APCNCS2026: Asia-Pacific Conference on Networks and Complex Systems
10-12 June 2026, Nanyang Technological University, Singapore

# Urban features shape variations in distance deterrence within metropolitan mobility networks

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*Keywords: Urban mobility, Distance deterrence, Gravity model, SHAP, Explainable machine learning*

## Extended Abstract

**Motivation.** Distance deterrence, representing decreasing mobility with distance, has been recognized as a core property of human mobility [1]. The degree of distance deterrence has been often captured as a single exponent using the gravity model. As such, while distance deterrence has long been treated constant, recent studies proposed its potential variations in a single urban system [2]. Here, we answer to the two questions:
(1) Does distance deterrence vary empirically within a metropolitan area?
(2) Which urban features explain this spatiotemporal variation?
If distance deterrence varies predictably and explainably across space and time, it would suggest that interacting structural and contextual factors may form deterrence within the urban mobility system. Identifying its drivers is essential for understanding how infrastructure, demographics, and environmental stress shape movement ranges in cities.

**Approach and Methodology.** We constructed a directed and weighted origin–destination (OD) mobility network for the Seoul Metropolitan Area at the town level ($n \approx 1172$ towns) using the publicly available OD log data from Seoul Open Data Portal containing over 5 million movements per day from May 2024 to September 2024. We estimated each town's deterrence exponent by fitting the gravity models to inflow and outflow subnetworks. For this fitting, the Poisson Pseudo-Maximum Likelihood (PPML) estimation was used to incorporate heteroskedasticity [3]. The analysis was repeated across two time-of-day windows (Morning-Noon and Afternoon-Evening) and four age groups, yielding a spatiotemporal panel of deterrence exponents.
To explain variations in these deterrence exponents with high predictability, we adopted XGBoost [4] to predict the exponents from features including transit accessibility, population density, demographic composition, temporal indicators, and heat stress, and found important features using SHapley Additive exPlanations (SHAP) [5]. SHAP quantifies the nonlinear contribution of each feature to predictability as well as the interactive effects between different features.

**Results.** Distance deterrence exhibits a core–periphery structure, with lower values in central Seoul and higher values in peripheral areas. However, some peripheral areas near major metro stations display locally reduced deterrence (Fig. 1a), indicating that transit accessibility shapes effective mobility ranges.
Distance deterrence varies by age and time. Adolescent age groups (00-19) exhibit the strongest spatial confinement, whereas the 20-39 age group show the weakest. Overall, deterrence tends to decrease on weekends compared to weekdays, which may reflect greater discretionary mobility. However, during weekend afternoons, deterrence increases among

working-age groups (20–50) residing in core areas. This pattern underscores the importance of spatiotemporal disaggregation when interpreting distance deterrence.
The SHAP analysis shows that traffic accessibility, population density, and day-off are the main factors influencing distance deterrence (Fig. 1a). SHAP interaction analysis reveals two key nonlinear mechanisms. First, the deterrence-reducing effect of transit accessibility weakens in high-density areas, indicating diminishing returns of infrastructure concentration (Fig. 1b). Second, extreme heat reduces deterrence more strongly on weekends than on weekdays, suggesting that discretionary mobility amplifies environmental effects (Fig. 1c).

**Conclusions and Outlook.** Distance deterrence behaves as a condition-dependent property rather than a fixed structural constant. Its variation reflects complex nonlinear interactions between accessibility, demographic structure, and environmental stress. This perspective and these findings provide a basis for diagnosing accessibility imbalances and for designing adaptive mobility strategies under conditions of infrastructure concentration and environmental stress.

This work was supported by KOITA grant funded by MSIT (KOITA20250002-83) and the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2023-00242528, 2025S1A5C3A0100835411).

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# Ethics Statement

Mobility data are aggregated and anonymized. No individual-level identifiers are used.

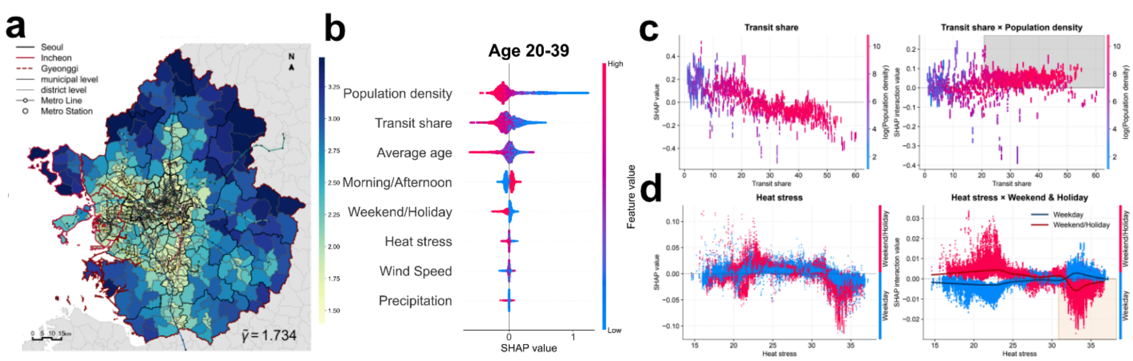


**Figure 1. (a)** Choropleth map of the distance deterrence exponents estimated for inflow networks in Morning-Noon period. **(b)** SHAP beeswarm plot showing global feature importance across age groups. **(c–d)** SHAP dependence and interaction effects illustrating nonlinear relationships for transit accessibility and heat stress.