# Does the Temporal Asymmetry of Station Traffic Mirror Urban Functions? Evidence from Budapest Bike-Sharing

Márton Korompay(✉) and Dávid Földes

Department of Transport Technology and Economics, Faculty of Transportation Engineering and Vehicle Engineering, Budapest University of Technology and Economics, Muegyetem rkp. 3., Budapest H-1111, Hungary
korompaymarton@edu.bme.hu

**Abstract.** Bike-sharing supports sustainable mobility as a flexible, low-emission transport alternative. The study explores temporal trends in a year, identifying asymmetries in station activity and defining station profiles. The temporal analysis spans several dimensions to capture variations in demand. The method was applied to a case study in Budapest, Hungary, where MOL Bubi station-based bike-sharing system operates. The study focuses on weekdays, and the spatial analysis was interpreted in the South-Buda university environment. Peak hour analysis shows asymmetries in station behaviour, identifying sink (origin) and source (destination) stations. Accordingly, three station profiles were defined: a station in profile 1 acts as a sink during morning peak hour and as a source in the afternoon, while in profile 3, a station behaves the opposite way. Moreover, in profile 2, a station exhibits nearly balanced behaviour during the whole day; it is equally used as an origin and a destination. The results verified the assumed characteristics of the application environment – the profiles correspond to the urban function of the station environment – stations in the residential area are sources in the morning peak and sinks in the afternoon peak, thus stations next to the university campuses are sinks in the morning.

**Keywords:** Bike-sharing · Usage patterns · Station asymmetry

## 1 Introduction

Bike-sharing systems (BSS) have become an integral part of sustainable urban mobility, providing flexible and environmentally friendly transport alternatives across many European cities. While numerous studies address the rebalancing problem, the underlying causes of asymmetric station traffic are often assumed rather than explicitly analyzed [1]. Previous studies have shown that origin-destination flows are strongly shaped by time-of-day intervals, particularly morning and afternoon peaks, which define whether a station acts as a source (origin) or a sink (destination) [2, 3].

Research on BSS asymmetry highlights two major findings with implications for both planning and operations. Spatial source-sink patterns emerge between residential

© The Author(s) 2027
D. Esztergár-Kiss et al. (Eds.): TRAconference 2026, LNMOB, pp. 1104–1111, 2027.
https://doi.org/10.1007/978-3-032-37192-8_132

and employment areas: morning peaks generate large demand from peripheral neighborhoods toward city centers, while the reverse occurs in the afternoon, creating structural imbalances that necessitate rebalancing strategies [4]. Asymmetries vary across time, being most pronounced during morning and evening peak hours, and less evident at night or weekends. They are further amplified by seasonal and weather effects [5]. Understanding asymmetry reveals the gap between demand and supply in BSS, informing rebalancing policies, station placement [6], and the integration of shared micromobility into broader urban transport networks [7].

To measure bike-sharing station origin-destination traffic imbalances, researchers typically apply absolute indicators (difference between pick-ups and drop-offs) and relative indicators (normalizing by total station traffic) to allow comparability across locations [8]. Beyond pure volume differences, studies in Helsinki and London have highlighted the importance of station profiles, defined by clustering temporal distribution to capture typical behavioural patterns [9, 10]. These profiles often distinguish morning sources, evening sinks, balanced stations, or leisure-oriented stations, providing a functional classification of station roles within the system. European case studies further confirm that spatio-temporal asymmetry is not random but reflects land-use, transport connectivity, and seasonal effects. Residential areas tend to generate departures in the morning and arrivals in the evening, while business districts show the opposite pattern [11]. BSS systems around universities show clear source-sink asymmetries driven by academic schedules. Campus stations act as sinks in the morning as students, teachers, and university employees arrive, and sources in the afternoon, when they return to residential areas [12, 13]. Seasonal variation has also been reported, with higher usage in spring and summer than in winter [14]. These results suggest that profiling stations by their temporal asymmetries offers an interpretable framework for understanding demand dynamics.

Despite this progress, Eastern European cities remain underrepresented in the literature, even though their socio-spatial structures may produce distinct usage patterns [15]. This study addresses this gap by applying a descriptive, data-driven analysis to a full year of trip-level data from the MOL Bubi BSS in Budapest. By combining temporal aggregation, asymmetry indices, the clustering of station profiles, and spatial mapping, we aim to provide new evidence on the dynamics of asymmetric station traffic in a Central European context.

The structure of the paper is as follows. The research context outlines the key characteristics of the bike-sharing service examined, the datasets employed, and the steps of the methodological analysis. In the results and discussion, the main findings of the analysis are presented, their implications for bike-sharing operations are interpreted, and the outcomes are compared with relevant literature. The paper is completed with concluding remarks.

## 2 Research Context: Case Study Location, Data, Methodology

The case study focuses on Budapest, Hungary, where the public bike-sharing system Mol Bubi operates with more than 200 docking stations and several thousand bicycles. The service records millions of rentals annually, offers affordable pricing (a monthly

pass costs €2.5, including the first 30 min free), and is partially integrated into the public transport network (without a common tariff system), supporting first- and last-mile connections. Therefore, Budapest's expanding bike-sharing system provided an appropriate context for applying the analytical approach developed in this research.

The study follows a descriptive, data-driven methodology based on a full year of anonymized trip-level data from Mol Bubi, provided by the Centre for Budapest Transport (BKK). Each trip record includes a unique identifier, start and end times, station codes and names, and GPS coordinates.

The steps of the analysis are as follows.

1. **Asymmetry analysis.** Examining how station traffic differs in the specified time intervals using the absolute and relative asymmetry index. The absolute asymmetry index is the difference between the number of pick-ups and drop-offs, while the relative asymmetry index is the ratio of absolute asymmetry to the total number of pick-ups and drop-offs.
2. **Temporal analysis.** Trips are aggregated by various time intervals: ***seasonal*** (regular, holiday, year-end), ***monthly, weekly,*** **and** ***time-of-day*****.** We determined the time intervals based on the following criteria:
   (a) We examined all the 24-h.
   (b) We applied absolute asymmetry (difference between pick-ups and drop-offs), as the early morning and late evening have less significant activity.
   (c) We used **RMS** (Root Mean Square) to describe the behaviour of all stations for a given hour. By eliminating signs, RMS provides a possible solution for detecting the asymmetry characteristic of the data set.
   (d) Based on the 24-h RMS values, we determined the number and range of intraday time intervals using the SSE (Sum of Squared Errors) method.
3. **Profile formation.** The stations' origin-destination traffic has its own characteristics, but there are many similarities; stations with similar temporal asymmetries can be integrated into the same station profile (by tracking changes in source-sink behaviour). The algorithm developed clusters the stations by applying the relative asymmetry index. The relative index reflects the asymmetric behaviour of individual stations more accurately (in the case of the absolute indicator, minor asymmetry at high-traffic stations can be misleading). It ensures interpretability through cluster prototypes, making station roles easy to classify (e.g., morning source, evening sink, balanced).
4. **Spatial analysis.** Based on the map representation of profiles assigned to stations, spatial analysis can be performed. By monitoring the location of stations with similar characteristics, it is possible to draw conclusions about the asymmetric behaviour of the system.

## 3 Results and Discussion

We analysed the demand characteristics in temporal analysis in monthly, weekly, and daily aggregates. We applied temporal and spatial limitations during the analysis. Temporal limitation: analysis of weekdays only; spatial limitation: interpretation of results in the South-Buda university environment.

Significant asymmetries only occurred during intraday periods. In terms of asymmetric behaviour, the peak hours are from 7–9 am and the afternoon from 16–18. Based

on the absolute asymmetry index, Fig. 1 presents the specified time intervals applying the RMS and the SSE method. We defined eight time intervals for measuring asymmetry to understand how similarities and differences exist between the stations' behaviour.

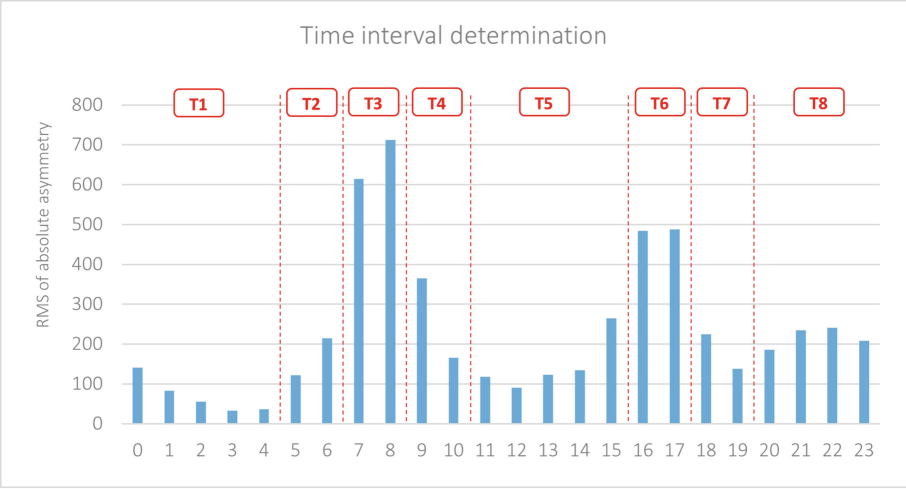



**Fig. 1.** Time intervals based on absolute asymmetry index

These defined time intervals are based on the actual characteristics of the daily rentals in Budapest. Other studies examined temporal variations in bike-sharing demand using different and more generalized approaches. Weekday–weekend distinctions were applied to capture systematic differences in usage patterns [16], while intraday segmentation divided the day into five intervals: peak morning (6:01–10:00), midday (10:01–14:00), peak afternoon (14:01–18:00), evening (18:01–23:00), and overnight (23:01–6:00) [13].

Based on the relative asymmetry index, we defined three station profiles. We determined prototypes for all three profiles by averaging the relative asymmetry indices of stations. Figure 2 shows the changes assigned to these prototypes according to the specified time intervals.

We established that the behaviour of the three profiles is entirely different, especially in the morning peak. The degree of asymmetry is lower in the afternoon – presumably due to increased leisure-motivated rentals. Similar findings were reported for Helsinki, where a spatiotemporal functional analysis revealed strong morning imbalances with 'mountain-shaped' patterns in working areas and 'valley-shaped' patterns in residential zones. Weekday imbalances were also more significant than weekends and holidays [9].

The characteristics of the profiles are summarized in Table 1.

The profiles assigned to the stations are illustrated in Fig. 3.

The spatial distribution of station profiles reflects surrounding land-use characteristics, particularly residential neighbourhoods, university campuses, and multimodal transport nodes. The stations in the residential area are red (profile 3: morning peak source, afternoon peak sink), while those near the university and working centers are blue (profile 1: morning peak sink, afternoon peak source). The bike station at Kelenföld

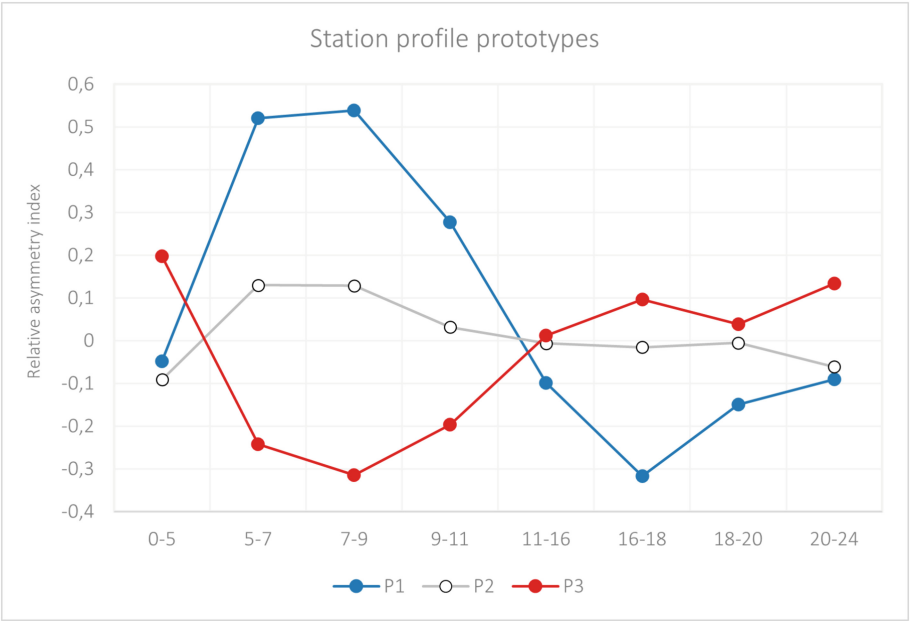



**Fig. 2.** Prototypes of station profiles

**Table 1.** Prototype behaviour in peak hours according to profiles

| | Morning peak | Afternoon peak |
|---|---|---|
| Profile 1 | sink | source |
| Profile 2 | neutral | neutral |
| Profile 3 | source | sink |

railway station (1131) is red because people arriving by train and suburban buses may not necessarily use public transport in the city. At Mórcz Zsigmond Square (1107), the station color is white; there is an M4 subway line that people can use all day in both directions, so no asymmetry in the number of pick-ups and drop-offs.

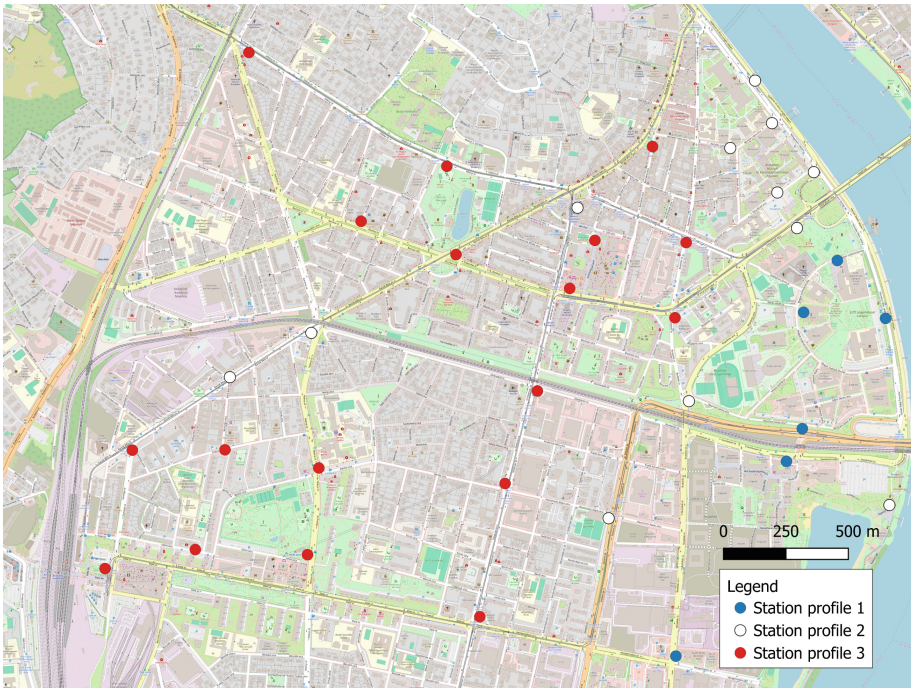



**Fig. 3.** Map representation of station profiles

## 4 Conclusion

We developed a comprehensive analysis of station traffic imbalances. The study builds on temporal asymmetry analysis, particularly asymmetries within weekday time intervals. The relative asymmetry index was applied in the behavioural analysis to cluster stations into profiles. Three station profiles were defined according to changes in the source-sink behaviour of stations during the day.

The results verified the assumed characteristics of the application environment. We found that the stations in the residential area are sources in the morning peak and sinks in the afternoon peak, while those near the university and working centers act in the opposite way – are sinks in the morning peak and sources in the afternoon peak. The findings demonstrated that spatiotemporal usage patterns are not random but reflect the socio-spatial structure of the city, underlining that the method has a universal applicability criterion for connecting usage data with urban area characteristics.

Future research should focus on increasing the depth of the analysis by extending the number of identified station profiles and by applying the methodology to the entire service area. Such a comprehensive evaluation would allow a more detailed understanding of the spatial heterogeneity of station behaviour and strengthen the generalizability of the findings.

**Acknowledgement.** Márton Korompay would like to express his gratitude for the following scholarship program: Project no. 2024-2.1.2-EKÖP-KDP-2024-00005 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the EKÖP_KDP-24-1-BME-12 funding scheme.

## References

1. Médard de Chardon, C., Caruso, G., Thomas, I.: Bike-share rebalancing strategies, patterns, and purpose. J. Transp. Geogr. **55**, 22–39 (2016). https://doi.org/10.1016/j.jtrangeo.2016.07.003
2. Tong, Z., Liu, Y., Zhang, Z., An, R., Zhu, Y.: Bike-sharing source-sink space recognition based on riding flow density clustering method. Geomatics Inf. Sci. Wuhan Univ. **50**, 184-196and206 (2025). https://doi.org/10.13203/j.whugis20220467
3. Lu, K.-F., Liu, Y., Peng, Z.-R.: Unraveling urban bike-sharing dynamics: spatiotemporal imbalances in bike rentals and returns in Washington D.C. Cities. **162**, 105967 (2025). https://doi.org/10.1016/j.cities.2025.105967
4. Dell'Amico, M., Hadjicostantinou, E., Iori, M., Novellani, S.: The bike sharing rebalancing problem: mathematical formulations and benchmark instances. Omega. **45**, 7–19 (2014). https://doi.org/10.1016/j.omega.2013.12.001
5. Kim, K.: Investigation on the effects of weather and calendar events on bike-sharing according to the trip patterns of bike rentals of stations. J. Transp. Geogr. **66**, 309–320 (2018). https://doi.org/10.1016/j.jtrangeo.2018.01.001
6. García-Palomares, J.C., Gutiérrez, J., Latorre, M.: Optimizing the location of stations in bike-sharing programs: a GIS approach. Appl. Geogr. **35**, 235–246 (2012). https://doi.org/10.1016/j.apgeog.2012.07.002
7. Oeschger, G., Carroll, P., Caulfield, B.: Micromobility and public transport integration: the current state of knowledge. Transp. Res. D. **89**, 102628 (2020). https://doi.org/10.1016/j.trd.2020.102628
8. Nair, R., Miller-Hooks, E., Hampshire, R.C., Bušić, A.: Large-scale vehicle sharing systems: analysis of Vélib. Int. J. Sustain. Transp. **7**, 85–106 (2013). https://doi.org/10.1080/15568318.2012.660115
9. Piter, A., Otto, P., Alkhatib, H.: The Helsinki bike-sharing system—insights gained from a spatiotemporal functional model. J. R. Stat. Soc. Ser. A Stat. Soc. **185**, 1294–1318 (2022). https://doi.org/10.1111/rssa.12834
10. Liu, Y., Chen, M., Arribas-Bel, D., Singleton, A.: Profiling the Dynamic Pattern of Bike-sharing Stations: a case study of Citi Bike in New York City. In: Proceedings of the 29th Annual GIS Research UK Conference (GISRUK 2021), Cardiff. Zenodo, Geneva (2021). https://doi.org/10.5281/zenodo.4665706
11. Faghih-Imani, A., Eluru, N.: Analysing bicycle-sharing system user destination choice preferences: Chicago's divvy system. J. Transp. Geogr. **44**, 53–64 (2015). https://doi.org/10.1016/j.jtrangeo.2015.03.005
12. Kutela, B., Teng, H.: The influence of campus characteristics, temporal factors, and weather events on campuses-related daily bike-share trips. J. Transp. Geogr. **78**, 160–169 (2019). https://doi.org/10.1016/j.jtrangeo.2019.06.002
13. El-Assi, W., Salah Mahmoud, M., Nurul Habib, K.: Effects of built environment and weather on bike sharing demand: a station level analysis of commercial bike sharing in Toronto. Transportation. **44**, 589–613 (2017). https://doi.org/10.1007/s11116-015-9669-z

14. Talavera-Garcia, R., Romanillos, G., Arias-Molinares, D.: Examining spatio-temporal mobility patterns of bike-sharing systems: the case of Bici MAD (Madrid). J. Maps. **17**, 7–13 (2021). https://doi.org/10.1080/17445647.2020.1866697
15. Radzimski, A., Dzięcielski, M.: Exploring the relationship between bike-sharing and public transport in Poznań. Transp. Res. A. **145**, 189–202 (2021). https://doi.org/10.1016/j.tra.2021.01.003
16. An, Q., Qin, Z., Cheng, L., Li, W.: Assessing the temporal and spatial resilience of bike-sharing demand: a spatiotemporal dynamic analysis. KSCE J. Civ. Eng. **29**, 100045 (2025). https://doi.org/10.1016/j.kscej.2024.100045

**Open Access** This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

