

VeStat GDPR-Compliant Cameras for Empirical Research in Public Spaces: Unlocking Trip-Chaining via White-Label Parcel Lockers at Public Transportation Stations

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Abstract:

Climate-neutral urban mobility requires the integration of public transport (PT) and last-mile (LM) logistics. While white-label parcel lockers (wl PL) are discussed as a promising solution to reduce travel distances and emissions, empirical evidence on their interaction with PT and their potential to enable trip-chaining remains limited. This study addresses this gap by piloting the GDPR-compliant, edge-AI-based VeStat camera client/server system at PT stations in Vienna. Results show that privacy-compliant visual data collection is feasible and generates reliable movement patterns. Empirical findings indicate clear trip-chaining behavior, with a substantial share of wl PL users accessing PL in direct connection with PT. The majority of interactions occurred on foot or via PT, indicating a reduction of secondary emission. The study demonstrates the potential of wl PL at PT stations to support sustainable city logistics and positions VeStat as a scalable tool for data-driven urban mobility planning.

Keywords: GDPR-Compliant Camera System, Public Transportation, Parcel Lockers, Last-Mile Logistics, VeStat

1. Introduction and Literature

Achieving climate-neutral urban mobility requires a close integration of citizen transport – particularly through public transportation (PT) - and urban freight logistics to tackle the urgent challenges cities face in the next decades. A variety of logistics tasks must be addressed in order to facilitate the movement of citizens and consumer goods through urban areas. A proportion of these goods are destined for the end consumer, while others are intended for distribution to shops or (micro)hubs. In the public sphere, the execution of these tasks necessitates either a designated location for their consideration or a specific venue for their execution. On a more general note concerning climate-readiness cities a lot of landmark decisions need to be made. In order to be considered a 'future-ready' decision, urban areas respectively the decision makers

and administrators must be capable of making decisions based on empirical data and scientific research. The objective of these decisions in the realm of city logistics must be the creation of a resilient infrastructure that is able to deal with a wide range of requirements. Given the scarcity of public space and the constraints imposed by GDPR regulations and limited public budgets, there is a pressing need for a cost-effective, reliable, and GDPR-compliant source of data collection in the public space. It is evident that PT plays a pivotal role in facilitating sustainable, inclusive and shared mobility for all citizens and therefore a vital resource that needs to be leveraged. However, the increasing volumes of e-commerce pose a significant challenge (Deutsch & Golany 2018), necessitating the development of efficient last-mile (LM) solutions to address the rising demand for parcel delivery as the development is further compounded by the emergence of sustainability concerns (Buldeo Rai et al. 2023) especially in dense urban areas. To address these challenges of the LM, scalable solutions such as white-label parcel lockers (wl PL) have the potential to reduce travel distances and emissions in the LM (Niemeijer & Buijs 2023) while using public space efficiently functioning as Micro Hubs that can be accessed by authorised private and commercial customers. But wl PL in the public (owned) space are in competition with a lot of other interests and requirements; therefore accessibility and spatial location are a key success factor for wl PL (Campisi & Di Ruocco 2025), which evidently positions these public (owned) locations as those with considerable potential. Even if wl PL reduce travel distances and lower emissions due to bundled delivery (Peppel & Spinler 2022) empirical evidence on the interaction between PT and wl PL regarding enabling trip chaining is limited.¹ Despite the strategic importance of linking PT with LM logistics, empirical evidence on how individuals combine these mobility components remains scarce (Hofer et al. 2020). Real-world mobility behavior and micro-interactions in public spaces – especially at PT - are difficult to capture without direct observation in a pragmatic and cost-effective way. The lack of empirical data and ways to collect such data limits the ability to assess how public space in general should be designed and how PT can be leveraged even more to tackle sustainability objectives. This led to the following research question: Is it possible to determine whether wl PL at PT stations can effectively support the sustainable practice of trip-chaining and therefore contribute to sustainable city logistics?

2. Methods and Material

2.1 Camera Development

To address this gap, a pilot study was conducted at PT stations in the Vienna area using VeStat GDPR-compliant, edge-AI-supported client/server traffic analysis system, which was 100% developed by members of the project group in Vienna, Austria.² The data is therefore only stored

¹ The literature is as scarce on trip-chaining as it is on crowdshipping: Fessler, A., Cash, P., Thorhauge, M., & Haustein, S. (2023). A public transport-based crowdshipping concept: Results of a field test in Denmark. *Transport Policy*, 134, 106–118. <https://doi.org/10.1016/j.tranpol.2023.106118>

² While the broader project employed a mixed-methods design, incorporating focus groups on user acceptance, in-situ pre/post surveys, and an online survey with a factorial experiment design, these components are mentioned solely for the sake of complete documentation. The present study focuses exclusively on the camera-based empirical approach.

on Austrian servers. The system was enhanced with a multi-client topology enabling synchronized trajectory analysis across multiple camera nodes. The uniqueness and biggest advantage of this system approach is that, in addition to the automatically recorded traffic movements (individual trajectories or individual points), GDPR-compliant images of public spaces are generated and saved.³ This enables recording the number of people and vehicles of various types in order to derive (traffic) movements, traffic volumes and other mobility-related parameters to allow e.g. quality assurance. Technically, each camera is connected to a microprocessor with object detection capability. On site the software automatically evaluates the objects contained therein (e.g. cars, heavy vehicles, people, bicycles, etc.) within processing times of less than 200 milliseconds. Any people are overwritten with a grey rectangle and made unrecognisable. This process cannot be reversed, which means that identification is not possible at any stage. There are then two options:

Option A: Only the counted objects are transmitted to a server via 4G/5G data connection. After processing, the image is deleted and cannot be recovered.

Option B: For documentation purposes, the images with unrecognisable people footage are also sent to the server.

For the support equipment consisting of the power supply adapter and a spare power socket an IP44 compatible storage box was designed. Advantage of the setup is that only the power cables connecting the camera and the nearest power supply are exiting the storage box and can easily be isolated. The remaining items are stored inside of the box. In order to prevent head built-up and provide additional head shielding the storage box was bolted onto a mounting frame with at least 5 cm of space in-between the box and the frame. On the legal side, an independent law firm was commissioned to conduct a GDPR-related legal review of the above facts in order to determine whether the described procedure gives rise to any data protection obligations and, if so, whether any data protection labelling requirements must be met. They concluded that the irreversible anonymisation of individuals by the software means that it is not possible to identify the person, which is why the transmission of the images to the server does not fall within the scope of the GDPR due to the lack of personal data. The Data Protection Act (DSG), which contains provisions on image processing, is also applicable in addition to the GDPR. Since the camera is primarily intended to record the road and not people or vehicle registration numbers, and this serves scientific documentation purposes, the exception applies, meaning that labelling is also not required when sending images. This technical and legal setup facilitated the VeStat camera system that enables the anonymized detection and tracking of individual movement patterns in and around PT stations, allowing the reconstruction of trip-chains between PT use and LM logistics service wl PL without collecting personalised data (GDPR-conform).

2.2 Data Collection

The methodological workflow consisted of several stages. Initially, suitable PT locations were identified in cooperation with Wiener Linien and Wiener Lokalbahnen. At these selected locations, wl PL were publicly tendered and subsequently installed by wl PL operators.

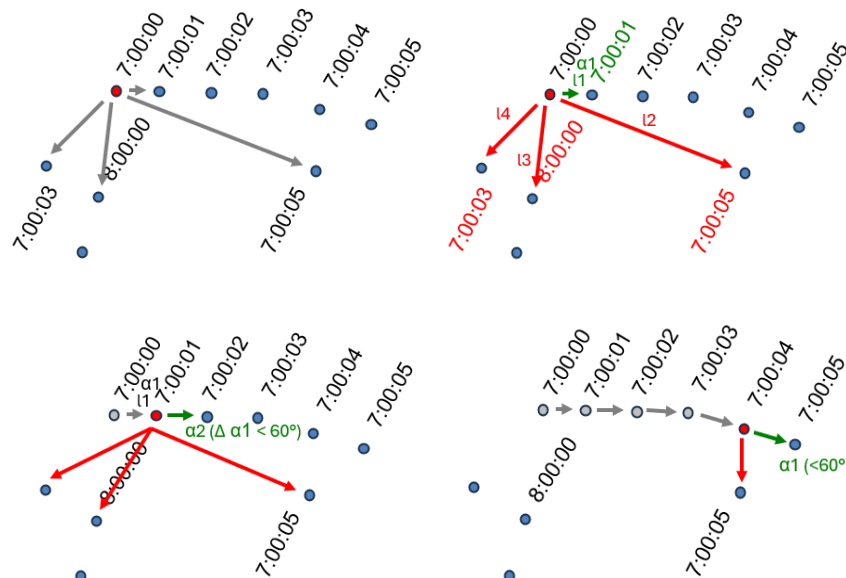
³ Systems on the market work mostly with pixelated images that are uploaded on data clouds and are then at a later stage processed or trajectories without corresponding images.

Subsequently, a case-specific data collection plan for the VeStat camera system was formulated. The plan defined spatial and temporal observation areas, determined optimal camera positions, and included on-site technical feasibility assessments. At each selected PT station, a trio of cameras was installed and calibrated to enable synchronized multi-perspective trajectory analysis across overlapping fields of view. The collection of data was conducted over a period of two weeks at each research location. The transmission of all image data was conducted in real time, in strict accordance with GDPR regulations, with no personally identifiable information retained. Up to the present moment, three PT locations in Vienna have been successfully equipped and assessed.

2.3 Data Analysis

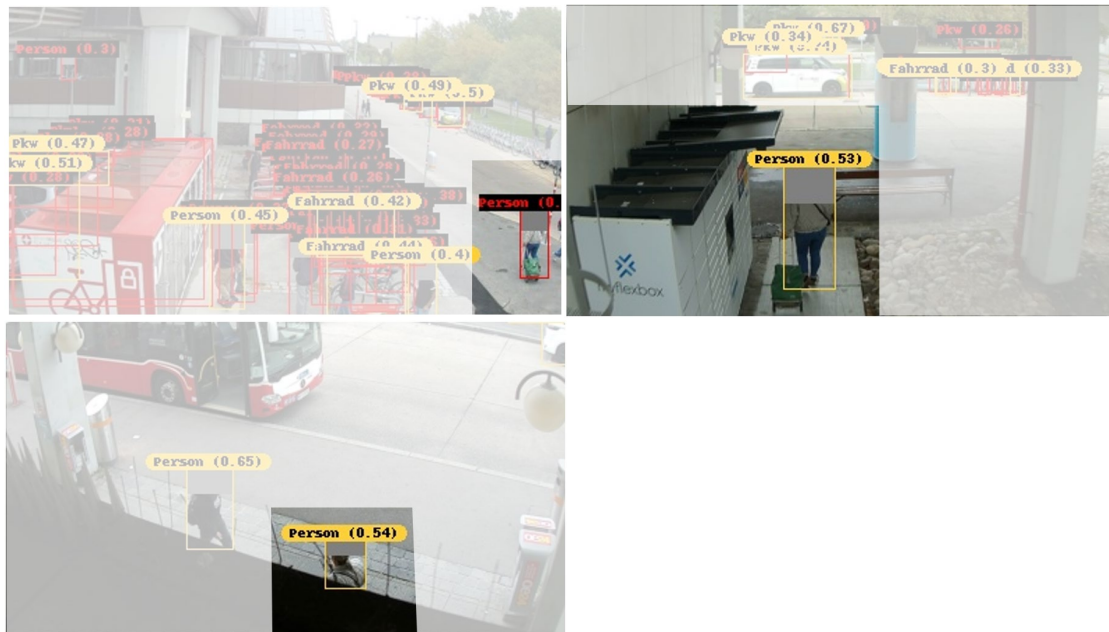
The system is designed for fully automated AI-based generation and evaluation of anonymized trajectories. Within the scope of the project a new set of trajectory reconstruction algorithms were developed, optimized and implemented as prototypical procedures. Lists of detected items of the same detection class such as pedestrians together with their georeferenced position were automatically extracted from the server system for a defined time period. For an initial starting position, applicable neighbour locations were assessed (see Graphic 1). The applicability as a neighbour was defined by calculating the speed between both positions. If the speed was within a defined threshold the point was defined as potential neighbour. Out of all applicable neighbours the closest neighbour point was then selected along with the angle between both positions for further assessments. For each position the procedure was repeated with the additional constraint that the angle between both positions needed to be within a defined threshold. As soon as no new end point can be found the trajectory ends.

Graphic 1: Neighborhood assessments for the automatic assessment of trajectories of individual users



Since the cameras are providing GDPR-compliant images in addition to the automated procedures manual image assessments have also been carried out in order to assess trip chains and interactions with wl PL (see Graphic 2: individual example).

Graphic 2: Visual review of a user's individual travel path to the wl PL (incl. interaction)



3. Results

3.1 Observations

The pilot demonstrated that GDPR-compliant visual data collection in public spaces is feasible and capable of generating reliable aggregated movement patterns. The VeStat system successfully captured anonymized individual trajectories and revealed how PT usage is connected to the LM logistics solution wl PL. In addition to the automated data collection, manual image-based analyses were conducted to examine interactions between PT users and wl PL in greater detail. For a selected reference weekday (no holidays, regular workday, late summer), all wl PL interactions at the stations of Wiener Linien “U6 Alterlaa” and Wiener Lokalbahnen “Guntramsdorf” were manually analyzed between 07:00 and 19:00, corresponding to the main activity period. At each location more than 20 interactions were observed during this time window, including end users and (CEP) service provider. The frame-by-frame analysis enabled the extraction of key characteristics, including gender distribution, type of interaction, duration of interaction, time of interaction (on average 40 to 60 seconds), and evidence of trip-chaining with PT (ranging from 5 % to 30 %).

Including the CEP service provider, the gender distribution was evenly balanced at 50% male and 50% female (60% female at Wiener Lokalbahnen “Guntramsdorf”). This indicates that wl PL infrastructure at safe and conveniently located PT stations is used equally by all genders, supporting its classification as an inclusive urban logistics technology.

With regard to the type of interaction, usage patterns clearly reflected the flow from logistics providers to end consumers. At “Wiener Linien “U6 Alt Erlaa” approximately 92% of users collected a parcel, 4% returned a parcel (one user), and 4% of interactions involved the CEP

service provider replenishing the locker system. This distribution confirms the intended functional role of wl PL within the LM delivery ecosystem.

Interaction duration was analyzed as an indicator of usability and service quality. The average interaction time was 40 to 58 seconds, suggesting a smooth and largely problem-free user experience. For Wiener Linien “U6 Alt Erlaa” when excluding the return transaction, the average duration decreased to 51 seconds. Further excluding the two longest interaction times, routine parcel collection required an average of 41 seconds. Experienced users were observed to complete interactions in as little as 25 to 35 seconds, indicating high efficiency and ease of use.

For Wiener Linien “U6 Alt Erlaa” temporal analysis revealed two parcel collections before 08:30, followed by the CEP delivery at 11:08 who delivered 22 parcels into the PL. The majority of interactions (17) occurred between 11:35 and 16:25, with four additional interactions recorded before the end of the observation period at 19:00. These findings suggest that wl PL are typically not used during the morning commute but rather in combination with other trip purposes. While dwell times cannot be empirically confirmed, it is reasonable to assume that many of the 22 parcels deposited at 11:08 were collected by users later that day as 21 interactions with the PL were recorded after the CEP delivery. One could also see that parcel collections did not occur during night times with a strong decrease of interactions after 19:00.

The central focus of this study is the analysis of trip-chaining behavior between PT and wl PL, as well as the associated reconstruction of travel chains. Using frame-by-frame image analysis, it was possible to determine whether tracked individuals entered the observation area directly from the entrance (exit respectively) of the U6 metro station, arrived from nearby bus stops, or approached from other directions. This approach enabled a reliable attribution of PL interactions to specific access modes. The results indicate that 29% of all observed interactions with the PL were directly linked to PT use. A further 63% of users approached the PL on foot before interacting with it. One individual (4%) arrived by private car. The CEP service provider entered the camera field on foot; however, the delivery vehicle was parked in close proximity⁴. This demonstrates that trip-chaining behavior can be observed shortly after the implementation of PL at PT stations. When PL infrastructure is spatially integrated into PT nodes, users actively combine passenger transport and LM logistics within a single travel chain. From a sustainability perspective, it is particularly noteworthy that 92% of all PL interactions were conducted either on foot or in direct connection with PT. This confirms that the location of PL at PT stations effectively prevents secondary environmentally harmful modes of transport (e.g. cars) by users at the point of parcel collection and thus safeguards a key sustainability condition: avoiding additional CO₂ emissions (secondary emissions) associated with private motorized access to the LM logistics service PL.

3.2 Take Aways

These findings confirm that anonymized trajectory data can be extracted in real public environments without compromising data protection, thus providing data for analyzing public space usage that could be applied in a variety of different use cases in the field of city-logistics or

⁴ Those primary emissions are not part of this paper, but are dependent on the various factors such as type of delivery vehicle.

urban planning. In terms of content-related findings, the pilot revealed clear indications of trip-chaining behavior between PT and wl PL. The anonymized trajectory data showed that PT some users in Vienna accessed the wl PL after completing their PT journey. This demonstrates a functional linkage between PT and LM logistics at the tested location and confirms the high potential of wl PL to support and incentivize sustainable trip-chaining practices especially with no negative secondary travel effects. For Wiener Lokalbahnen “Guntramsdorf” only a minority of users combined the parcel interactions when using the Wiener Lokalbahnen.

The empirical findings clearly support the implementation of wl PL at PT stations to encourage the sustainable practice of trip-chaining and use of public space. Such infrastructure reduces redundant travel linked to parcel pickup, increases the use of public space at train stages outside the main purpose and enhances the integration of passenger and freight mobility. Additionally, the study shows that the VeStat traffic analysis system has strong potential for future urban mobility research and can be further optimized for advanced monitoring (AI analysis) and planning applications. Overall, this work contributes to one of the first empirical analyses of integrated passenger-freight mobility in public spaces using GDPR-compliant AI-based sensing technologies.

4. Conclusion

This study demonstrates the strong potential of GDPR-compliant, edge-AI-based traffic analysis systems to support data-driven decision-making in public urban spaces. The VeStat system proved to be a cost-efficient, flexible, and rapidly deployable solution for empirically capturing anonymized movement patterns, thereby enabling reliable analyses of public space usage without compromising data protection. Its successful pilot application has already triggered follow-up initiatives with European partners, underlining both its scalability and practical relevance in the field. From a methodological and technological perspective, the project represents a significant innovation by combining synchronized multi-node trajectory analysis with strict privacy compliance in accordance with European regulations; shown in this paper with exemplary pilot evaluations that will be enhanced in the future. The integration of this latest data collection approach with the evaluation of wl PL at PT stations generated, for the first time, robust empirical evidence on the interaction between passenger and freight mobility in real public environments. In terms of substantive findings, the study provides clear illustrative empirical indications of trip-chaining behavior between PT usage and LM logistics. The exemplary observed linkage between PT journeys and subsequent use of wl PL highlights the high potential of such infrastructure to reduce redundant travel, optimize LM logistics, and support sustainable urban mobility systems. The analysis also provides empirical insights into the frequently debated issue of secondary emissions caused by end consumers when collecting parcels from PL. In the observed case, nine out of ten interactions were carried out either on foot or in combination with PT in Vienna. This strongly suggests that wl PL located at PT stations have a net CO₂-reducing effect by minimizing or eliminating additional private car trips only for parcel collection. Based on these findings, it can be inferred more generally that locations which enable trip-chaining for users are significantly more likely to generate positive environmental effects. By integrating LM logistics infrastructure into existing mobility routines, such sites reduce the need for dedicated secondary trips and thereby enhance the overall sustainability performance of urban logistics

solutions. Overall, the findings confirm that wl PL at PT stations represent a viable and future-oriented solution for integrating passenger and freight transport. In conclusion, this work contributes one of the first empirical analyses of integrated passenger–freight mobility in public spaces using AI-supported, GDPR-compliant sensing technologies, which in itself is a really promising and novel method of data collection in public spaces. It offers actionable insights for cities, municipalities, and logistics stakeholders and establishes a solid foundation for future research and evidence-based planning toward climate-neutral urban mobility.

Limitations

The results clearly show that real-time data processing, privacy protection, and AI-supported analysis can be successfully aligned. A new algorithm of trajectory reconstruction and classification was successfully prototyped and shall be applied more extensively within future projects. The system’s ability to operate in real time and without storing personal data demonstrates strong practical potential. Due to public administration and bureaucratic hurdles, it was not possible to establish a location in the ‘inner districts of Vienna’ and analyse it with the camera system. It is precisely here, where public space is under even greater pressure, that there is great potential to be explored, which now remains for future projects.

Literaturverzeichnis

Buldeo Rai, H., Touami, S., & Dabanc, T. (2023). Not all e-commerce emits equally: Systematic quantitative review of online and store purchases’ carbon footprint. *Environmental Science & Technology*, 57(1), 708–718. <https://doi.org/10.1021/acs.est.2c05872>

Campisi, T., & Di Ruocco, I. (2025). Accessibility and spatial location of parcel lockers in last-mile delivery: A literature review. *Open Transportation Journal*, 19, e26671212391037. <https://doi.org/10.2174/0126671212391037250827100344>

Deutsch, Y., & Golany, B. (2018). A parcel locker network as a solution to the logistics last mile problem. *International Journal of Production Research*, 56(1–2), 251–261. <https://doi.org/10.1080/00207543.2017.1395490>

Fessler, A., Cash, P., Thorhauge, M., & Haustein, S. (2023). A public transport-based crowdshipping concept: Results of a field test in Denmark. *Transport Policy*, 134, 106–118. <https://doi.org/10.1016/j.tranpol.2023.106118>

Hofer, K., Fluchner, S., Fellendorf, M., Schadler, M., & Hafner, N. (2020). Estimation of changes in customers’ mobility behaviour by the use of parcel lockers. *Transportation Research Procedia*, 47, 425–432. <https://doi.org/10.1016/j.trpro.2020.03.116>

Niemeijer, R., & Buijs, P. (2023). A greener last mile: Analyzing the carbon emission impact of pickup points in last-mile parcel delivery. *International Journal of Logistics Research and Applications*. <https://doi.org/10.1080/13675567.2023.2205714>

Peppel, M., & Spinler, S. (2022). The impact of optimal parcel locker locations on costs and the environment. *International Journal of Physical Distribution & Logistics Management*, 52(4), 324–350. <https://doi.org/10.1108/IJPDLM-07-2021-0287>