals on Wheels scenario is not an appropriate use case for the application of autonomous robots in combination with tram-based transport. These broader limitations reinforce the impracticality of the model and underline the decision to exclude it from KPI-based evaluation.

In conclusion, the combination of geographical constraints, excessive transfer times, and broader conceptual shortcomings justified the omission of KPI calculations for Use Case 3.

This decision reflects a pragmatic alignment of analytical resources with cases that better represent the potential and suitability of autonomous robot–tram integration.

7.4 Regulatory Coordination and Approval Process

The work on the project URBANE in the Karlsruhe Living Lab is intertwined with other similar projects. These projects have a different focus each and complement each other. One of these projects is regioKArgoTramTrain. URBANE activities support the work in regioKArgoTramTrain.

A regulatory coordination and approval steering group has been established to address all legal, administrative, and procedural aspects related to the operation of tram and light rail vehicles under both the German Ordinance on the Construction and Operation of Tramways (Straßenbahn-Bau- und Betriebsordnung, BOStrab) and the German Railway Construction and Operating Regulations (Eisenbahn-Bau- und Betriebsordnung, EBO). The initiative for this steering group emerged from the project's unique objective: to enable the shared use of tram-train infrastructure for both passenger and freight transport within a single operational concept.

This approval steering group consists of representatives from the Technical Supervisory Authority of Baden-Württemberg (Technische Aufsichtsbehörde, TAB BW) and the Federal Railway Authority (Eisenbahn-Bundesamt, EBA), which are the two primary regulatory bodies responsible for safety oversight, certification, and approval of tramway and railway systems in Germany. Their joint participation in the steering group represents a significant milestone, as it bridges two traditionally separate regulatory domains — urban tramway operation under BOStrab and regional or national rail operation under EBO. This duality is at the core of the TramTrain concept and poses both technical and legal challenges, especially when extending its use to freight applications.

The steering group functions as a continuous consultation and coordination platform, where the current project status, technical progress, and legal implications are discussed in detail. Regular meetings are held to review documentation related to vehicle design adaptations, safety management, operational planning, and signalling integration. Through this iterative exchange, the consortium ensures that all regulatory questions are clarified early in the development process and that the engineering solutions remain compatible with both regulatory frameworks.

A major focus of the discussions lies in the definition of operational boundaries between BOStrab and EBO domains. The aim is to develop a regulatory pathway that allows the seamless transition of TramTrain vehicles between networks governed by different safety standards and technical regulations. The joint assessment of TAB BW and EBA ensures that the resulting approach not only fulfils national requirements but also serves as a reference case for future multimodal systems in other German and European cities.

The overarching objective of the steering group, and of the coordinated sequence of regulatory actions resulting from it, is to establish a legally robust foundation for a prolonged demonstration phase of combined passenger and freight transport. Such a demonstration is intended to validate the safe and efficient integration of freight logistics into existing TramTrain operations. It will provide empirical evidence regarding the technical feasibility, operational efficiency, and societal acceptance of the concept, while maintaining full compliance with national safety standards.

The project partners aim to prepare the transition toward a temporary regular service starting in 2028. This phase would mark a significant step beyond experimentation, as it would bring the operation into a semi-commercial environment. To achieve this, the consortium and the authorities must jointly develop a framework for monitoring, documentation, and risk management that meets the expectations of both BOStrab and EBO.

Ultimately, the work of the steering group is not only about legal compliance but also about innovation governance — ensuring that pioneering mobility solutions can emerge within a structured, transparent, and safe regulatory environment. The collaborative approach adopted demonstrates how early coordination with supervisory authorities can accelerate the implementation of complex, cross-domain transport systems. By establishing trust and clear communication channels among all stakeholders, the project lays the groundwork for a sustainable integration of freight transport into public transit networks, supporting broader urban and regional goals of reducing emissions, congestion, and delivery-related traffic.

8. Lessons Learnt & recommendations

Lessons Learnt and Recommendations

The development and assessment within the Karlsruhe Living Lab have generated a range of important insights that go far beyond the purely technical dimensions of the project. The overarching aim of the Living Lab was to explore how innovative logistics concepts – specifically the integration of autonomous delivery robots and the existing TramTrain system – can contribute to more sustainable and efficient last-mile delivery solutions in urban environments. While the project succeeded in identifying and testing the promising approach, the process also revealed a number of critical lessons that concern the interplay between technology, regulation, and social acceptance.

Suitability and Limitations of Certain Use Cases

One of the most significant findings concerns the unsuitability of certain use cases for automation, even when the logistical framework initially appears compatible. The analysis of the *Meals on Wheels* Use Case 3 provided a particularly illustrative example. At first glance, this scenario seems ideal for the use of autonomous robots: it involves routine deliveries along largely predictable routes, with similar daily schedules and destinations. However, a closer examination with the service provider (Rotes Kreuz) revealed that this service encompasses much more than the simple distribution of meals. The delivery personnel are not only responsible for delivering food but also for checking the condition of the recipients, ensuring that they are safe, oriented, and in good health. Furthermore, these daily visits represent a vital source of social contact for many elderly or isolated individuals.

Replacing these human interactions with an automated process would therefore mean removing an essential social support function that contributes to the well-being of the service's users. In this respect, the *Meals on Wheels* Use Case illustrates that not all delivery services can be assessed solely from the perspective of technical feasibility or efficiency. Social and emotional dimensions play a key role, and these aspects must be considered when determining whether a use case is appropriate for automation. In short, technological capability does not automatically imply social desirability.

Broader Implications of Technological Use Cases

A second major lesson is that each use case carries implications that extend beyond the intended operational scope. The *Business-to-Customer (B2C)* Use Case 2 clearly demonstrates this. While the technical focus lies on achieving efficient and low-emission last-mile delivery, the implementation of such solutions can also generate secondary benefits in economic and policy domains. By offering environmentally friendly logistics options, local retailers can differentiate themselves from large-scale online platforms. This added value, or unique selling proposition (USP), can strengthen the position of local businesses and make city-centre commerce more attractive.

Such outcomes align closely with the urban policy objectives of the City of Karlsruhe, which seeks to enhance the vitality of local trade while simultaneously reducing transport emissions. Thus, the findings highlight that technological innovation in logistics should not be viewed as an isolated activity. Instead, it should be considered a strategic instrument that can contribute to broader urban development goals, including economic resilience, social inclusion, and sustainability. This recognition underscores the importance of cross-sectoral collaboration between city administrations, transport providers, and local business communities to fully exploit the potential of such innovations.

Technical and Non-Technical Challenges

Another core insight relates to the nature of challenges encountered during the project. It became evident that while technical challenges can be complex, they are generally manageable with sufficient time, resources, and expertise. Engineering solutions for vehicle automation, navigation, data exchange, or communication between robots and tram systems are all achievable within a well-structured research and development framework. However, non-technical challenges, especially those concerning legal, regulatory, and institutional aspects, proved far more difficult to address.

These issues often lie beyond the direct influence of the project partners. For instance, establishing a legal basis for the joint operation of passenger and freight services within the same TramTrain system requires the involvement of external authorities such as the *Technische Aufsichtsbehörde Baden-Württemberg (TAB BW)* and the *Eisenbahn-Bundesamt (EBA)*. The objective is to develop a legally sound framework.

Despite this collaborative approach, it became clear that administrative and legal procedures evolve more slowly than technical development. Regulatory changes often require formal decisions by higher-level institutions or political bodies, which means that project partners can primarily contribute through consultation and advocacy rather than through direct implementation. This experience reinforces the notion that successful innovation in public transport and logistics requires not only technical progress but also political commitment and institutional flexibility.

Integration of Autonomous Robots and the TramTrain System

The combination of autonomous mobile robots and the TramTrain network represents an innovative concept with significant potential for sustainable urban logistics. However, the process of integration revealed that viable solutions must be found on both the technical and organizational levels. On the technical side, challenges include ensuring the safe and efficient transfer of robots between public spaces and tram vehicles, maintaining communication links during transit, and aligning operational schedules between automated delivery and public transport systems.

Yet, the more persistent obstacles were again found in non-technical domains, such as the establishment of safety regulations for mixed passenger–freight tram operations, public acceptance, and liability issues. These findings echo the experiences reported from the Helsinki Living Lab, the twinning partner in this research project. In Helsinki, too, the implementation of automated delivery systems faced significant delays due to regulatory uncertainty and the lack of established procedures for approving novel transport modes. Thus, both Living Labs underline that institutional learning and regulatory adaptation must proceed hand in hand with technological development if such systems are to reach maturity.

Environmental and Economic Performance

The results of the Key Performance Indicators (KPIs) analysis consistently demonstrate that the proposed system offers a low-emission alternative to conventional last-mile logistics. The primary reason for this favourable outcome is the reliance on electric mobility, both for the TramTrain network and the autonomous delivery robots. The Karlsruhe tram system already operates using electricity from renewable energy sources, which substantially reduces greenhouse gas emissions. In contrast, many of today's delivery vehicles still depend on diesel or petrol, meaning that the transition to tram-based logistics can yield substantial environmental benefits.

However, the magnitude of these improvements depends strongly on the energy mix of the existing delivery fleet and the overall system boundaries used in the assessment. In cities where electric delivery vans or bicycles are already widespread, the additional benefits of tram-based logistics may be smaller. Nevertheless, the analysis shows that integrating logistics into existing tram infrastructure can help to maximize resource efficiency, avoid redundant traffic, and reduce urban congestion. From an economic perspective, cost efficiency will depend on factors such as vehicle utilization rates, depot locations, and delivery densities, but the environmental advantages are evident across all modelled scenarios.

Public Perception and Acceptance

Finally, one of the most encouraging findings concerns the public attitude toward innovative transport solutions in Karlsruhe. The surveys conducted among residents revealed a generally positive perception of technologies such as delivery robots and tram-based logistics. This openness can be attributed to several factors. First, the Karlsruhe tram network enjoys a long-standing reputation for reliability, cleanliness, and efficiency, which likely fosters public trust in any extension of its functionality. Second, the citizens of Karlsruhe are known for their progressive outlook and willingness to embrace experimental mobility solutions, as demonstrated in previous projects related to electric mobility and multimodal transport.

Such a supportive social environment is a valuable asset for the future implementation of new mobility concepts. Public acceptance not only facilitates pilot operations but also provides the social legitimacy required for long-term adoption. Nevertheless, maintaining this positive perception will require transparent communication, inclusive stakeholder engagement, and careful management of the visible presence of autonomous systems in public spaces.

Overall Reflections

In conclusion, the lessons learnt from the Karlsruhe Living Lab underscore the importance of adopting a holistic perspective when designing and evaluating innovative logistics systems. Technical innovation must be complemented by institutional adaptation, regulatory evolution, and societal inclusion. The project demonstrated that while autonomous technologies and tram-based logistics can deliver tangible environmental benefits, their real success depends on the integration of social, economic, and political dimensions.

Future work should therefore focus on developing cross-disciplinary frameworks that facilitate collaboration between engineers, city planners, policymakers, and citizens. Only through such comprehensive approaches can the full potential of sustainable urban logistics be realized, transforming not just how goods are moved, but how cities themselves evolve toward cleaner, more equitable, and more efficient mobility systems.

Commented [SR5]: Fix the references

References

Agora Verkehrswende (2017): *Mit der Verkehrswende die Mobilität von morgen sichern. 12 Thesen zur Verkehrswende*.

Alden, K.; Read, M.; Andrews, P. S.; Timmis, J.; Coles, M. (2014): Applying spartan to understand parameter uncertainty in simulations. *The R Journal*, 6(2), S. 63–80. https://doi.org/10.32614/RJ-2014-025.

Projekt „CarGoTram" (o. J.): *Logistikkonzept ID.3*. https://www.glaesernemanufaktur.de/de/news-ergebnisseite/logisitkkonzept-id3.html (accessed on 24.01.2025).

Projekt „LastMileTram RheinMain V" (o. J.): https://innovation.vgf-ffm.de/gueter-tram/ (accessed on 24.01.2025).

Projekt „Lieferverkehr der Zukunft für die Landeshauptstadt Schwerin" (2022): Deutsche Post DHL startet Pakettransport per Straßenbahn in Schwerin. https://group.dhl.com/de/presse/pressemitteilungen/2022/deutsche-post-dhl-startet-pakettransport-per-strassenbahn-in-schwerin.html (accessed on 24.01.2025).

Projekt „LOGISTIKTRAM" (o. J.): https://www.logistiktram.de/ (accessed on 24.01.2025).

Statistikportal (o. J.): *Ergebnisse auf Kreisebene – Einkommen*. https://www.statistikportal.de/de/vgrdl/ergebnisse-kreisebene/einkommen-kreise (accessed on 24.01.2025).

Stadt Karlsruhe (o. J.): *Transparenzportal der Stadt Karlsruhe*. https://transparenz.karlsruhe.de/ (accessed on 24.01.2025).

Stadt Karlsruhe, Amt für Stadtentwicklung – Statistikstelle (2024): *Statistisches Jahrbuch 2024*. https://web6.karlsruhe.de/Stadtentwicklung/statistik/pdf/2024/2024-jahrbuch.pdf (accessed on 24.01.2025).

Stadt Karlsruhe, Amt für Stadtentwicklung – Statistikstelle (2024): *Daten und Fakten 2024/2025*. https://web6.karlsruhe.de/Stadtentwicklung/statistik/pdf/2024/2024-25-daten-und-fakten.pdf (accessed on 24.01.2025).

Stadt Karlsruhe, Amt für Stadtentwicklung – Statistikstelle (2024): *Current statistics – Population*. https://web6.karlsruhe.de/Stadtentwicklung/statistik/pdf/2024/2024-06-bevoelkerung.pdf (accessed on 24.01.2025).

Vargha, A.; Delaney, H. D. (2000): A critique and improvement of the CL common language effect size statistic of McGraw and Wong. *Journal of Educational and Behavioral Statistics*, 25, S. 101–132. https://doi.org/10.3102/10769986025002101


FRAGIL
FRAGIL

Annex I > Use Case 2

KPIs for Use Case 2

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	**Average**
Length km/trip	2,0	3,0	1,7	1,2	5,2	1,5	1,8	**2,3**
Duration [h:m:s]	0:35:34	00:41:15	00:47:31	00:27:57	00:41:52	00:32:33	00:37:58	**0:37:49**
Deliveries/trip	1	1	1	1	1	1	1	**1**
CO2 per parcel	0	0	0	0	0	0	0	**0**
Fuel per parcel	0	0	0	0	0	0	0	**0**

Run 1

Time		Event	Duration	
14:45:13	ECE-Center	Delivery Order received	10:00	Assumption: 10 min from Order to loading
14:55:13	ECE-Center	in ECE-Center	3:00	Loading
14:58:13		Start of ride to tram stop	2:52	Distance (143m) covered at 3 km/h
15:01:05	Arriving at tram stop	Waiting on tram line 4	3:55	Assumption: Tram arrives as scheduled
15:05:00		Tram arrives		
15:05:22		Getting in .	0:22	
		Drive to destination tram stop	10:00	Duration of Tram ride from schedule
15:15:21	Arriving at tram stop	Getting out	0:18	
15:15:40	Tram stop Sophienstr.	Ride Tram to "Sophienstr."		
15:17:43	Arriving at destination	Drive to Schillerstr. 50	2:02	Distance (135m) covered with 4 km/h
15:20:43	Receiver opens Compartment		3:00	Assumption: he needs 3 min from arrival
15:20:47	Receiver closes the compartment		0:05	Assumption: he needs 5sec to deload

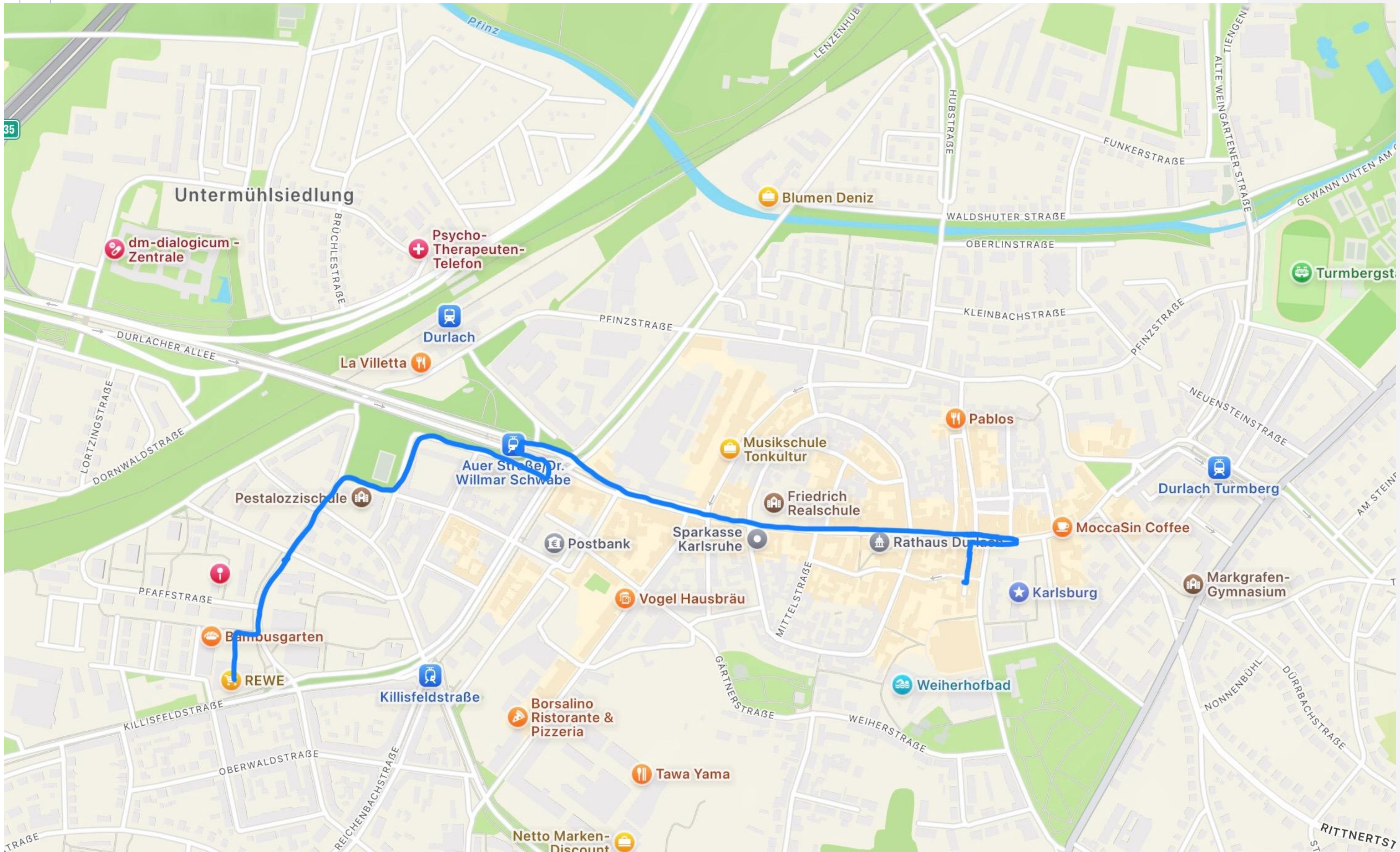
Run 2

Time		Event	Duration	
11:52:30		Delivery Order recieved	10min	Assumption: 10 min from Order to loading
12:02:30	IKEA	im IKEA	4min	Loading
12:06:30		Start of ride to tram stop	90s	~70m with 3km/h
12:08:00	Arriving at tram stop "Weinweg"	Waiting on Tram line 1	3min	Assumption: Tram arrives as scheduled
12:11:00		Tram arrives		
12:11:22		Getting in	22sec	
		Drive to tram stop "Durlach Auer Str./Dr. Wilmar Schwabe"	3min	Duration of Tram ride from schedule
12:14:22	Arriving at tram stop	Getting out	18sec	
12:14:40	Tram stop "Durlach Auer Str. ..."	Outside of Tram		
12:30:40	Arriving at destination	Drive to Pfaffstraße 10	16min	~800m with 3km/h
12:33:40	Receiver opens Compartment		3min	Assumption: he needs 3 min from arrival
12:33:45	Receiver closes the compartment		5sec	Assumption: he needs 5sec to deload


stadt by IHG
OSTRING
Autohaus Werner Beier
Lidl
dm
Bauhaus
Alnatura
ELFMORGENBRUCHSTRAßE
E35
10
EnBW - Zentrale
Audi Zentrum Karlsruhe GmbH
Pfinz
IKEA
XXXLutz
Kaufland
Durlach Center
TotalEnergies
McDonald's
DURLACHER ALLEE
Untermühlsiedlung
dm-dialogicum - Zentrale
Psycho-Therapeuten-Telefon
Durlach
PFINZSTRAßE
DURLACHER ALLEE
Willmar Schwabe
Dornwaldsiedlung
DORNWALDSTRAßE
PFINZTALSTRAßE
Postbank
E35
Vogel Hausbr
Bambusgarten
REWE
Emil Frey Ungeheuer

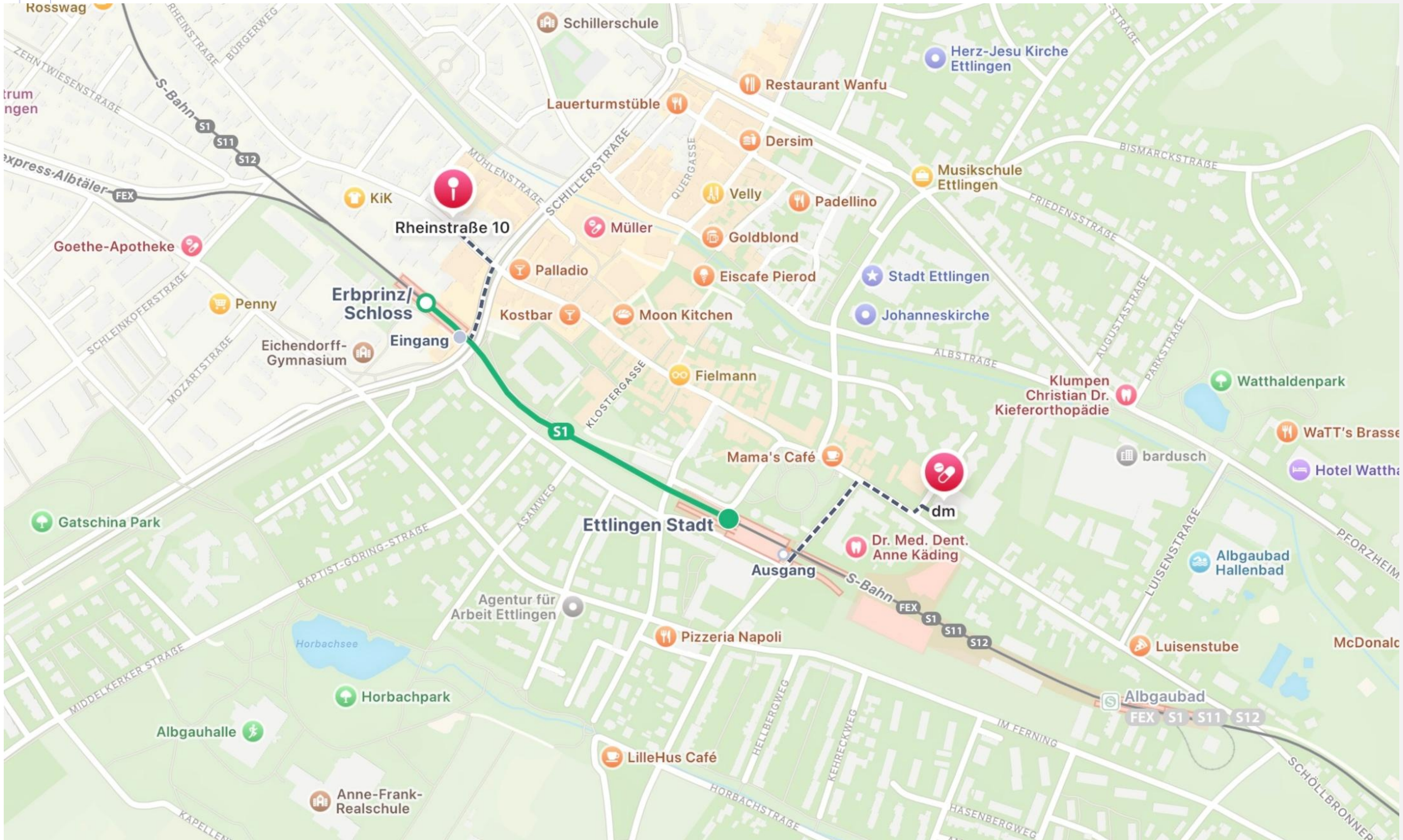
Run 3

Time		Event	Duration	
17:26:14		Delivery Order recieved	10min	Assumption: 10 min from Order to loading
17:36:14	REWE (Raiherwiesenstr.)	im Rewe	3min	Loading
17:39:14		Start of ride to tram stop	18min	~900m with 3km/h
17:57:14	Arriving at tram stop "Durlach Auer Str. ..."	Waiting on Tram line 1	6min 46sec	Assumption: Tram arrives as scheduled
18:04:00		Tram arrives		
18:04:22		Getting in	22sec	
		Drive to tram stop "Durlach Schlossplatz"	3min	Duration of Tram ride from schedule
18:07:22	Arriving at tram stop	Getting out	18sec	
18:07:40	Tram stop Schlossplatz	Outside of tram		
18:10:40	Arriving at destination	Drive to Rebenstr. 6	3min	~150m with 3km/h
18:13:40	Receiver opens Compartment		3min	Assumption: he needs 3 min from arrival
18:13:45	Receiver closes the compartment		5sec	Assumption: he needs 5sec to deload


Untermühlsiedlung
dm-dialogicum - Zentrale
Psycho-Therapeuten-Telefon
Blumen Deniz
Durlach
La Villetta
Pfinz
Pfinzstraße
Durlacher Allee
Brüchlestraße
Lenzenhub
Hubstraße
Funkerstraße
Waldshuter Straße
Oberlinstraße
Kleinbachstraße
Alte Weingartener Straße
Gewann Unten am
Turmbergst
Pablos
Neuensteinstraße
Musikschule Tonkultur
Friedrich Realschule
Auer Straße/Dr. Willmar Schwabe
Durlach Turmberg
Pestalozzischule
Postbank
Sparkasse Karlsruhe
Rathaus Durlach
MoccaSin Coffee
Markgrafen-Gymnasium
Karlsburg
Mittelstraße
Vogel Hausbräu
Pfaffstraße
Bambusgarten
REWE
Killisfeldstraße
Oberwaldstraße
Reichenbachstraße
Borsalino Ristorante & Pizzeria
Tawa Yama
Netto Marken-Discount
Gärtnerstraße
Weiherhofbad
Weiherstraße
Nonnenbühl
Dürrbachstraße
Rittnertst
Lortzingstraße
Dornwaldstraße
Pfinzstraße

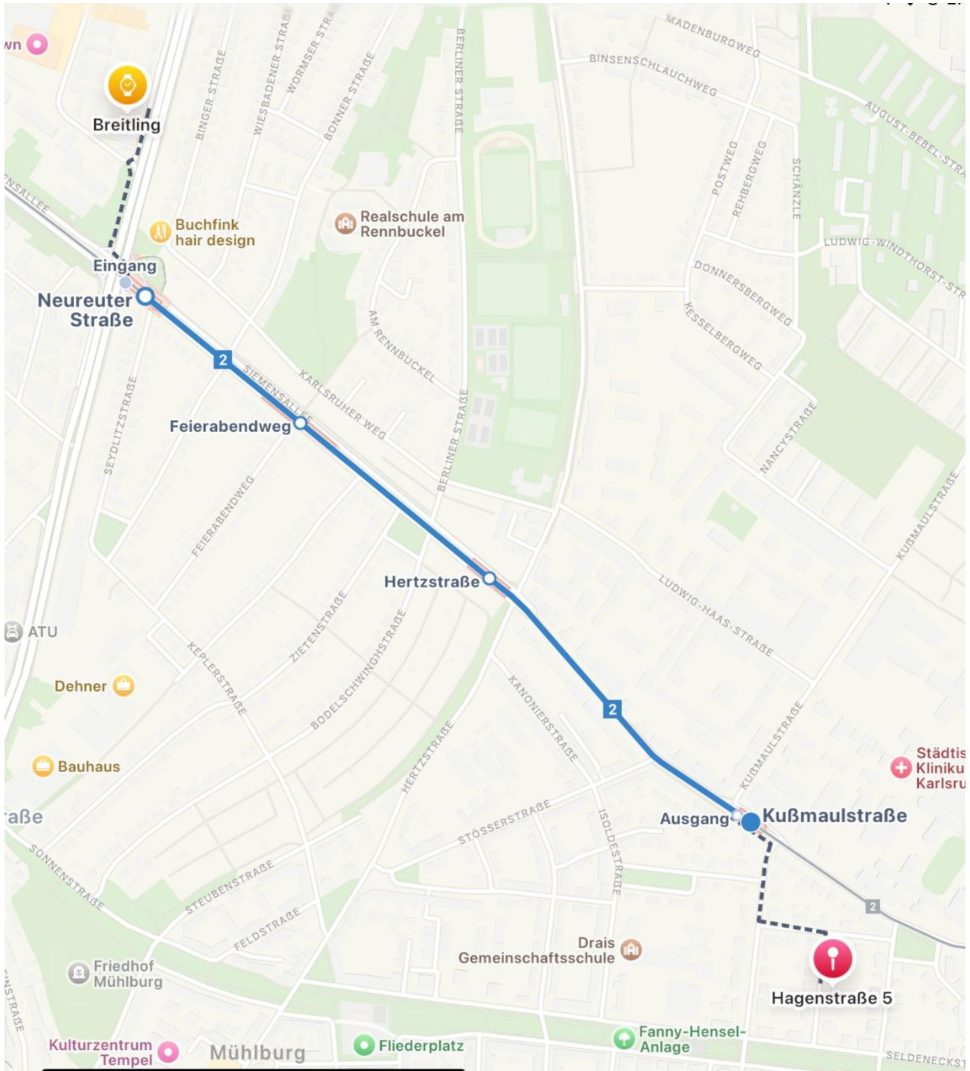
Run 4

Time		Event	Duration	
13:07:48		Delivery Order recieved	10min	Assumption: 10 min from Order to loading
13:17:48	Dm "Schöllbronner Str."	Im DM	3min	Loading
13:20:48		Start of ride to tram stop	6min	~300m with 3km/h
13:26:48	Arriving at tram stop "Ettlingen Stadt"	Waiting on Tram line S1	1min 12sec	Assumption: Tram arrives as scheduled
13:28:00		Tram arrives		
13:28:22		Getting in	22sec	
		Drive to tram stop "Erbprinz/Schloss"	1min	Duration of Tram ride from schedule
13:29:22	Arriving at tram stop	Getting out	18sec	
13:29:40	Tram stop "Erbprinz/Schloss"	Outside of tram		
13:32:40	Arriving at destination	Drive to Rheinstr. 10	3min	~200m with 4km/h
13:35:40	Receiver opens Compartment		3min	Assumption: he needs 3 min from arrival
13:35:45	Receiver closes the compartment		5sec	Assumption: he needs 5sec to deload


Rosswag
Schillerschule
Herz-Jesu Kirche Ettlingen
Restaurant Wanfu
Lauerturmstüble
Dersim
Musikschule Ettlingen
S-Bahn
S1
S11
S12
Express-Albtäler
FEX
KiK
Rheinstraße 10
Velly
Padellino
Müller
Goldblond
Goethe-Apotheke
Palladio
Eiscafe Pierod
Stadt Ettlingen
Erbprinz/ Schloss
Penny
Kostbar
Moon Kitchen
Johanneskirche
Eingang
Eichendorff-Gymnasium
Fielmann
Klumpen Christian Dr. Kieferorthopädie
Watthaldenpark
WaTT's Brasse
barduscH
Mama's Café
Hotel Wattha
dm
Gatschina Park
Ettlingen Stadt
Dr. Med. Dent. Anne Käding
Ausgang
Albgaubad Hallenbad
Agentur für Arbeit Ettlingen
Pizzeria Napoli
Horbachsee
Luisenstube
McDonald
Albgaubad
Horbachpark
Albgauhalle
LilleHus Café
Anne-Frank-Realschule
Zehntwiesenstraße
Rheinstraße
Bürgerweg
Mühlenstraße
Schillerstraße
Quergasse
Bismarckstraße
Friedensstraße
Schleinkoferstraße
Mozartstraße
Klostergasse
Albstraße
Augustastraße
Parkstraße
Luisenstraße
Pforzheimer
Baptist-Göring-Straße
Middelkerker Straße
Hellbergweg
Kehreckweg
Im Ferning
Horbachstraße
Hasenbergweg
Schöllbronner
Kapellen

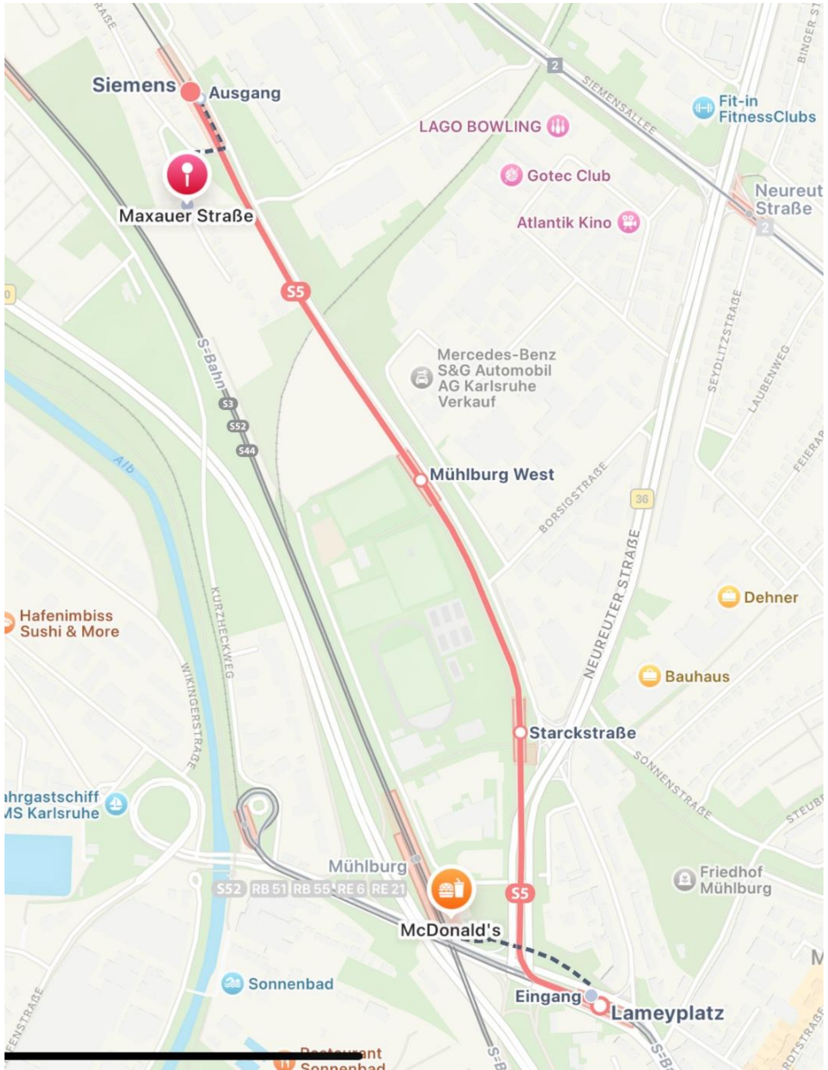
Run 5

Time		Event	Duration	
09:23:08		Delivery Order recieved	10min	Assumption: 10 min from Order to loading
09:33:08	Breitling Karlsruhe	In Breitling Store	1min 30sec	Loading
09:34:38		Start of ride to tram stop Neureuter Str.	6min	~300m with 3km/h
09:49:38	Arriving at tram stop	Waiting on Tram line 2	2min 22sec	Assumption: Tram arrives as scheduled
09:52:00		Tram arrives		
09:52:22		Getting in	22sec	
		Drive to tram stop "Kußmaulstr."	4min	Duration of Tram ride from schedule
09:56:22	Arriving at tram stop	Getting out	18sec	
09:56:40	Tram stop "Kußmaulstr."	Outside of tram		
10:01:55	Arriving at destination	Drive to Hagenstr.5	5min 15sec	~350m with 4km/h
10:04:55	Receiver opens Compartment		3min	Assumption: he needs 3 min from arrival
10:05:00	Receiver closes the compartment		5sec	Assumption: he needs 5sec to deload


Breitling
Buchfink hair design
Realschule am Rennbuckel
Eingang
Neureuter Straße
Feierabendweg
Hertzstraße
ATU
Dehner
Bauhaus
Ausgang
Kußmaulstraße
Hagenstraße 5
Drais Gemeinschaftsschule
Friedhof Mühlburg
Kulturzentrum Tempel
Mühlburg
Fliederplatz
Fanny-Hensel-Anlage
Binger Straße
Wiesbadener Straße
Wormser Straße
Bonner Straße
Berliner Straße
Madenburgweg
Binsenschlauchweg
Postweg
Rehbergweg
Schänzle
August-Bebel-Str
Ludwig-Windthorst-Str
Donnersbergweg
Kesselbergweg
Am Rennbuckel
Karlsruher Weg
Siemensallee
Seydlitzstraße
Feierabendweg
Nancystraße
Kußmaulstraße
Ludwig-Haas-Straße
Keplerstraße
Zietenstraße
Bodelschwinghstraße
Kanonierstraße
Hertzstraße
Stösserstraße
Isoldestraße
Sonnenstraße
Steubenstraße
Feldstraße
Seldenecks

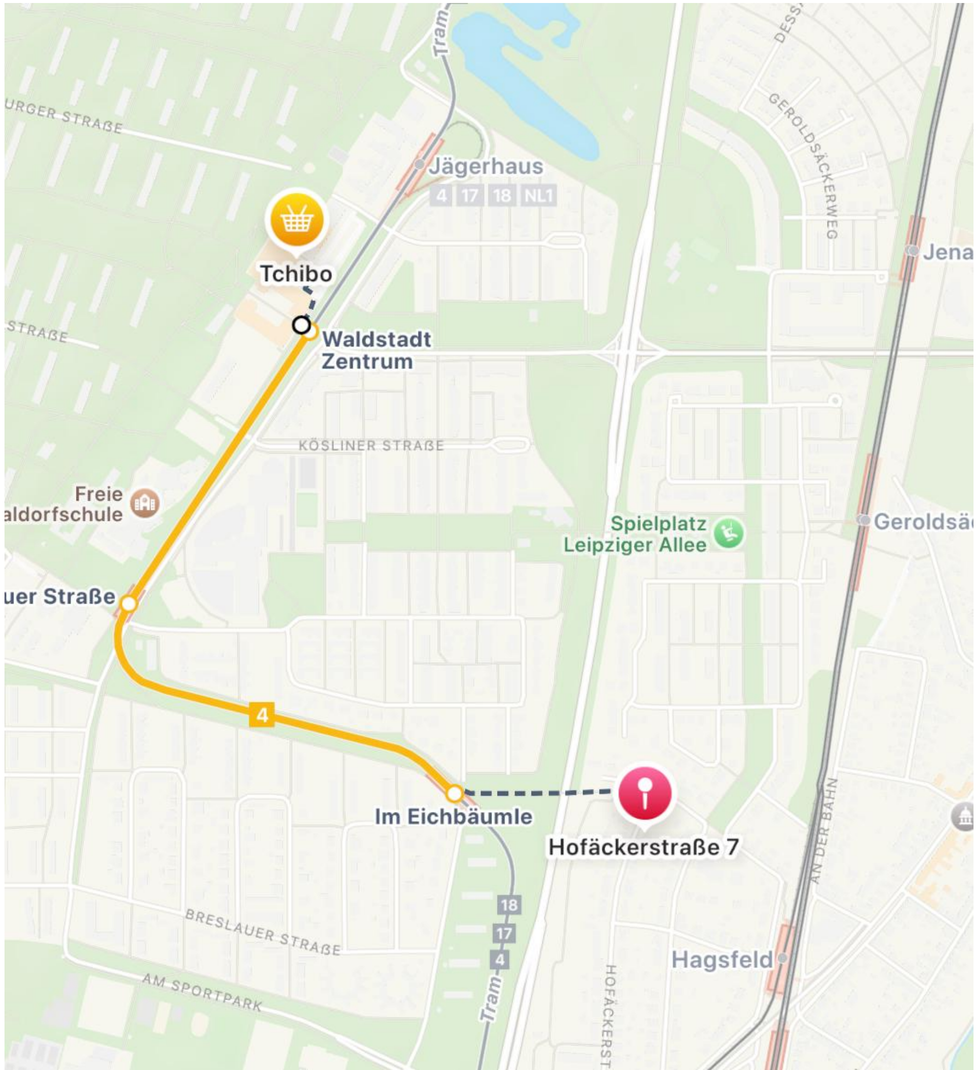
Run 6

Time		Event	Duration	
19:46:00		Delivery Order recieved	10min	Assumption: 10 min from Order to loading
19:56:00	McDonalds Mühlburg	In McDonalds	2min	Loading
19:58:00		Start of ride to tram stop Lameyplatz	5min	~250m with 3km/h
20:03:00	Arriving at tram stop	Waiting on Tram line S5	5min	Assumption: Tram arrives as scheduled
20:08:00		Tram arrives		
20:08:22		Getting in	20sec	
		Drive to tram stop "Siemens"	3min	Duration of Tram ride from schedule
20:11:22	Arriving at tram stop	Getting out	18sec	
20:11:40	Tram stop "Siemens"	Outside of tram		
20:15:28	Arriving at destination	Drive to Maxauer Str. 11	4min 48sec	~300m with 4km/h
20:18:28	Receiver opens Compartment		3min	Assumption: he needs 3 min from arrival
20:18:33	Receiver closes the compartment		5sec	Assumption: he needs 5sec to deload


Siemens
Ausgang
Maxauer Straße
LAGO BOWLING
Gotec Club
Atlantik Kino
Fit-in FitnessClubs
Neureut Straße
S5
Mercedes-Benz S&G Automobil AG Karlsruhe Verkauf
Mühlburg West
S-Bahn
Dehner
Bauhaus
Hafenimbiss Sushi & More
Starckstraße
ahrgastschiff MS Karlsruhe
Friedhof Mühlburg
Mühlburg
McDonald's
Sonnenbad
Eingang
Lameyplatz
NEUREUTER STRASSE
SONNENSTRASSE
SEYDLITZSTRASSE
BORSIGSTRASSE
WIKINGERSTRASSE
KURZHECKWEG
SIEMENSALLEE
Alb

Run 7

Time		Event	Duration	
20:08:00		Delivery Order recieved	10min	Assumption: 10 min from Order to loading
20:18:00	Tchibo Waldstadt	In Tchibo	2min	Loading
20:20:00		Start of ride to tram stop Waldstadt Zentrum	1min 48sec	~90m with 3km/h
20:21:48	Arriving at tram stop	Waiting on Tram line 4	13min 12sec	Assumption: Tram arrives as scheduled
20:35:00		Tram arrives		
20:35:20		Getting in	20sec	
		Drive to tram stop "im Eichbäumle"	2min	Duration of Tram ride from schedule
20:37:20	Arriving at tram stop	Getting out	18sec	
20:37:38	Tram stop "im Eichbäumle"	Outside of tram		
20:42:53	Arriving at destination	Drive to Hofäckerstraße 7	5min 15sec	~350m with 4km/h
20:45:53	Receiver opens Compartment		3min	Assumption: he needs 3 min from arrival
20:45:58	Receiver closes the compartment		5sec	Assumption: he needs 5sec to deload


Tram
URGER STRAßE
Jägerhaus
4 17 18 NL1
Tchibo
Waldstadt
Zentrum
STRAßE
KÖSLINER STRAßE
Freie
aldorfschule
uer Straße
4
Im Eichbäumle
Hofäckerstraße 7
Spielplatz
Leipziger Allee
GEROLDSÄCKERWEG
Jena
Geroldsä
AN DER BAHN
Hagsfeld
18
17
4
Tram
BRESLAUER STRAßE
AM SPORTPARK
HOFÄCKERST

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101069782

URBANE

CIVITAS
Sustainable and smart mobility for all

Annex II > Questionnaire

URBANE Befragung

Ihre Meinung ist gefragt!

Im EU-Projekt URBANE erforschen wir in Karlsruhe, wie Pakete umweltfreundlich mit der Straßenbahn und von einem autonomen Roboter zugestellt werden können. Nun möchten wir Ihre Meinung dazu erfahren!

Wie stehen Sie zu dieser innovativen Art der Paketzustellung? Nehmen Sie sich kurz Zeit für unsere Umfrage – Ihre Einschätzung ist uns wichtig!

Inwieweit halten Sie traditionelle Hauszustellungen für positiv oder negativ im Hinblick auf (1 = sehr negativ, 5 = neutral, 10 = sehr positiv) (ein Kreuz pro Zeile setzen)

	1	2	3	4	5	6	7	8	9	10
Empfang eines Pakets an einem günstigen Ort.										
Empfang eines Pakets zu einem günstigen Zeitpunkt.										
Geringe Umweltbelastung.										
Gute Arbeitsbedingungen für den Kurier.										
Niedrige Lieferkosten.										
Vertraulichkeit der Paketdaten (Sendungsarten oder Absender werden nicht preisgegeben).										

Inwieweit halten Sie die Zustellung an den Sammelstellen für positiv oder negativ in Bezug auf (1 = sehr negativ, 5 = neutral, 10 = sehr positiv) (ein Kreuz pro Zeile setzen)

	1	2	3	4	5	6	7	8	9	10
Empfang eines Pakets an einem günstigen Ort.										

Empfang eines Pakets zu einem günstigen Zeitpunkt.	
Geringe Umweltbelastung.	
Gute Arbeitsbedingungen für den Kurier.	
Niedrige Lieferkosten.	
Vertraulichkeit der Paketdaten (Sendungsarten oder Absender werden nicht preisgegeben).	

Inwieweit halten Sie die Zustellung mit einem <u>autonomen Fahrzeug</u> für positiv oder negativ in Bezug auf (1 = sehr negativ, 5 = neutral, 10 = sehr positiv) (ein Kreuz pro Zeile setzen)

	1	2	3	4	5	6	7	8	9	10
Empfang eines Pakets an einem günstigen Ort.										
Empfang eines Pakets zu einem günstigen Zeitpunkt.										
Geringe Umweltbelastung.										
Gute Arbeitsbedingungen für den Kurier.										
Niedrige Lieferkosten.										
Vertraulichkeit der Paketdaten (Sendungsarten oder Absender werden nicht preisgegeben).										

Inwieweit stimmen Sie den folgenden Aussagen zu? (ein Kreuz pro Spalte setzen)

	Ich stimme voll und ganz zu	Ich stimme eher zu	Ich stimme weder zu noch lehne ich ab	Ich stimme nicht zu	Ich stimme überhaupt nicht zu
Ich würde den Lieferroboter nutzen, wenn es in meiner					

Gegend eine Liefermöglichkeit gäbe.

Ich fühle mich sicher, wenn ein autonomer Roboter in meiner Nachbarschaft unterwegs ist.

Ich mag die Flexibilität des Zeitplans (ich kann eine geeignete Abholzeit wählen).

Erreichbarkeit des Dienstes (die Lieferstellen befinden sich in der Nähe meines Wohnorts).

Ich teste gerne neue Dienstleistungsoptionen.

Was sind Ihrer Meinung nach die wichtigsten potenziellen Vorteile von autonomen Roboterlieferungen in Städten? (mehrere Antworten möglich)

- Schnellere und pünktlichere Lieferung
- Flexibilität bei Zeit und Ort der Abholung
- Nachhaltigere Lieferungen
- Günstigere Lieferungen
- Reduziert die Anzahl der Lieferfahrzeuge in meinem Gebiet
- Andere (bitte angeben):

Was sind, Ihrer Meinung nach, die möglichen Bedenken in Bezug auf autonome Roboterlieferungen in Städten? (mehrere Antworten Möglich)

- Der Roboter nimmt zu viel Platz auf der Straße ein.
- Sicherheitsprobleme, wie Fehlfunktionen des Roboters oder Kontrollverlust.
- Negative Auswirkungen auf Lieferaufträge.
- Verlust von Paketen aufgrund einer Fehlfunktion des Roboters.
- Sicherheitsrisiko für die Pakete.
- Andere (bitte angeben):

Ich fände es gut, wenn es in meiner Stadt mehr Lieferroboter geben würde.

- Ja
- Keine Meinung
- Nein

Ich würde den Lieferroboter nutzen, wenn es in meiner Gegend eine Liefermöglichkeit gäbe.

- Ja
- Keine Meinung
- Nein

Ich fühle mich sicher, wenn ein autonomer Roboter in meiner Nachbarschaft unterwegs ist.

- Ja
- Keine Meinung
- Nein

Als Fußgänger würde ich mich sicher fühlen, wenn sich Lieferroboter auf den Fußgängerwegen bewegen.

- Ja
- Keine Meinung
- Nein

Welche Faktoren würden Sie davon überzeugen, sich für die Roboterlieferung zu entscheiden? (mehrere Antworten möglich)

- Erreichbarkeit des Dienstes (die Lieferstellen sind in der Nähe meines Wohnorts).
- Flexibilität des Zeitplans (ich kann eine geeignete Abholzeit wählen).
- Ich teste gerne neue Dienstleistungsoptionen.
- Der Lieferservice ist emissionsfrei.
- Soziale Distanzierung während der Pandemie.
- Andere (bitte angeben):

Warum sollten Sie sich nicht für die Roboterlieferung entscheiden? (mehrere Antworten möglich)

- Ich habe kein Vertrauen in die Zustellung meines Pakets.
- Ich fühle mich nicht sicher im Umgang mit dem Roboter.
- Ich möchte mein Paket an einem herkömmlichen Paketkasten oder einer anderen Abholstelle abholen.

- Ich halte die derzeitigen Lieferoptionen für ausreichend.
- Andere (bitte angeben):

Welche der folgenden Zustellungsmethoden würden Sie bevorzugen? Sie können mehrere Optionen auswählen. (mehrere Antworten möglich)

- Der Lieferroboter bringt die Lieferung zu einem öffentlichen Platz in der Nähe meines Hauses.
- Der Lieferroboter bringt die Lieferung an meine Haustür oder einen anderen privaten Bereich in der Nähe meiner Wohnung.
- Ich möchte nicht, dass Pakete in meinem Gebiet von Lieferrobotern zugestellt werden.
- Andere (bitte angeben):

Wählen Sie die am besten geeignete Option. (bitte nur eine Antwort ankreuzen)

- Es ist mir wichtig, dass das Paket bis an meine Haustür geliefert wird.
- Es ist mir wichtig, dass ich den Zeitplan für die Lieferung selbst bestimmen kann.
- Der Zustellroboter bietet zusätzliche barrierefreie Abholmöglichkeiten für Menschen mit Behinderungen.
- Der Lieferroboter ist eine nachhaltige Ergänzung für die Zustellung auf der letzten Meile.
- In meiner Nähe gibt es genügend Abholstellen für Pakete.
- Der Roboter würde die Abholung von Paketen in meinem Gebiet vereinfachen.

Welche Technologien zur Interaktion mit Lieferrobotern können Sie sich vorstellen? (Mensch zum Roboter) (Mehrere Antworten möglich)

- Webseite
- Smartphone Applikation
- eigenes Display am Lastenradanhänger und Lieferroboter
- Andere (bitte angeben):

Welche Informationen würden Sie am Lieferroboter dargestellt erwarten? (mehrere Antworten möglich)

- Projektinformation
- CO_2 Reduktion

- Akkuzustand
- Anzahl ausgelieferter Pakete
- Anzahl im Lastenradanhänger und Lieferroboter enthaltende Pakete
- Fahrziel des Lastenradanhängers und Lieferroboters
- Datum / Temperatur
- Andere (bitte angeben):

Welche Technologien würden Sie zur Kommunikation des Status vom Lieferroboter erwarten? (Roboter zum Menschen) (mehrere Antworten möglich)

- Licht
- Sound
- Text
- Haptik
- Andere (bitte angeben):

Welche Technologien würden Sie zur Kommunikation während der autonomen Fahrt des Lieferroboters erwarten? (Roboter zum Menschen) (mehrere Antworten möglich)

- Licht
- Sound
- Text
- Haptik
- Andere (bitte angeben):

Bitte ordnen Sie die folgenden Möglichkeiten nach der erwarteten Häufigkeit der Nutzung, wobei 1 für die wichtigste und 4 für die am wenigsten wichtige Option steht:

- Entnahme von Paketen in der Bahn (während der Bahnfahrt)
- Entnahme von Paketen an der Haltestelle
- Entnahme von Paketen an der Haustür
- Entnahme von Paketen an einer Pop-Up Packstation

Was sind Ihre größten Sorgen und Bedenken im Zusammenhang mit der Einführung von Lieferrobotern?

- Fehlfunktion des Lieferroboters
- Unfälle mit der Straßenbahn/Zug

- Unfälle mit anderen Fahrzeugen
- Unfälle mit Fahrgästen
- Lieferroboter könnte in das Gleisbett fallen
- Erhebung, Nutzung und Schutz von Daten
- Verschulden und Haftung bei Schäden an Lieferrobotern
- Andere (bitte angeben):

Soziodemografische Variablen

Geschlecht

- Männlich
- Weiblich
- Divers
- Ohne Angabe

Geburtsjahr:

Bildungsniveau (höchster erfolgreich abgeschlossener Bildungsgrad):

- Grundschulbildung
- Sekundarschulbildung
- Technische Ausbildung
- Bachelor-Abschluss oder gleichwertiges Niveau
- Master-Abschluss oder gleichwertiges Niveau
- Doktorat oder gleichwertiger Grad

Gesamtzahl der Mitglieder des Haushalts (Haushaltsgröße):

Haupterwerbsstatus/Beschäftigungssituation:

- Angestellt
- Selbstständig
- Im Ruhestand
- Arbeitsunfähig
- Student
- Erledigung häuslicher Aufgaben
- Andere (bitte angeben):

Wie oft nutzen Sie die Straßenbahn?

- Einmal am Tag
- Mehrmals täglich
- Einmal in der Woche
- Einmal im Monat
- Nie
- Andere (bitte angeben):

Welche der folgenden Angaben beschreibt am besten Ihren typischen Zeitplan, wenn Sie aufgrund von Arbeit oder anderen Verpflichtungen nicht zu Hause sind?

- Meistens zu Hause (ich arbeite von zu Hause aus oder habe keine regelmäßigen außerhäuslichen Verpflichtungen)
- Außer Haus, unregelmäßige Arbeitszeiten (mein Zeitplan variiert von Tag zu Tag)
- Außerhalb der Wohnung, tagsüber (z. B. 9 bis 17 Uhr)
- Außerhalb des Hauses, regelmäßige Abend-/Nachtstunden (z. B. 17 Uhr bis Mitternacht oder Nachtschichten)
- Außer Haus, Teilzeitarbeit (ich bin regelmäßig einen Teil des Tages außer Haus)

Welche der Beschreibungen trifft am ehesten auf Ihre derzeitige Wohnsituation zu?

- Ich wohne in einer Wohnung oder ähnliches
- Ich wohne in einer Doppelhaushälfte oder einem Reihenhaus
- Ich wohne in einem Einzelhaus
- Andere (bitte angeben):

Welche der folgenden Beschreibungen trifft am ehesten zu, wie Sie das Einkommen Ihres Haushalts heute einschätzen?

- Ich lebe bequem mit meinem derzeitigen Einkommen.
- Ich komme mit meinem derzeitigen Einkommen aus.
- Ich komme schwierig mit meinem derzeitigen Einkommen aus.
- Ich komme sehr schwierig mit meinem derzeitigen Einkommen aus.
- Ich möchte nicht antworten.

Postleitzahl:

Annex III > Input Data Preparation for MASS-GT for Karlsruhe LL

The regression analysis conducted in this study aims to explore the relationship between parcel demand and two independent variables: people (population) and income (income). The overview of the script used and included in the Parcel Demand module of MASS-GT is shown below:

```
# --- Read input data ---
segs  = pd.read_csv(segs_path)
zones = gpd.read_file(zones_path)

# --- Build regression inputs from SEGS ---
# Independent variables
X = pd.DataFrame({
    "people": segs["POP01"],
    "income": segs["income"],
})

# Dependent variable (target)
y = segs["sample_dem"]

# Add constant
X_const = sm.add_constant(X)

# --- Fit OLS model ---
model = sm.OLS(y, X_const).fit()
print(model.summary())

# --- Predict parcels for SEGS and store in segs ---
segs["parcels_pred"] = np.round(model.predict(X_const)).astype(int)
```

Using an Ordinary Least Squares (OLS) regression model, we found that the coefficients for the predictors "people" and "income" are 0.5799 and 4.421e-05, respectively. The predictor "people" is statistically significant (p-value < 0.001), indicating that as the number of people increases, the dependent variable also increases. In contrast, the income indicator is not statistically significant (p-value = 0.741), providing no strong evidence that income affects the dependent variable. Nevertheless, given the theoretical relevance of income and the small magnitude of its coefficient, we retained the income term in the final model.

```
                            OLS Regression Results
==============================================================================
Dep. Variable:             sample_dem   R-squared:                       1.000
Model:                            OLS   Adj. R-squared:                  1.000
Method:                 Least Squares   F-statistic:                 1.782e+09
Date:                Tue, 25 Nov 2025   Prob (F-statistic):           3.36e-31
Time:                        12:16:34   Log-Likelihood:                 2.0795
No. Observations:                  10   AIC:                             1.841
Df Residuals:                       7   BIC:                             2.749
Df Model:                           2
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const       5.627e-13      0.166   3.39e-12      1.000      -0.393       0.393
people         0.5799   1.57e-05    3.7e+04      0.000       0.580       0.580
income      4.421e-05      0.000      0.344      0.741      -0.000       0.000
==============================================================================
Omnibus:                        0.200   Durbin-Watson:                   1.229
Prob(Omnibus):                  0.905   Jarque-Bera (JB):                0.374
Skew:                          -0.169   Prob(JB):                        0.829
Kurtosis:                       2.115   Cond. No.                     3.21e+04
==============================================================================
```

Annex IV > Consistency analysis

The Vargha-Delaney A-test was applied to determine the number of replications needed to minimize uncertainty arising from the stochastic nature of the model and to identify the minimal sample size required for result convergence. This non-parametric test quantifies the effect size between two distributions with a statistic ranging from 0 to 1. A value of 0.5 indicates similar medians, reflecting consistent outcomes across replications. Values near 0.44 or 0.56 correspond to small differences, around 0.36 or 0.64 indicate moderate differences, and below 0.29 or above 0.71 signify large differences.

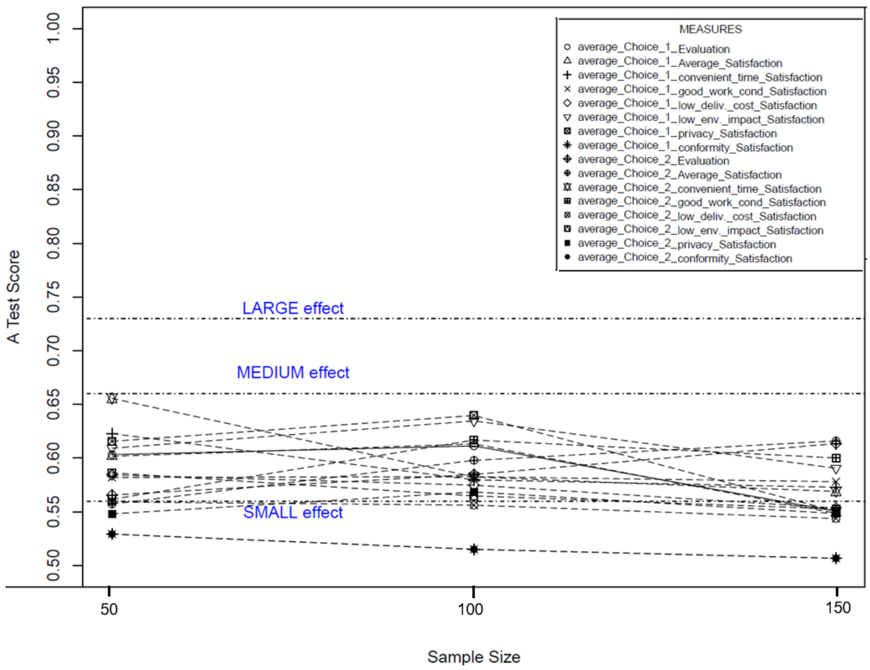


FIGURE 5 MAXIMUM A – TEST SCORES FOR EACH SAMPLE SIZE

For this study, the model output analyzed was the satisfaction with choosing ADR (choice 2) or collection point (choice 1). Replication counts of 50, 100, 150 were evaluated, with twenty sets of each used as input for the Vargha-Delaney A-test. The results indicated a small effect size at approximately 150 replications (values around 0.56[26]), suggesting that the observed outcomes are primarily due to the model dynamics rather than stochastic variability (Figure 5).

[26] Vargha A, Delaney HD. A critique and improvement of the CL common language effect size statistic of McGraw and Wong. Journal of Educational and Behavioral Statistics. 2000;25:101–132. doi:10.3102/10769986025002101.

Annex V > Deliverable Scoring Sheet

[Guidance: This is to be filled by the peer reviewers, and the authors after addressing reviewer comments. Please do not change anything in this section, apart from the Annex number. This should be the last Annex of every deliverable.]

URBANE Deliverable Scoring Sheet

Deliverable No:	DX4.2
Deliverable Title:	Karlsruhe Demonstrator
Lead Beneficiary	AENET
Reviewer Name	Satu Reijonen (FVHI)
Review Date	[15/12/2025]

Grading Scheme: Please paint the 'Score' box with the appropriate colour.

Green	Good quality. Perhaps some minor comments.
Yellow	Reasonable quality, but some revision is necessary.
Red	Substantial revision and / or additional work is necessary.

Please note that a red score in the 'Overall' section in the end means the deliverable must undergo peer review again to approve the revised version.

Criterion	Description	Grade	Reviewer Comments	Author Response
Language	The deliverable is easy to understand, with good use of English, and suitable terminology.	Green	The language is generally professional, clear, and uses appropriate terminology for the domain (logistics, public transport, robotics). The report is easy to follow.	
Visuals	Fonts, figures, tables etc. are easy to read and referenced in the text.	Yellow	While many diagrams are clear, some BPMN diagrams (e.g., Figure 41 on page 87) appear quite small or complex and may be difficult to read without zooming in. Ensure high-resolution versions are used in the final PDF. Tables are generally legible.	Comments are addressed by adding explanatory text before the figure.

Glossary	The glossary of the deliverable is complete (acronyms, unusual terms).		The glossary (p. 13-14) covers many acronyms (AMR, BOStrab, EBO, etc.). However, check if "LSP" (Logistics Service Provider) and "LMD" (Last Mile Delivery) are consistently defined upon first use or added to the glossary for completeness, as they appear frequently in later chapters.	Glossary is improved and extended
Clarity	Vision, contributions & state of the art improvements are discussed explicitly and are clear.		The vision (combining trams and robots) is explicitly stated. Contributions are clear, particularly regarding regulatory hurdles and public acceptance. State-of-the-art improvements are implied through the comparison with existing non-automated freight tram projects.	
Symbols	Mathematical symbols and nomenclature are well-defined and understood.		Mathematical symbols (e.g., in the robot dimension calculations on p. 42) are standard and well-defined.	
Template Application	The template is successfully applied.		The deliverable appears to be using the project template consistently.	
References	The deliverable uses a consistent style to cite all external work referenced in the document.		The references section (p. 128) seems sparse and formatting could be more consistent (some are just URLs). Check: Ensure all external sources cited in the text are listed here properly.	The references section is improved, checked for consistency and extended.
Objectives	The deliverable clearly addresses the objectives of the involved tasks.		The deliverable clearly addresses the objectives of Task 4.2, including feasibility, implementation planning, and evaluation.	
DoA Compliance	The content clearly contributes to the project plan and is consistent with the DoA.		The content aligns well with the Description of Action (DoA) for WP4, covering the pilot setup, regulatory analysis, and impact assessment.	

Task Mapping	It is clear which WP Tasks inform all parts of the deliverable's main content.		The mapping to GA commitments (Table 1, p. 16) clearly identifies which tasks inform specific chapters.
Methodology	The methodological framework is explained clearly and the approach is scientifically sound.		The methodology (surveys, live demos, simulation models) is explained well. The link between the physical pilot and the digital twin simulation is established.
Contributions	Challenges are clearly addressed and the document stimulates further research.		The document clearly articulates the challenges (regulatory, technical, social) and the project's contributions to overcoming them (e.g., the approval steering group).
Conclusions	All key contributions and challenges are discussed clearly and are reflected in the deliverable.		Key contributions and challenges are summarized effectively in the "Lessons Learnt & Recommendations" chapter.
Overall	The deliverable is of good quality and can be finalised in time.		The deliverable is of good quality. It provides a comprehensive overview of the Karlsruhe Living Lab. With minor polish to the visuals and references, it should be ready for submission.

Suggestions and Comments (Reviewer)

Deliverable is coherent, well-established, grammatically very good and easily understandable- I have included some minor suggestions to make it excellent. No further modifications needed.

Project Coordinator: **Ioanna Fergadiotou**
ioanna.fergadiotou@inlecomsystems.com

Project Coordinator: **John Limaxis**
john.limaxis@inlecomsystems.com

Communication, Dissemination, and Upscaling Manager: **Antonios Tsiligiannis**
atsiligiannis@polisnetwork.eu

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the granting authority. Neither the European Union nor the granting authority can be held responsible for them. Any communication or dissemination activity related to the action must use factually accurate information.

Funded by The European Union