# RIDE-PARCEL-POOLING:
# INTEGRATING ON-DEMAND PASSENGER TRANSPORTATION AND CITY LOGISTICS

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## ABSTRACT

Ride Parcel Pooling (RPP) is the integrated transportation of passengers and parcels. It builds on what's known as on-demand ride-pooling, which dynamically assigns customer trips to fleet vehicles in real time, sharing their rides, and thus aiming to save on driving distances and fleet size compared to on-demand ride-hailing services. In the case of RPP, a additional parcel demand is introduced that is less sensitive to longer travel and waiting times and is less negatively affected by changing vehicles. In this case, parcels are served with a lower priority than passengers and simply ride along with appropriate passenger trips. This makes it possible to achieve a more efficient use of vehicle capacity and further reduce the total distance traveled for passenger and logistics mobility. This research is divided into a conceptual and scenario definition part to define the proposed service and develop possible operational scenarios, a theoretical simulation-based approach to quantify the potential of the proposed RPP service, and a practical field test to investigate its real-world applicability. Agent-based RPP simulations show that the integration of logistics services into a ride-pooling service is possible and can exploit unused system capacity without degrading passenger service. Depending on the assignment strategies, parcels can be served up to a parcel-to-passenger demand ratio of 1:10, while total fleet kilometers can be reduced compared to the status quo, as the additional mileage for logistics service can be fully integrated. In the base scenario of the simulation, approximately 50,000 passengers and 5,000 parcels are transported by a fleet of 600 cars or 1,200 rickshaws. The RPP field test included a mobile phone web app and five bicycle rickshaws offering the RPP service in the Maxvorstadt district in Munich, Germany. Each rickshaw had two passenger seats and additional space for parcels. The service was available daily between 11:00 and 19:00 for one week and was completely free for users. The field test showed that the RPP service is ready to operate today and provided interesting insights into the real-world operational parameters for such a service.

## 1. INTRODUCTION

In 2022, Earth Overshoot Day, which marks the day of the year when humanity has exhausted nature's budget for the year, already fell on July 28 [1]. The transportation sector emitted 7.7 Gt of $CO_2$, a significant share of 37% of global $CO_2$ emissions in 2021 [2]. At the same time, the demand for transport in our cities is growing rapidly in many places, as is the number of vehicles on urban roads. This trend in urban passenger transport is accompanied by phenomena such as longer travel times, high space consumption, increased local pollution and climate-impacting emissions. In addition to passenger transport, freight transport in cities is also growing steadily and, according to a modelling by the European Commission, is responsible for around 40% of total $CO_2$ emissions from the transport sector

[3]. In Germany, an average of 15 million shipments were sent to 9 million recipients every day in 2022, an increase of 11.2% over the previous year [4]. It is therefore time to fundamentally rethink all sectors that are primarily responsible for $CO_2$ emissions. This is especially true for the transportation sector, which is a major contributor to global warming. These developments call for new mobility solutions with flexible and affordable vehicle types that can provide an easy and more importantly a sustainable transportation. Sometimes looking back in history is just as rewarding as introducing new solutions. As early as 1610, the first recorded stagecoach traveled between Edinburgh and Leith, carrying passengers as well as small parcels [5]. At that time, the problem was not overcrowded roads, but the availability of vehicles. The solution was to make a virtue of necessity and create the best possible use of the resources at hand, the result being integrated passenger and freight transport. It is the same approach that can guide us today in the fight against climate change, but also in ensuring the efficient flow of traffic in our cities.

The remainder of this paper is structured as follows: First, it reviews the state of the art in integrated passenger and freight transportation, followed by a methodology section. In the following chapters it presents the results for the different parts of the project and finally discusses the findings of this paper.

## 2. STATE OF THE ART

Existing approaches to combining passenger and freight transportation are either practical, real-world experiments aimed at investigating the operational feasibility of integration or are of a scientific nature and focus on exploiting unused capacity. In addition, there are some innovative concept studies for integrated passenger and freight transport [6–9] and historically grown systems in operation, such as the auto rickshaw services in South Asia or the Turkish "Dolmuş" [10]. However, they usually lack efficient dispatching, routing, and pooling of the vehicle fleet. A distinction can be made between integration into line-based and free-floating transport modes, see Figure 1. The difference is that line-based transportation can only stop at certain stations to pick up and drop off passengers or freight, while free-floating systems can operate door-to-door. In this classification, bus services are counted as line-based, even though they naturally use the road infrastructure. Free-floating systems include all types of transportation network companies, taxis, and private vehicles that can stop anywhere on the road network and operate door-to-door.

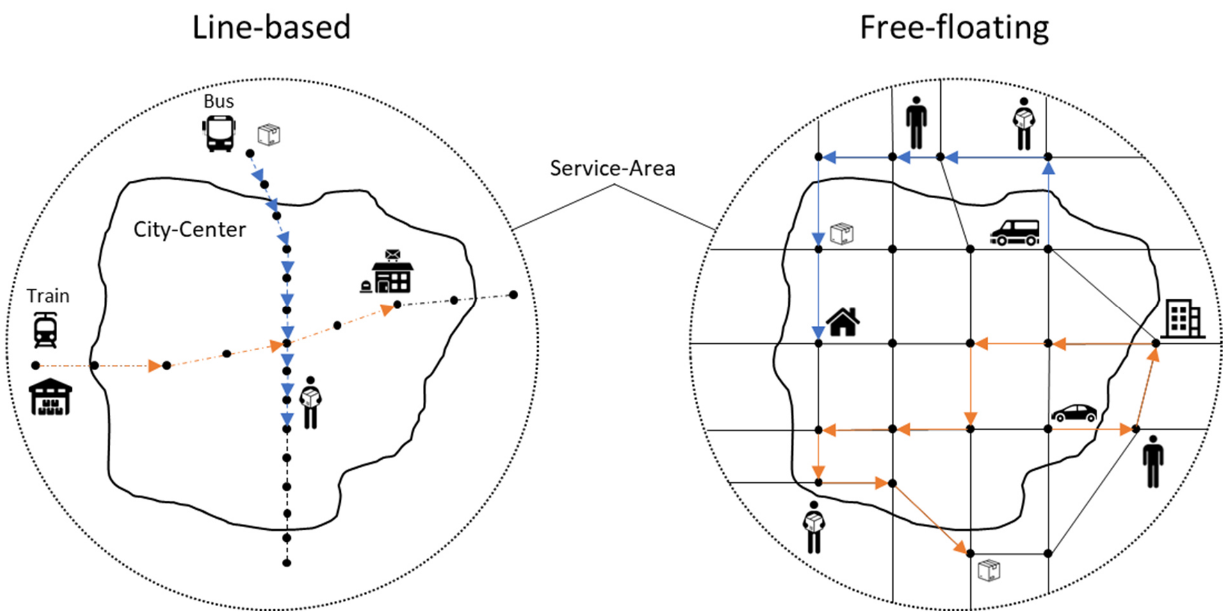


*Figure 1 – Line-based and free-floating modes for integration of passenger and freight transportation.*

Line-based transportation systems can be beneficial for transporting freight from the outskirts of a city to the city center, acting as a feeder system to the station network, from where the freight can be distributed by a subsystem or stored in parcel lockers. Free-floating systems, on the other hand, can operate door-to-door without transferring the freight to another system, but they typically offer less free capacity for additional freight transport.

## 2.1. REAL-WORLD TEST BEDS

In the following, this paper addresses the state of the art for real-world testing. As shown in Figure 1, we distinguish between line-based and free-floating systems, although there are of course hybrid systems that combine both approaches.

*Line-based Systems:*

As mentioned earlier, feeder systems play an important role in line-based integration testing. These either bring freight from out-of-town depots into the city center, where the goods are then finely distributed, or collect freight in the city and bring it out of the city center. Such systems have been tested, for example, in Dresden to supply an automobile plant [11], in Zurich to collect electronic or bulky waste [12], or in Paris as a delivery tram for a fashion house [13]. In addition, there are crowd-sourced approaches where passengers pick up shipments on their way on public transport [14–16]. Another concept is the centrally organized, line-based, integrated transport of courier, express and parcel (CEP) shipments on public transport [15, 17–19], where a CEP company and the public transport operator usually cooperate. Finally, line-based integration of passenger and freight flows exists not only in urban contexts, but also in rural areas [20, 21].

*Road-based Systems:*

Road-based, free-floating solutions are rare compared to line-based approaches, as a true integration of the two transportation flows requires complex assignment solutions to exploit existing passenger routes without compromising too much on the passenger comfort, i.e., waiting and travel times. To the best of the authors' knowledge, this has not yet been tested in the real world, perhaps due to the lack of a legal basis [22]. The only existing approaches focus on transporting either passengers or freight with the same vehicle fleet [23] and fail to take advantage of existing passenger trips for additional freight transport.

## 2.2. SCIENTIFIC RESEARCH PAPERS

Existing research on the integration of passenger and freight transportation is mainly found in operations research [24]. The focus is on the allocation, routing, and efficient use of vehicle fleets [25]. Again, a distinction is made between line-based and free-floating systems. There is research that focuses on the strategic, tactical, and operational levels of integrating line-based passenger and freight transportation.

*Line-based Systems*

Line-based systems are primarily found in public transportation. In terms of vehicles, line-based transportation systems are either trains (e.g., metro or light rail), buses, or boats traveling on waterways. Some of the studies focus on the economic aspects, while others highlight the potential environmental benefits. In addition to the different modes of transportation, the research papers also differ in the level of integration. While some consider mixed passenger and parcel operations [26–33], others focus only on shared infrastructure (e.g., rail) without sharing the vehicle (e.g., train) [34, 35]. These still operate independently of each other, so it is not possible to speak of integrated transport in the strict sense. They also differ in the logistics service provided, which can be scheduled [27–35] or immediate [26, 33]. In terms of system optimization, line-based transportation systems can be classified as static (i.e., information is known a priori) [28, 32, 33, 35] or dynamic (i.e., information is known over time and the system needs to be re-optimized) [26, 27, 29, 31, 34].

*Free-floating Systems*

Free-floating systems are mainly found in the private or semi-private transport sector and can be divided into crowd-sourced solutions [36–39] and demand responsive transportation services [40–45]. In the case of crowdsourced solutions, a distinction can be made between integration approaches that consider a hired fleet of vehicles [36–39] and occasional drivers [36, 38, 39], recruited through an online platform. For demand-responsive transportation services, one can distinguish between ride-haling (i.e., one request/customer per trip) [38, 40, 41] and ride-pooling (i.e. multiple requests/customers share a vehicle on their trip) [42, 44–47] can be made. Furthermore, the research papers consider immediate [36–41, 43, 44] and scheduled [42, 45] logistics services and can be divided into static and dynamic models.

From the literature review presented, it can be seen that research on combined passenger and freight transportation in urban areas is diverse. However, the line-based approaches have the major disadvantage that they are not suitable for direct door-to-door delivery, which is still the most popular form of delivery in most European countries [48] and require additional personal for loading and unloading. The free-floating integration approaches only provide a sustainable benefit if most of the existing passenger trips are used and therefore only minimal additional vehicle kilometers are induced. Therefore, scheduled logistics services are to be preferred, as they offer a longer time horizon for optimization than immediate deliveries. These two assumptions open the research gap for the RPP idea introduced in [42] and [45] and are also the basis for the comprehensive RPP research project presented in the following.

## 3. METHODOLOGY

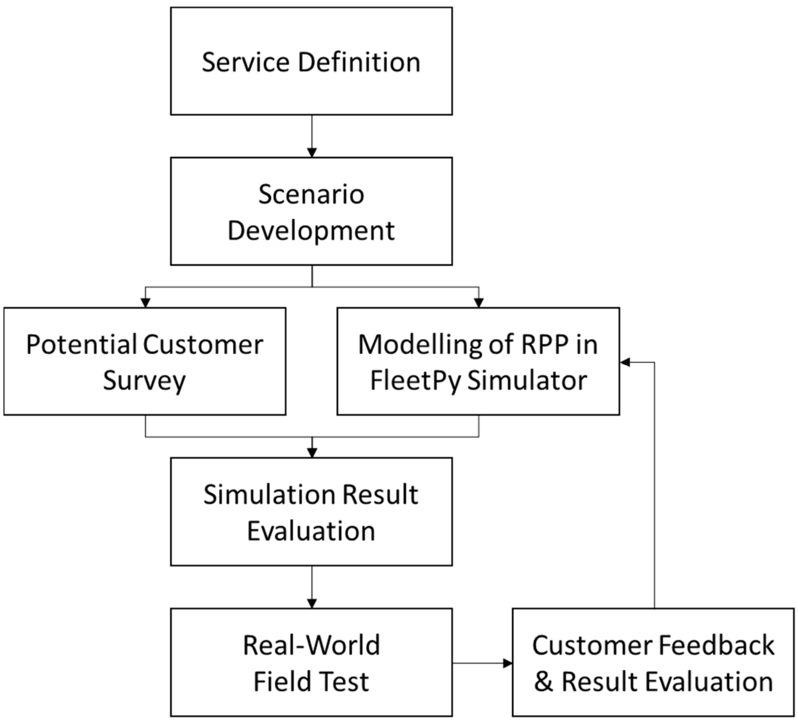


*Figure 2 – Methodological research flowchart.*

The methodology of this research paper consists of RPP service and scenario definition, followed by a potential customer survey and RPP modeling using the agent-based fleet simulation framework "FleetPy" [49]. In the next step, the obtained simulation results are evaluated, and a real-world field test is conducted. The feedback from the field test is then used in a feedback loop to calibrate the simulation, see Figure 2. In the next sections this paper presents the results obtained from all mentioned steps and puts them into the context of the project.

## 4. RESULTS

The results of this paper are structured according to the steps of the project methodology presented in Section 3 and include the RPP service- and scenario-definition, the simulation results from modeling RPP, and the real-world test of the service.

### 4.1. SERVICE AND SCENARIO DEFINITION

To define the RPP service and set up the simulation scenarios, this research used a stakeholder analysis and examined trends in urban transportation systems, including passenger and freight transportation, through expert interviews and workshops. It was found that an RPP service could fill unused capacity in a traditional ridesharing service and thus contribute to a reduction in driven distance compared to a traditional delivery service.

To verify the initial assumptions for the service definition and to gain further insight into how customers of a potential RPP service would value and use the transportation solution, a customer survey was conducted as part of the project [50]. The questionnaire was structured into a socio-demographic and socio-economic part, followed by attitudes and parameters towards a potential RPP service, and finally the acceptance of RPP scenarios and the rickshaw as a potential RPP vehicle. The survey showed that the respondents were very positive about the idea of RPP and found the presented service scenarios beneficial. Moreover, the results showed that the potential increase in travel time due to the additional logistics service will be critical for customer satisfaction. One solution could be financial compensation for inconvenience, which, according to the survey, often changes the extent of detours accepted. Respondents were also asked for their opinion on a rickshaw as a possible vehicle for the RPP service. The results for this question are shown in Table 1.

*Table 1 – Advantages and disadvantages of a rickshaw as RPP vehicle [50].*

| Rickshaw Pros | Rickshaw Cons |
|---|---|
| • Environmentally friendly (lower $CO_2$ footprint, emissions, noise).<br>• Solves space problem in cities and more flexible (size) during rush hours.<br>• Great means of transportation for short distances.<br>• Large luggage compartment.<br>• Alleviate crowded streets.<br>• Riding experience in urban space, fresh air/ see more. | • Effort of the driver (smell, discomfort, pity, etc.).<br>• Confined space (especially when pooling), limited pooling capacity.<br>• Low speed, only suitable for short trips.<br>• Unfamiliar, one feels observed, safety concerns (accidents, luggage, parcels).<br>• Insufficient weather protection. |

Subsequently, an impact analysis was set up to quickly evaluate the consequences a RPP service could have on the existing stakeholders, processes, and systems. On this basis three different simulation scenarios were set up, representing different levels of integration, as shown in Figure 3. While the *Status Quo* scenario represents separated transportation of passengers and parcels, *Moderate RPP Integration* assumes that parcels can only be picked-up or dropped-off when no passenger is on-board, however they can travel together. *Full RPP Integration* allows parcels to be picked up or dropped off also while passengers are traveling.

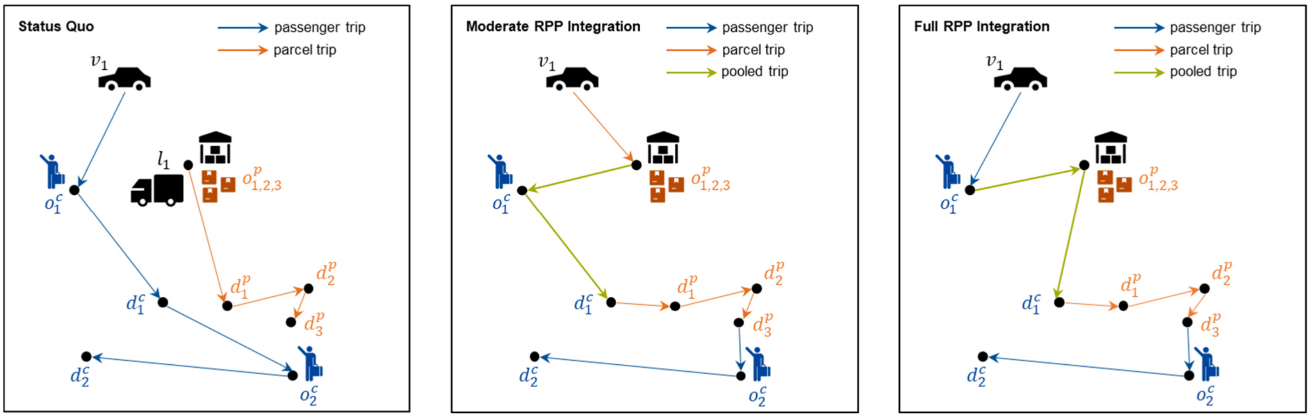


*Figure 3 – Ride-parcel-pooling scenarios (status quo, moderate, and full RPP integration).*

Finally, the RPP concept has been enriched with potential service extensions, including the use of vehicles as *Mobile Parcel Lockers* that can be placed at the center of a number of delivery request locations during off-peak passenger hours; *Parcel Hopping*, a term used to describe that parcels are allowed to change vehicles, making more efficient use of unused vehicle capacity; and *In-vehicle Delivery*, a service that delivers a parcel to its recipient directly in the vehicle during a reserved passenger trip.

## 4.2. MODELLING AND SIMULATION

To model the RPP service and investigate its potential, the fleet simulation framework for mobility on-demand services “FleetPy” was extended to represent additional parcel transportation to a conventional ride-pooling service. A detailed description of the simulation environment for the RPP service can be found in [45]. For a case study in Munich, Germany, the agent-based simulation reveals that the integration of logistics services into a ride-pooling service is possible and can exploit unused system capacities without deteriorating passenger transportation. The results suggest that parcels can be served until a parcel to passenger demand ratio of 1:10 while the overall fleet kilometers can be deceased compared to the status quo. For this paper the simulation was repeated using rickshaws instead of the conventional passenger cars of the latter paper. This means that passenger capacity decreases from four to two and parcel capacity is also halved, resulting in four average-sized parcels per rickshaw. The fleet size was therefore doubled, resulting in a fleet of 1,200 rickshaws (600 cars). In addition, the traveling speed was reduced to an average of 15 km/h, which is not varied by time, as the rickshaws are allowed to use dedicated bike lanes and therefore avoid congested road traffic. For parcel assignment the *Combined Decoupled Parcel Assignment (CDPA)* algorithm, introduced in [45], and the *Full RPP Integration Scenario* were chosen, as this strategy results in the lowest traveled distance and thus provides the most sustainable version of RPP. This strategy inserts parcel pick-up and drop-off into a vehicle schedule if the resulting detour does not exceed a certain threshold. The CDPA threshold parameter was set to $\tau_{th} = 0.8$, which describes a maximum detour of 20% for the additional transportation of parcels compared to the pure passenger trip.

*Influence of RPP on Operator Performance Indicators*

To quantify the impact of the additional transportation of parcels on the performance indicators of a ride-pooling service, the number of parcels and customers served, the total distance traveled, and the distance traveled per customer and parcel were evaluated. Figure 4 shows the performance indicators of a ride-pooling operator under variation of parcel demand penetration for a car and a rickshaw fleet. Both the car and the rickshaw fleet can match the 'Status Quo' up to a parcel demand penetration of about 10%. This means that the RPP fleet can transport one parcel for every ten passengers in the system without significantly degrading passenger service or increasing the total distance traveled. Of course, the distance traveled per parcel and passenger decreases as the penetration of parcel demand increases, but higher parcel penetration rates result in slightly more unserved customers and a slightly higher distance traveled for both the car and rickshaw fleets. Looking at the plots of served MoD customers and driven distance, it can be seen that the rickshaw fleet can handle higher parcel penetration rates better than the car fleet and results in a lower total driven distance due to the lower number of transported parcels and the higher number of vehicles.

*Influence of RPP on Customer Performance Indicators*

The impact of the additional parcel transport on the customer of a ride-sharing service is measured by the increase in waiting and travel time. The simulation results show that for a rickshaw fleet, the average increase in waiting and travel time is about 1%. For a car fleet, the difference is even smaller, ranging from an average increase of 0.1% to 0.5% in travel and waiting times compared to a pure ride-pooling service.

Overall, the simulations show that the additional transport of parcels by a ride-pooling service does not lead to a noticeable deterioration of operator or customer performance indicators. However, the integration of RPP allows to transport significant volumes of parcels by exploiting unused system capacity. It also shows that a city-wide ride-pooling service could be provided by a fleet of rickshaws and does not necessarily require large and faster vehicles. Although it remains to be considered that the double number of drivers and the comparatively higher travel times could have a negative influence in real-world operations. In the future, however, at least the driver issue and thus the main cost factor of such systems could be solved by automating such rickshaw systems [51]. The lower speeds compared to passenger cars could also lead to an earlier and easier market introduction.

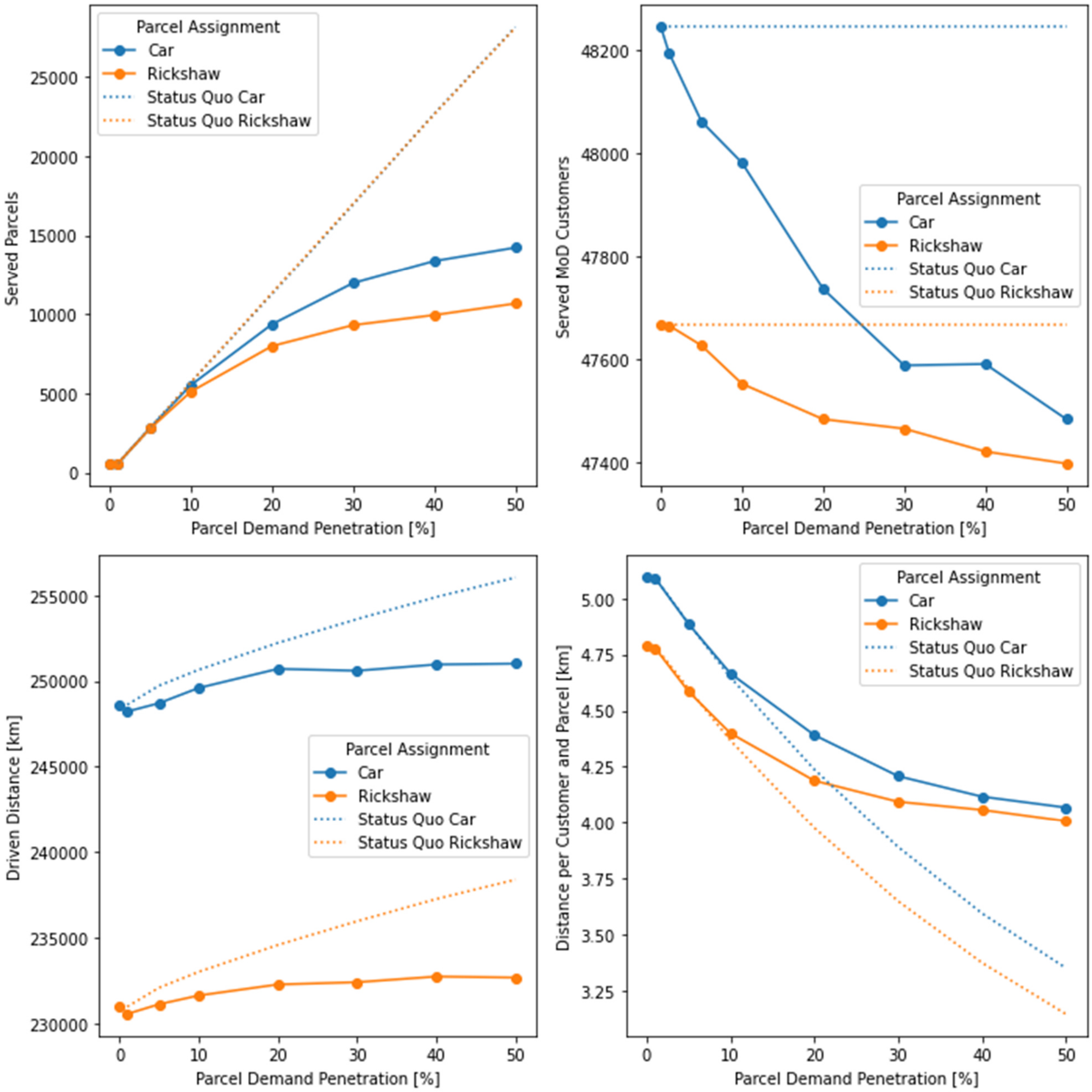


*Figure 4 – Simulation results for RPP vehicle fleets of 600 passenger cars and 1,200 rickshaws.*

## 4.3. REAL-WORLD TEST

During the week of Monday, August 22, 2022, to Friday, August 26, 2022, a real-world test for the RPP service was conducted, offering free passenger rides and parcel transport from 10:00 to 19:00. The real-world test of the RPP project consisted of a web application and a fleet of five test vehicles (rickshaws).

### *RPP Web-Application*

The RPP web application consists of a ReactJS frontend for customers, drivers, and administrators that connects to a backend via REST API and is displayed on a website. The Java-based backend infrastructure is the interface between the frontend and the fleet-control infrastructure. It is built for data distribution and storage via MariaDB and provides the representational state transfer for the API connection. The Python-based fleet-control (FleetPy), as the third main part of the web application, provides the assignment and routing algorithms and gives feedback to the customers on their requests. Figure 5 provides a schematic overview of the web application infrastructure described above.

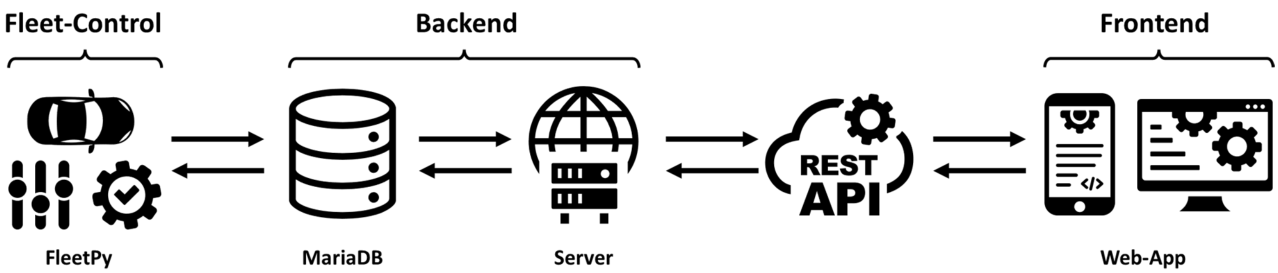


*Figure 5 – Schematic overview of the RPP web application infrastructure.*

### *RPP Test Vehicles*

The RPP test vehicles are prototypes developed as part of the research project and consist of a compartment for two passengers, a roof rack, and an optional trailer for transporting parcels, see Figure 6. The electric rickshaw reaches a maximum speed of about 25 km/h on a flat, windless road and travels at an average speed of about 15 km/h under normal traffic conditions. In this context, the rickshaw benefits from the classification as a bicycle, with a maximum electric assist speed of 25 km/h in Germany, and is thus allowed to use the bicycle infrastructure, which results in travel time savings in congested road traffic.


*Figure 6 – RPP rickshaw (prototype for the integrated transportation of passengers and freight).*

*RPP Field Test*

During the real-world field test, the RPP service was offered to the public free of charge. For five consecutive weekdays in August 2022, people could request rides and have the service transport parcels in a predefined area of operation (see blue outlined area in Figure 10) in the district of Maxvorstadt in the city of Munich, Germany. In addition to the free rides, in-kind donations of broken small appliances and old clothes were also collected to create parcel demand. Figure 7 provides a sample view of the RPP web application, where frames (1) and (2) show the customer view, and frames (3) and (4) show the driver front-end.

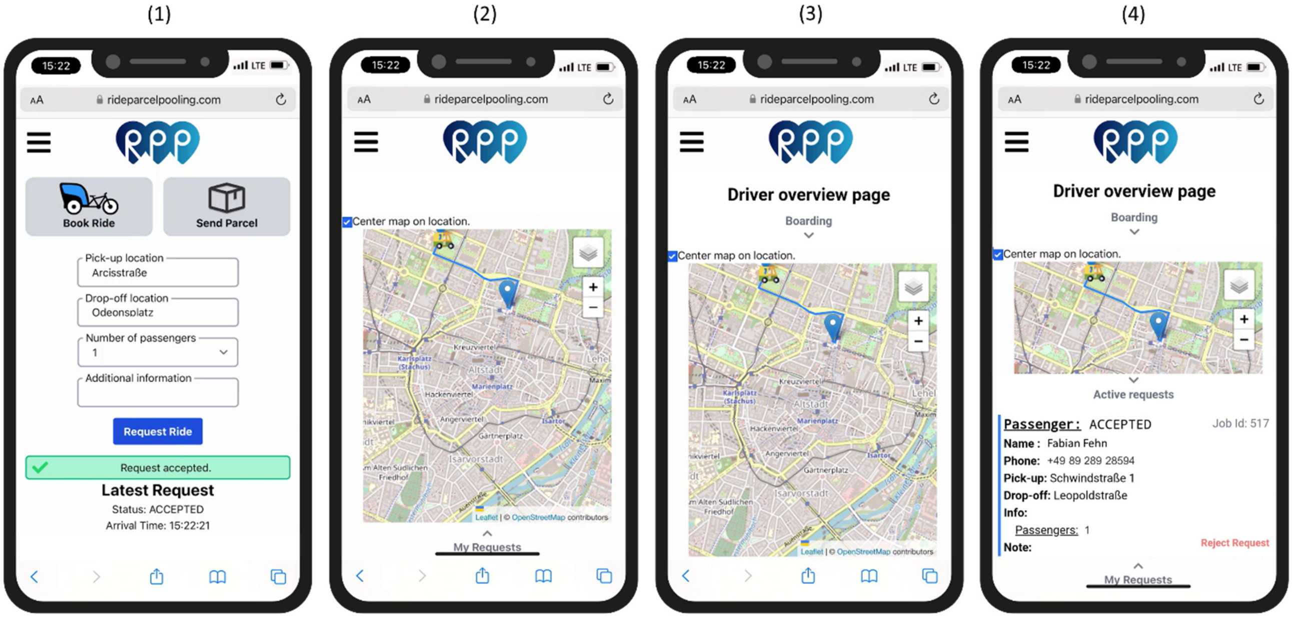


*Figure 7 – RPP web-application user (1), (2) and driver (3), (4) front-end.*

During the test phase, 54 people created and actively used an account, resulting in a total of 191 valid requests, of which 87% were passenger requests and 13% were parcel requests. The total number of trips served is significantly lower than the number of valid requests. This is for several reasons: First, many requests were canceled by the users themselves, most likely to test or exceed the acceptable waiting time. Second, drivers were able to reject requests if, for example, they could not find the client. Third, technical problems lead to some failures, especially at the beginning of the test. These included system failures and multiple requests for the same trip. In total, 47 valid trips were recorded, 74% of which were passenger trips, 18% parcel trips and 8% shared trips with passenger(s) and parcel(s) on board. The lengths of the performed trips are shown in Figure 8.

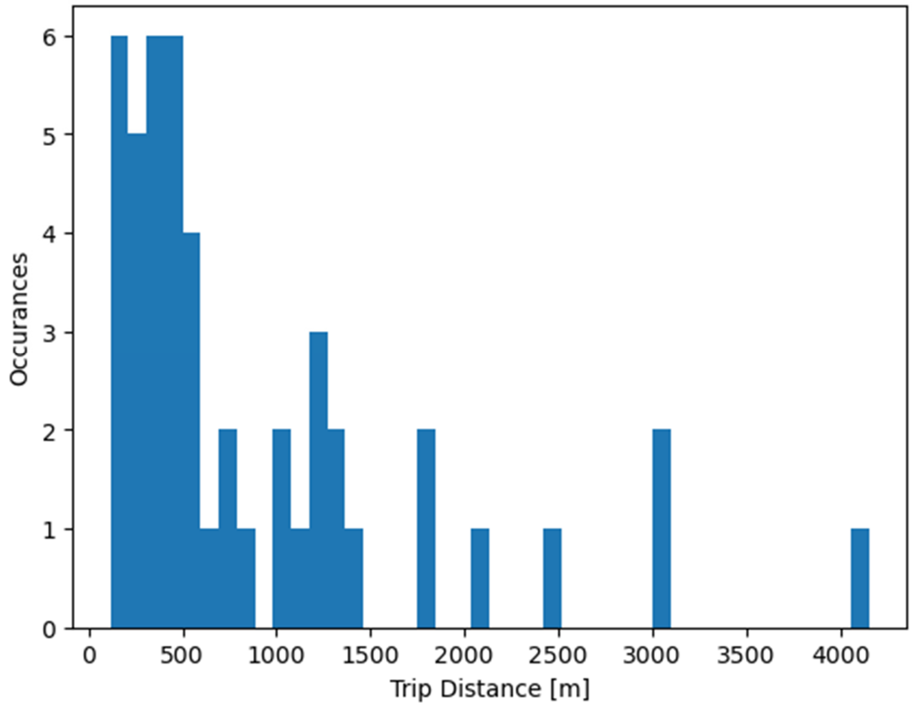


*Figure 8 – Counts of requested trip lengths.*

The total distances covered by each rickshaw during the five days of the field test are shown in Figure 9. The distances vary considerably from rickshaw to rickshaw, mostly due to the number of trips assigned to each rickshaw. Some rickshaws seem to have been better located at existing demand hotspots than others, which may have led to a higher assignment probability.

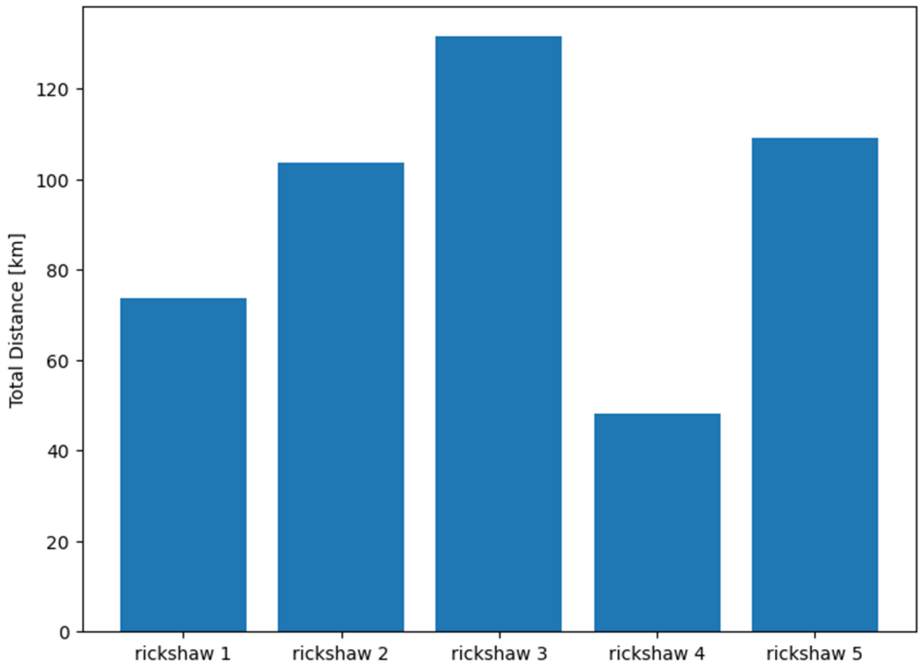


*Figure 9 – Total covered distance by during the test phase by rickshaw.*

Self-organized pick-ups and deliveries by drivers without a ride request via the app were also recorded and may be outside the service area, but are clearly in the minority, see Figure 10.

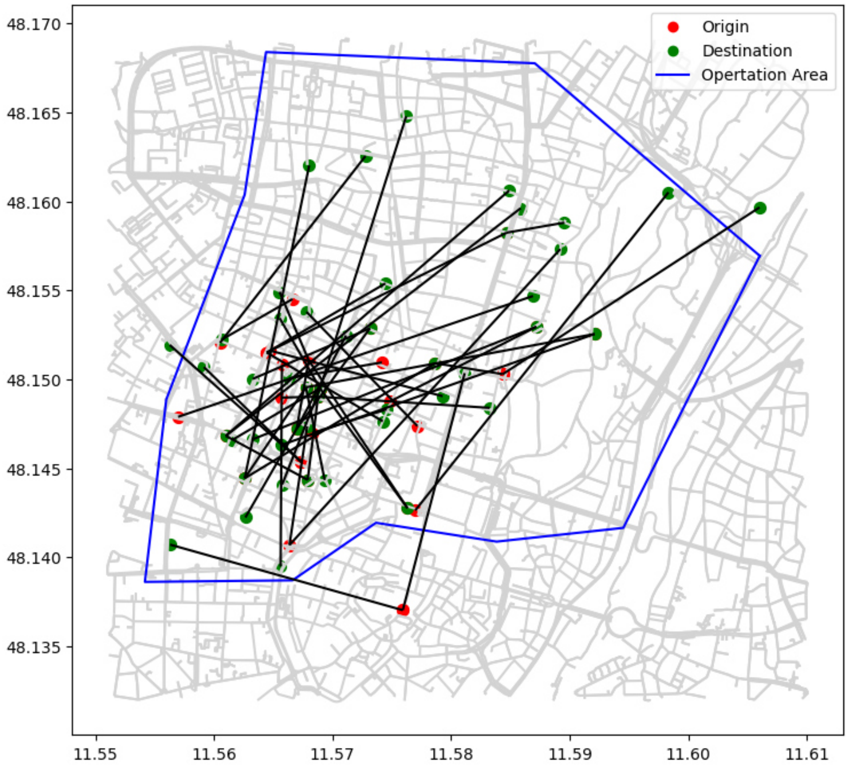


*Figure 10 – Served requests and operation area for the RPP field test.*

The average speed recorded was 14.1 km/h and the average boarding time was 56.7 seconds. In this study, boarding time describes the time from vehicle arrival to the start of the trip, including vehicle parking, passenger contact, passenger boarding, and preparation for departure. The average occupancy rate of the rickshaws, calculated based on the number passengers per request, was 1.4 passengers. Real shared passenger trips were not observed during the field test, however there were four passenger trips with a parcel on-board. The low pooling rate was probably, due to the low demand, which was far from the system capacity. All relevant values obtained during the field test are shown in Table 2.

*Table 2 – Service parameters derived from the field test.*

| Parameter | Value |
|---|---|
| Active Unique User Accounts | 54 |
| Total Number of Requests | 191 |
| Share of Passenger Requests | 87% |
| Share of Parcel Requests | 13% |
| Total Number of Served Trips | 47 |
| Share of Passenger Trips | 74% |
| Share of Parcel Trips | 18% |
| Share of Combined Trips | 8% |
| Average Trip Length | 0,88 km |
| Min. Trip Length | 0,12 km |
| Max. Trip Length | 4,15 km |
| Average Vehicle Speed | 14,1 km/h |
| Average Passenger Occupancy | 1,4 |
| Average Boarding Time | 56,7 s |

## 5. CONCLUSION

This paper proposes the integrated transportation of on-demand passengers and parcels in an urban context, called Ride-Parcel-Pooling (RPP). The comprehensive research project investigates RPP from the conceptual phase, including service and scenario definition, through its impact analysis via an agent-based simulation, to the testing of the service in the real-world environment in Munich, Germany.

This research has developed a working RPP service concept that shows great potential in a city-wide simulation study comparing fleets of cars and electric rickshaws. Both fleets can transport approximately 5,000 parcels per day, without negatively impacting operator or customer performance.

During a five-day field trial, the RPP service was tested in the district Maxvorstadt of the city of Munich, Germany. A web application, including all the necessary IT infrastructure, was set up for this purpose. The field test proved that the RPP service is ready for real-world application and that rickshaws are a valid and accepted vehicle for providing urban ride-pooling services, even in Western European countries. Nevertheless, to evaluate long term customer acceptance, more extensive field tests must be conducted.

In the future, vehicle automation, including automated rickshaws [51] or other pod systems, could provide new opportunities for RPP and promote the business case for small-capacity vehicles, as today the driver is still the main cost factor in such mobility systems, often leading to large-capacity vehicle systems. In addition, the final parcel delivery could also be automated. This would probably be based on systems such as the delivery robots or parcel lockers already in use. The resulting solution for parcel delivery to the customer would pave the way for integrating a logistics system into large-scale Mobility on Demand systems and operating it efficiently.

## 6. AUTHOR CONTRIBUTIONS

Study conception and design: FF, RE, MM, KB; data collection: FF, RE; analysis and interpretation of results: FF, RE; simulation model: RE, FF; field-test preparation: FF, RE; service demonstration: FF, RE, MM; draft manuscript preparation: FF, RE, MM, KB. All authors reviewed the results and approved the final version of the manuscript.

## 7. ACKNLOWLEDGMENTS

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## REFERENCES

[1] Global Footprint Network, *Earth Overshoot Day.* [Online]. Available: https://www.overshootday.org/ (accessed: Jan. 10 2022).

[2] International Energy Agency, *Transport Improving the sustainability of passenger and freight transport.* [Online]. Available: https://www.iea.org/topics/transport (accessed: Jan. 10 2022).

[3] European Comission, *COMMISSION STAFF WORKING DOCUMENT A call to action on urban logistics.* [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/ffac1877-67ca-11e3-a7e4-01aa75ed71a1 (accessed: Jan. 13 2023).

[4] Bundesverband Paket und Express Logistik, *KEP-Studie 2022 – Analyse des Marktes in Deutschland.* [Online]. Available: https://www.biek.de/files/biek/downloads/papiere/BIEK_KEP-Studie_2022.pdf (accessed: Jan. 13 2023).

[5] M. G. Lay, *Ways of the world: A history of the worlds's roads and of the vehicles that used them*. New Brunswick, NJ: Rutgers Univ. Press, 1992.

[6] Hugh Frost, *Freight*Bus, The bus that Delivers!* [Online]. Available: http://www.onroutebus.co.uk/ (accessed: Feb. 22 2022).

[7] Herbert Riemann, *Logistiktram.* [Online]. Available: http://logistiktram.de/ (accessed: Sep. 23 2022).

[8] ONOMOTION GmbH, *Thinking about mobility differently: The Cargo Tram operating for the "Last Mile".* [Online]. Available: https://onomotion.com/en/cargotram/ (accessed: Nov. 8 2022).

[9] Sunglider AG, *Smart Uberground Metros - Sunglider.* [Online]. Available: https://www.sunglider.eu/ (accessed: Dec. 29 2022).

[10] Tom Brosnahan, *Turkish Dolmus Taxi or Minibus.* [Online]. Available: http://turkeytravelplanner.com/trans/LocalTransport/Dolmush.html (accessed: Dec. 21 2022).

[11] O. Winfried, *Die Dresdner Güterstraßenbahn – Ein System für alle Fälle?* [Online]. Available: https://www.dvb.de/-/media/files/die-dvb/dvb-vortrag-cargotram.pdf (accessed: Nov. 8 2022).

[12] City of Zurich, *Cargo-Tram and E-Tram.* [Online]. Available: https://www.stadt-zuerich.ch/ted/de/index/entsorgung_recycling/entsorgen/wo-wann-entsorgen/cargo-tram_und_e-tram.html (accessed: Feb. 22 2022).

[13] J. Maes and T. Vanelslander, "The use of rail transport as part of the supply chain in an Urban logistics context," in *City Distribution and Urban Freight Transport: Multiple Perspectives*, pp. 217–233. [Online]. Available: 10.4337/9780857932754.00018

[14] Fraunhofer Austria, *KEP-Train.* [Online]. Available: https://www.fraunhofer.at/de/zusammenarbeit/laufende-studien.html (accessed: Nov. 8 2022).

[15] V. Fochler, *Erste Fahrt der GüterBim in Wien.* [Online]. Available: https://www.ots.at/presseaussendung/OTS_20050517_OTS0210/erste-fahrt-der-gueterbim-in-wien-bild (accessed: Nov. 8 2022).

[16] M. Hayek, *Pakettransport in den Öffis: Jetzt startet die konkrete Entwicklung.* [Online]. Available: https://idw-online.de/en/news799907 (accessed: Sep. 23 2022).

[17] Kai-Oliver Schocke, Petra K. Schäfer, Silke Höhl, Andreas Gilbert, "Bericht zum Forschungsvorhaben LastMileTram - Empirische Forschung zum Einsatz einer Güterstraßenbahn am Beispiel Frankfurt am Main," 2020.

[18] Forschungszentrum Informatik (KIT), *Innovatives Logistikkonzept zur Entlastung des Straßenverkehrs.* [Online]. Available: https://logiktram.de/ (accessed: Aug. 11 2022).
[19] Mobilität der Zukunft, *Amsterdam City Cargo Tram.* [Online]. Available: https://mobilitaetderzukunft.at/de/artikel/zukunftspotenzial-gueterstrassenbahn.php (accessed: Feb. 22 2022).
[20] A. Sylvester, *LandLogistik: Die andere Sichtweise: freie Flächen für regionale Produkte.* [Online]. Available: https://www.regionalbewegung.de/fileadmin/user_upload/2019/Fachforum_IGW_Nr._21/IGW_Zukunftsforum_Nr_21_LandLogistik_AnjaSilvester_24012019.pdf (accessed: Sep. 23 2022).
[21] Deutsche Post AG, *kombiBAHN.* [Online]. Available: https://landlogistik.eu/wp-content/uploads/kombiBAHNNordhessen_LandLogistik_Pressemitteilung.pdf (accessed: Sep. 23 2022).
[22] Ralf Bammerlin, *Protokoll zum Arbeitstreffen „Rechtliche Rahmenbedingungen für den Gütertransport im ÖPNV" am 21. Juni 2021 per Webex.* [Online]. Available: https://bmdv.bund.de/SharedDocs/DE/Anlage/G/protokoll-rechtliche-rahmenbedingungen-oepnv.pdf?__blob=publicationFile (accessed: Jan. 9 2023).
[23] IsarFunk Kurier, *Der Premium-Stadtkurier für München.* [Online]. Available: https://isarfunkcourier.de/ (accessed: Apr. 10 2022).
[24] N. Boysen, S. Fedtke, and S. Schwerdfeger, "Last-mile delivery concepts: a survey from an operational research perspective," *OR Spectrum*, vol. 43, no. 1, pp. 1–58, 2021, doi: 10.1007/s00291-020-00607-8.
[25] J. Li, E. Rombaut, and L. Vanhaverbeke, "A systematic review of agent-based models for autonomous vehicles in urban mobility and logistics: Possibilities for integrated simulation models," *Computers, Environment and Urban Systems*, vol. 89, p. 101686, 2021, doi: 10.1016/j.compenvurbsys.2021.101686.
[26] W. Behiri, S. Belmokhtar-Berraf, and C. Chu, "Urban freight transport using passenger rail network: Scientific issues and quantitative analysis," *Transportation Research Part E: Logistics and Transportation Review*, vol. 115, pp. 227–245, 2018, doi: 10.1016/j.tre.2018.05.002.
[27] A. Trentini and N. Malhene, "Flow Management of Passengers and Goods Coexisting in the Urban Environment: Conceptual and Operational Points of View," *Procedia - Social and Behavioral Sciences*, vol. 39, pp. 807–817, 2012, doi: 10.1016/j.sbspro.2012.03.149.
[28] V. Ghilas, E. Demir, and T. van Woensel, "An adaptive large neighborhood search heuristic for the Pickup and Delivery Problem with Time Windows and Scheduled Lines," *Computers & Operations Research*, vol. 72, pp. 12–30, 2016, doi: 10.1016/j.cor.2016.01.018.
[29] R. Masson, A. Trentini, F. Lehuédé, N. Malhéné, O. Péton, and H. Tlahig, "Optimization of a city logistics transportation system with mixed passengers and goods," *EURO Journal on Transportation and Logistics*, vol. 6, no. 1, pp. 81–109, 2017, doi: 10.1007/s13676-015-0085-5.
[30] K. de Langhe, H. Meersman, C. Sys, E. van de Voorde, and T. Vanelslander, "How to make urban freight transport by tram successful?," *J. shipp. trd.*, vol. 4, no. 1, 2019, doi: 10.1186/s41072-019-0055-4.
[31] V. Ghilas, J.-F. Cordeau, E. Demir, and T. van Woensel, "Branch-and-Price for the Pickup and Delivery Problem with Time Windows and Scheduled Lines," *Transportation Science*, vol. 52, no. 5, pp. 1191–1210, 2018, doi: 10.1287/trsc.2017.0798.
[32] Y. Ye, J. Guo, and L. Yan, "A Metro Freight Plan for Mixed Passenger and Freight Transportation," *Journal of Advanced Transportation*, vol. 2022, pp. 1–13, 2022, doi: 10.1155/2022/6602387.
[33] Z. Zeng and X. Qu, "Optimization of Electric Bus Scheduling for Mixed Passenger and Freight Flow in an Urban-Rural Transit System," *IEEE Trans. Intell. Transport. Syst.*, pp. 1–11, 2022, doi: 10.1109/tits.2022.3221332.
[34] E. Fatnassi, J. Chaouachi, and W. Klibi, "Planning and operating a shared goods and passengers on-demand rapid transit system for sustainable city-logistics," *Transportation Research Part B: Methodological*, vol. 81, pp. 440–460, 2015, doi: 10.1016/j.trb.2015.07.016.
[35] Z. Li, A. Shalaby, M. J. Roorda, and B. Mao, "Urban rail service design for collaborative passenger and freight transport," *Transportation Research Part E: Logistics and Transportation Review*, vol. 147, p. 102205, 2021, doi: 10.1016/j.tre.2020.102205.

[36] C. Archetti, M. Savelsbergh, and M. G. Speranza, “The Vehicle Routing Problem with Occasional Drivers,” *European Journal of Operational Research*, vol. 254, no. 2, pp. 472–480, 2016, doi: 10.1016/j.ejor.2016.03.049.
[37] A. M. Arslan, N. Agatz, L. Kroon, and R. Zuidwijk, “Crowdsourced Delivery—A Dynamic Pickup and Delivery Problem with Ad Hoc Drivers,” *Transportation Science*, vol. 53, no. 1, pp. 222–235, 2019, doi: 10.1287/trsc.2017.0803.
[38] I. Dayarian and M. Savelsbergh, “Crowdshipping and Same‐day Delivery: Employing In‐store Customers to Deliver Online Orders,” *Prod Oper Manag*, vol. 29, no. 9, pp. 2153–2174, 2020, doi: 10.1111/poms.13219.
[39] N. Kafle, B. Zou, and J. Lin, “Design and modeling of a crowdsource-enabled system for urban parcel relay and delivery,” *Transportation Research Part B: Methodological*, vol. 99, pp. 62–82, 2017, doi: 10.1016/j.trb.2016.12.022.
[40] B. A. Beirigo, F. Schulte, and R. R. Negenborn, “Integrating People and Freight Transportation Using Shared Autonomous Vehicles with Compartments,” *IFAC-PapersOnLine*, vol. 51, no. 9, pp. 392–397, 2018, doi: 10.1016/j.ifacol.2018.07.064.
[41] C. Chen and S. Pan, “Using the Crowd of Taxis to Last Mile Delivery in E-Commerce: a methodological research,” in *Service Orientation in Holonic and Multi-Agent Manufacturing*: Springer, Cham, 2016, pp. 61–70. [Online]. Available: https://link.springer.com/chapter/10.1007/978-3-319-30337-6_6
[42] F. Fehn, R. Engelhardt, and K. Bogenberger, “Ride-Parcel-Pooling - Assessment of the Potential in Combining On-Demand Mobility and City Logistics,” in *2021 IEEE International Intelligent Transportation Systems Conference (ITSC)*, 2021.
[43] B. Li, D. Krushinsky, H. A. Reijers, and T. van Woensel, “The Share-a-Ride Problem: People and parcels sharing taxis,” *European Journal of Operational Research*, vol. 238, no. 1, pp. 31–40, 2014, doi: 10.1016/j.ejor.2014.03.003.
[44] S. Meinhardt, T. Schlenther, K. Martins-Turner, and M. Maciejewski, “Simulation of On-Demand Vehicles that Serve both Person and Freight Transport,” *Procedia Computer Science*, vol. 201, pp. 398–405, 2022, doi: 10.1016/j.procs.2022.03.053.
[45] F. Fehn, R. Engelhardt, F. Dandl, K. Bogenberger, and F. Busch, “Integrating Parcel Deliveries into a Ride-Pooling Service -- An Agent-Based Simulation Study,” May. 2022. [Online]. Available: https://arxiv.org/pdf/2205.04718
[46] T. Schlenther, K. Martins-Turner, J. F. Bischoff, and K. Nagel, “Potential of Private Autonomous Vehicles for Parcel Delivery,” *Transportation Research Record*, vol. 2674, no. 11, pp. 520–531, 2020, doi: 10.1177/0361198120949878.
[47] S. Zhang, C. Markos, and J. J. Q. Yu, “Autonomous Vehicle Intelligent System: Joint Ride-Sharing and Parcel Delivery Strategy,” *IEEE Trans. Intell. Transport. Syst.*, vol. 23, no. 10, pp. 18466–18477, 2022, doi: 10.1109/tits.2022.3162609.
[48] dpd Group, *E-shopper barometer: Global Report.* [Online]. Available: https://www.readkong.com/page/e-shopper-barometer-report-2017-3826533 (accessed: Jan. 9 2022).
[49] R. Engelhardt *et al.,* “FleetPy: A Modular Open-Source Simulation Tool for Mobility On-Demand Services,” Jul. 2022. [Online]. Available: https://arxiv.org/pdf/2207.14246
[50] F. Fehn, L. Hamm, R. Engelhardt, and B. Klaus, “Ride-Parcel-Pooling: Insights to Integrated Passenger and Freight Transportation through a Customer Survey,” in . [Online]. Available: https://mediatum.ub.tum.de/doc/1655046/document.pdf
[51] M. Margreiter, M. Ilic, A. Joshi, and K. Bogenberger, *A Self-Driving Rickshaw for Autonomous Urban Passenger and Freight Transport*. Prague, Czech Republic, 2023.
[52] A. Kutsch *et al.,* “TEMPUS - Test Field Munich - Pilot Test for Urban Automated Road Traffic,” in *2022 IEEE 25th International Conference*, pp. 2514–2519.