TOP 10 DIRECTIONS: THE TEMPORAL DYNAMICS OF BIKE-SHARING DEMAND IN BUDAPEST

MÁRTON KOROMPAY [a] *, DÁVID FÖLDES [a]

[a] *Faculty of Transportation Engineering and Vehicle Engineering, Budapest University of Technology and Economics, Budapest, Hungary*
* *corresponding author: korompaymarton@edu.bme.hu*

1. Introduction

Bike-sharing systems have emerged as a vital element of sustainable urban mobility, offering flexible and low-emission transport alternatives while generating large-scale data that provide valuable insights into travel demand and network dynamics. Previous studies have extensively examined bike-sharing systems in system-level optimization, rebalancing strategies [1], and demand forecasting [2]. Origin-Destination (OD) matrix analysis has been widely applied to capture spatial flows, identify key mobility corridors, and understand usage patterns across different urban contexts [3]. Furthermore, OD-based approaches have been used to highlight travel imbalances [4], classify station types [5], and explore user heterogeneity [6].

While these contributions provide a strong foundation for understanding system performance, relatively few studies have addressed the temporal stability of the most demanded OD directions. Existing research tends to focus on aggregated flows, optimization, or clustering, with less emphasis on whether the same dominant directions persist across months, weekdays versus weekends, or consecutive hours. This represents a gap in research, as the stability and variability of key directions directly impact operational efficiency, redistribution planning, and service reliability.

The study focuses on the Top 10 OD directions in the Bubi station-based bike-sharing system in Budapest. The analysis applies the Rank-Biased Overlap (RBO) method [7], [8], which is designed for comparing ranked lists by considering both the degree of overlap and the ordering of elements. Unlike traditional similarity indices, RBO is top-weighted and accommodates lists of unequal length, making it suitable for evaluating ranked mobility directions. By applying the RBO method to annual, monthly, day-type, and hourly temporal slices, this study aims to reveal which dominant directions remain stable or change over time – thereby contributing new evidence on the temporal dynamics of bike-sharing demand.

2. Methodology

The analysis evaluated the temporal dynamics of the most demanded bike-sharing directions. The methodological framework is summarized in Figure 1.

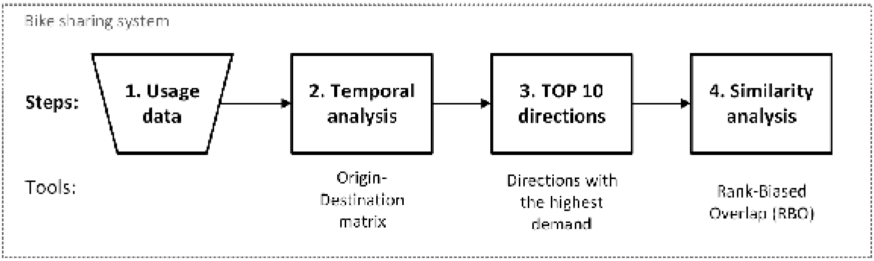

Figure 1: Methodological steps of the TOP 10 direction analysis

2.1. Step 1. Usage data
Collecting usage data, such as trip-based records including the origin station, destination station, start time, and end time. The database is to be pre-processed to remove incomplete or inconsistent records. In this study, the analysis relied on one year of bike-sharing trip records (September 2023 – August 2024). In the period, more than 200 stations and several thousand bicycles were operated, resulting in approximately 3.5 million possible OD-pairs.

2.2. Step 2. Temporal analysis
To capture temporal variations, the dataset was segmented into different time periods. The following breakdowns were applied:

- Annual level.
- Monthly level.
- Daytype level (weekday vs. weekend).
- Hourly level.

An OD matrix was constructed for each temporal category, where each cell represented the number of trips between a pair of stations during the given period.

2.3. Step 2. Top 10 directions
From each OD matrix, the TOP 10 directions were selected. These represent the network's strongest relations, highlighting the bike-sharing system's main travel corridors.

2.4. Step 4. Similarity analysis
A similarity metric was applied to assess the stability and variability of the Top 10 directions over time. The Rank-Biased Overlap (RBO) method was chosen, as it measures the similarity between two ranked lists while accounting for both overlap and ordering. RBO is top-weighted: higher-ranked elements contribute more strongly to the similarity score. This property makes it suitable for comparing ordered lists of the most demanded directions, where the first positions reflect the most dominant relations.

3. Results

The analysis reveals typical attributes of the dominant directions. The Top 10 trips are short-distance rides and reflect the local character of bike-sharing use. They are linked to recreational trips on

Margaret Island, a major leisure destination in Budapest, while another significant share originates from the immediate surroundings of universities, serving student mobility during weekdays. In addition, several key directions are concentrated in the inner-city area, often tied to specific locations with consistently high demand, underlining the role of central hubs in the system.

In Table 1, the month-to-month RBO matrix indicates that similarity values are higher between spring, summer and autumn, with the strongest overlaps observed between Mar-Oct and April-May. These months correspond to the peak cycling season, where user demand and station interactions are more stable. In contrast, winter months, particularly December and January, show the lowest similarity values, suggesting that usage patterns in these periods are distinct from the rest of the year.

RBO	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Jan	-	0.31	0.15	0.07	0.10	0.07	0.06	0.11	0.21	0.21	0.22	0.20
Feb		-	0.29	0.17	0.21	0.17	0.19	0.24	0.37	0.33	0.25	0.13
Mar			-	0.44	0.52	0.33	0.49	0.44	0.38	0.56	0.22	0.15
Apr				-	0.54	0.49	0.42	0.52	0.31	0.41	0.07	0.03
May					-	0.43	0.46	0.51	0.33	0.47	0.12	0.06
Jun						-	0.32	0.44	0.31	0.29	0.06	0.02
Jul							-	0.41	0.31	0.45	0.10	0.07
Aug								-	0.35	0.46	0.13	0.05
Sept									-	0.44	0.21	0.14
Oct										-	0.23	0.13
Nov											-	0.28
Dec												-

Table 1: Month-to-month RBO matrix

When comparing the monthly Top 10 lists to the annual ranking, the highest similarity is found in spring and autumn (March, May, October), while winter months align poorly with the overall yearly profile (Figure 2). This indicates that the annual structure of demand is shaped mainly by the warm-season months.

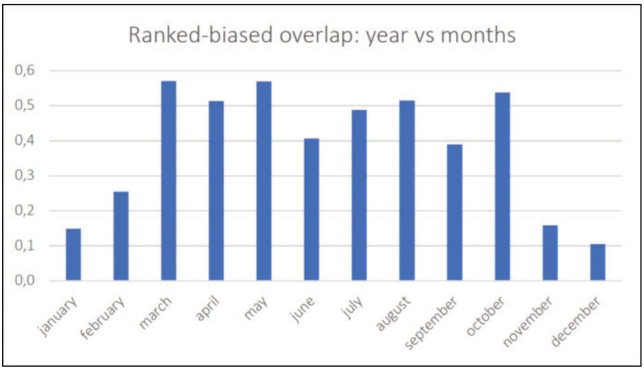

Figure 2: Ranked-biased overlap: year vs months

The comparison between weekdays and weekends reveals a relatively low RBO score (0.216). This confirms a strong structural difference: weekday travel patterns are dominated by short commuting flows, often between universities and nearby hubs, whereas weekend usage is more heterogeneous and strongly shaped by leisure-oriented rides.

The RBO analysis of adjacent hours is demonstrated in Table 2. Smooth transitions with high RBO values are visible during the late morning to afternoon period (13:00-15:00, 18:00-19:00), indicating stable directions across consecutive hours. Conversely, very low overlaps occur during the early morning (03:00-06:00) and around peak-hour boundaries (09:00-10:00), reflecting abrupt changes in usage patterns. These discontinuities capture the shift between nighttime special demand, morning commuting near universities, and later daytime leisure activities in recreational areas.

0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
0.442	0.507	0.402	0.022	0.000	0.000	0.348	0.281	0.380	0.086	0.157	0.374
12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
0.433	0.530	0.538	0.379	0.447	0.394	0.542	0.387	0.384	0.242	0.390	0.429

Table 2. Adjacent hours RBO matrix

4. Conclusion

This study demonstrated that the Rank-Biased Overlap (RBO) method provides a powerful tool for capturing the temporal stability and variability of the TOP 10 bike-sharing directions. The results provide insights into the temporal dynamics and reveal seasonal effects with similarities across the spring and summer months, contrasted by low stability in winter. Structural differences were also evident between weekdays and weekends, reflecting the divergence between commuting and leisure-oriented demand. Hourly analysis highlighted smooth transitions during daytime use and sharp shifts around commuting peaks and nighttime periods. The findings underscore that dominant bike-sharing directions are shaped by temporal dynamics and spatial-functional contexts such as recreational areas, universities, and central city hubs, offering valuable insights for planning and operational strategies.

Acknowledgements

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] C. Médard de Chardon, G. Caruso, and I. Thomas, "Bike-share rebalancing strategies, patterns, and purpose," *J. Transp. Geogr.*, vol. 55, pp. 22–39, July 2016, doi: 10.1016/j.jtrangeo.2016.07.003.

[2] C. Xu, J. Ji, and P. Liu, "The station-free sharing bike demand forecasting with a deep learning approach and large-scale datasets," *Transp. Res. Part C Emerg. Technol.,* vol. 95, pp. 47–60, Oct. 2018, doi: 10.1016/j.trc.2018.07.013.

[3] E. Come, N. A. Randriamanamihaga, L. Oukhellou, and P. Aknin, "Spatio-temporal Analysis of Dynamic Origin-Destination Data Using Latent Dirichlet Allocation: Application to Vélib' Bike Sharing System of Paris," in *TRB 93rd Annual meeting*, France: TRANSPORTATION RESEARCH BOARD, 2014, p. 19p. Accessed: Oct. 01, 2025. [Online]. Available: https://hal.science/hal-01052951

[4] P. Vogel, T. Greiser, and D. C. Mattfeld, "Understanding bike-sharing systems using Data Mining: Exploring activity patterns," in *Procedia Soc. Behav*. Sci., 2011, pp. 514–523. doi: 10.1016/j.sbspro.2011.08.058.

[5] P. Jiménez, M. Nogal, B. Caulfield, and F. Pilla, "Perceptually important points of mobility patterns to characterise bike sharing systems: The Dublin case," *J. Transp. Geogr.*, vol. 54, pp. 228–239, 2016, doi: 10.1016/j.jtrangeo.2016.06.010.

[6] S. Ji, C. R. Cherry, L. D. Han, and D. A. Jordan, "Electric bike sharing: Simulation of user demand and system availability," *J. Clean. Prod.*, vol. 85, pp. 250–257, 2014, doi: 10.1016/j.jclepro.2013.09.024.

[7] WebberWilliam, MoffatAlistair, and ZobelJustin, "A similarity measure for indefinite rankings," *ACM Trans. Inf. Syst. TOIS*, Nov. 2010, doi: 10.1145/1852102.1852106.

[8] Moffat, Alistair, and Zobel, Justin, "Rank-biased precision for measurement of retrieval effectiveness," ACM Trans. Inf. Syst. TOIS, Dec. 2008, doi: 10.1145/1416950.1416952.