Modal split and accessibility: forecasting transport use through the modal accessibility gap

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Short summary

Accessibility is a central lens through which transport geographers understand potential mobility, yet it is rarely used to predict realised behaviour such as modal shares. This paper proposes a territory-based predictive modal split model in which the Modal Accessibility Gap (MAG), operationalised through multimodal Spatial Availability (mSPAV), serves as the primary predictor of car use in home-work trips across the Madrid metropolitan area. Three accessibility measures of increasing sophistication are evaluated: a Hansen-type gravity indicator, a unimodal Spatial Availability, and a population-group-neutral multimodal Spatial Availability. Results show mSPAV-based MAG significantly outperforms the others. A cubic regression model incorporating MAG alongside income and motorisation achieves $R^2 = 0.658$. The approach is theoretically grounded in random utility theory, data-efficient, and operationally simple, offering a spatially meaningful alternative to individual-based mode choice models in data-scarce or upstream planning contexts.
Keywords: accessibility; modal accessibility gap; modal split; multimodal spatial availability; transport modelling; Madrid

1 Introduction

Transport practice calls for predictive tools that can inform modal shift and target investments where they most effectively connect people with opportunities (Banister, 2008). Accessibility combines land use and networks into a single metric (Levinson & Krizek, 2020), yet it has most often been used to characterise potential mobility (Geurs & van Wee, 2004; Hansen, 1959; Shen, 1998) rather than to predict realised modal shares.

Predictive mode choice modelling typically relies on individual utility-based approaches such as binary or multinomial logit (Ben-Akiva & Lerman, 1985; Ortúzar & Willumsen, 2001), requiring detailed choice data, individual sociodemographics, and carefully calibrated utility functions at significant data and operational cost (McNally, 2008). This reveals a methodological gap: accessibility offers a powerful spatial perspective on how opportunities are structured, but is rarely operationalised for forecasting modal outcomes.

The Modal Accessibility Gap (MAG) — the normalised difference between public transport and car accessibility (Kwok & Yeh, 2004) — has been linked to commuting behaviour (Kawabata & Shen, 2006) and spatial equity analyses (Yang et al., 2017), but has remained diagnostic rather than predictive. No study has yet formalised MAG as a territory-based predictor of modal share. This paper addresses that gap. We evaluate three MAG variants — using Hansen (Hansen, 1959), unimodal Spatial Availability (Soukhov et al., 2023), and population-group-neutral multimodal Spatial Availability (mSPAV) (Soukhov & Páez, 2024) — as predictors of car use in home-work trips for the Community of Madrid. mSPAV-based MAG yields the strongest predictive performance. By shifting the unit of analysis from individuals to zones, the model reframes modal behaviour as a territorial accessibility benefit, providing a data-efficient and theoretically grounded approach to modal split forecasting.

2 Methodology

Study area and data

The study area is the Community of Madrid, comprising 1,259 Traffic Analysis Zones (TAZs) structured in four functional rings: the Almendra Central (city core), Madrid Municipality, the Metropolitan Area, and the Rest of the Community (rural-urban fringe). The 2018 Household Mobility Survey (EDM18) provides home-work trip flows, population and job weights per zone, and observed modal shares. Mode-specific travel time matrices are computed with `r5r` (Pereira et al., 2021) using a car network (OpenStreetMap via Geofabrik) and a public transport network (GTFS: Cercanías, Metro, regional and local buses), returning median travel times capped at 120 minutes. Mode-specific impedance functions are calibrated by fitting gamma distributions to observed trip time distributions from the survey, selected over lognormal and logistic alternatives on the basis of lower AIC and BIC. Control variables — motorisation index (vehicles per 1,000 inhabitants) and median personal income — are derived from EDM18 and Spanish census data.

Accessibility measures

Three accessibility measures of increasing conceptual realism are computed for car and public transport.
The **Hansen-type** indicator (Hansen, 1959) is the weighted sum of opportunities using mode-specific impedance, without accounting for competition:

$$S_i^m = \sum_j O_j \cdot f^m(t_{ij}) \tag{1}$$

The classical **multimodal Spatial Availability** (Soukhov et al., 2023; Soukhov & Páez, 2024) introduces singly-constrained competition among mode-specific population groups:

$$V_i^m = \sum_j O_j \cdot \frac{P_i^m \cdot f^m(t_{ij})}{\sum_{m' \in M} \sum_k P_k^{m'} \cdot f^{m'}(t_{kj})} \tag{2}$$

The **population-group-neutral mSPAV** retains mode-specific impedance in the numerator but pools population across modes in the denominator, avoiding conditioning on observed modal shares and thereby preventing circularity in the prediction:

$$W_i^m = \sum_j O_j \cdot \frac{P_i \cdot f^m(t_{ij})}{\sum_k \left(P_k \cdot \sum_{m' \in M} f^{m'}(t_{kj}) \right)} \tag{3}$$

In all formulations, i and j denote origin and destination zones, $m \in M$ the focal transport mode, O_j jobs at destination j, $f^m(t_{ij})$ the mode-specific impedance, and P_i the population weight of origin i.

Modal Accessibility Gap and regression

For each accessibility measure, MAG is constructed as:

$$MAG^n = \frac{A_{PT}^n - A_{car}^n}{A_{PT}^n + A_{car}^n} \tag{4}$$

ranging from -1 (full car advantage) to $+1$ (full PT advantage). OLS regression models are estimated with observed car modal share as the dependent variable. A bivariate comparison across all three MAG variants is performed first. A multivariate cubic polynomial model then introduces motorisation and income as controls. Ring-specific models examine spatial heterogeneity across the urban-rural gradient. The cubic form was retained after comparison with linear and quadratic specifications, as it best captures asymptotic behaviour at both MAG extremes, consistent with its sigmoid nature.

3 Results and Discussion

Modal Accessibility Gap maps

Figure 1 shows the three MAG maps. Hansen-type and unimodal SPAV reinforce a centripetal structure, overstating central PT advantage and obscuring peripheral nuance. The population-

group-neutral mSPAV reveals a more complex spatial structure: corridors of relative PT competitiveness emerge along radial infrastructure axes, while car-dominant zones persist beyond those corridors regardless of distance from the centre. This functional geometry of modal competition is invisible to simpler indicators.

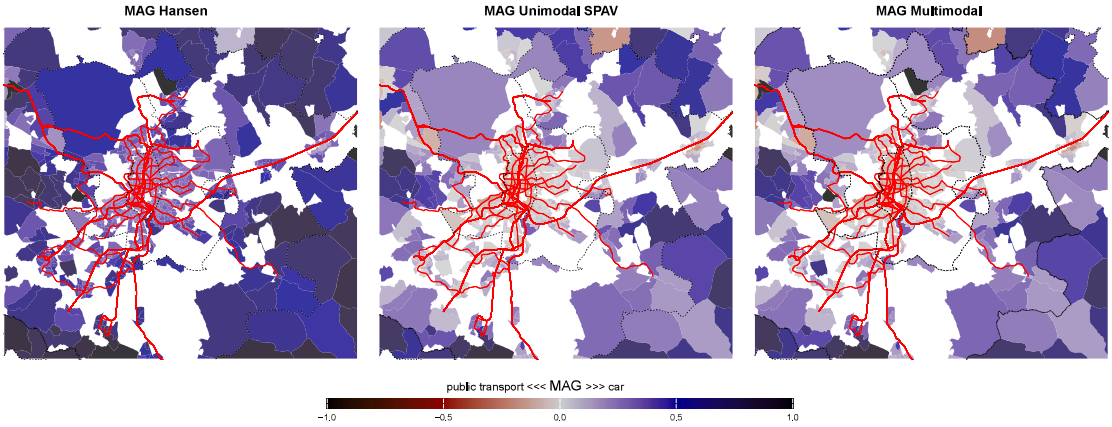


Figure 1: Modal Accessibility Gap maps by accessibility indicator (Hansen, Unimodal SPAV, Multimodal SPAV).

Regression results

Bivariate results confirm progressive improvement with indicator sophistication. Hansen-type MAG shows near-zero correlation with observed car share. Classical SPAV-based MAG improves marginally. Population-group-neutral mSPAV-based MAG achieves $R^2 = 0.61$ in a bivariate cubic model. The multivariate model combining mSPAV MAG, motorisation, and income yields $R^2 = 0.658$, explaining 65.8% of zonal variance in car share. The MAG coefficient ($\beta = 27.3$, $p < 0.001$) remains significant when controlling for socioeconomic variables, confirming that territorial accessibility structure has an independent effect on modal behaviour.
Three behavioural zones emerge along the MAG distribution: a PT-competitive zone (MAG > 0) where small changes produce large modal shifts; a transition zone near zero where car adoption consolidates; and a car-dominant zone (MAG < -0.5) where PT is not a viable alternative. Figure 2 shows this relationship disaggregated by metropolitan ring. Predictive performance is strongest in the Metropolitan Area and Rest of the Community, confirming that mSPAV-based MAG captures inter-urban and rural-urban fringe dynamics particularly well. Central zones show higher residual dispersion, attributable to soft mode use and fine-grained built environment variation not captured by the model.

Theoretical resonance with binary logit models

The empirical success of mSPAV-based MAG has a theoretical basis. In a binary logit model, the probability of choosing car over PT depends on the utility difference $\Delta V_n = V_{car,n} - V_{PT,n}$. When utilities include exponential impedance, this corresponds to the difference in accessibility logsums (Williams, 1977; Ben-Akiva & Lerman, 1985):

$$logsum_i^n = \ln \sum_j O_j \cdot e^{V_{ij}} = \ln A_i^n \tag{5}$$

MAG is therefore proportional to the logsum difference between modes, constituting a territory-level reduced form of the binary logit:

$$MAG^n \propto \Delta V_n \longrightarrow P(car \mid n) = \frac{1}{1 + e^{-\Delta V_n}} \tag{6}$$

By shifting from individuals to zones, the model treats territorial accessibility benefit as the primary determinant of modal behaviour, without requiring individual-level survey data.

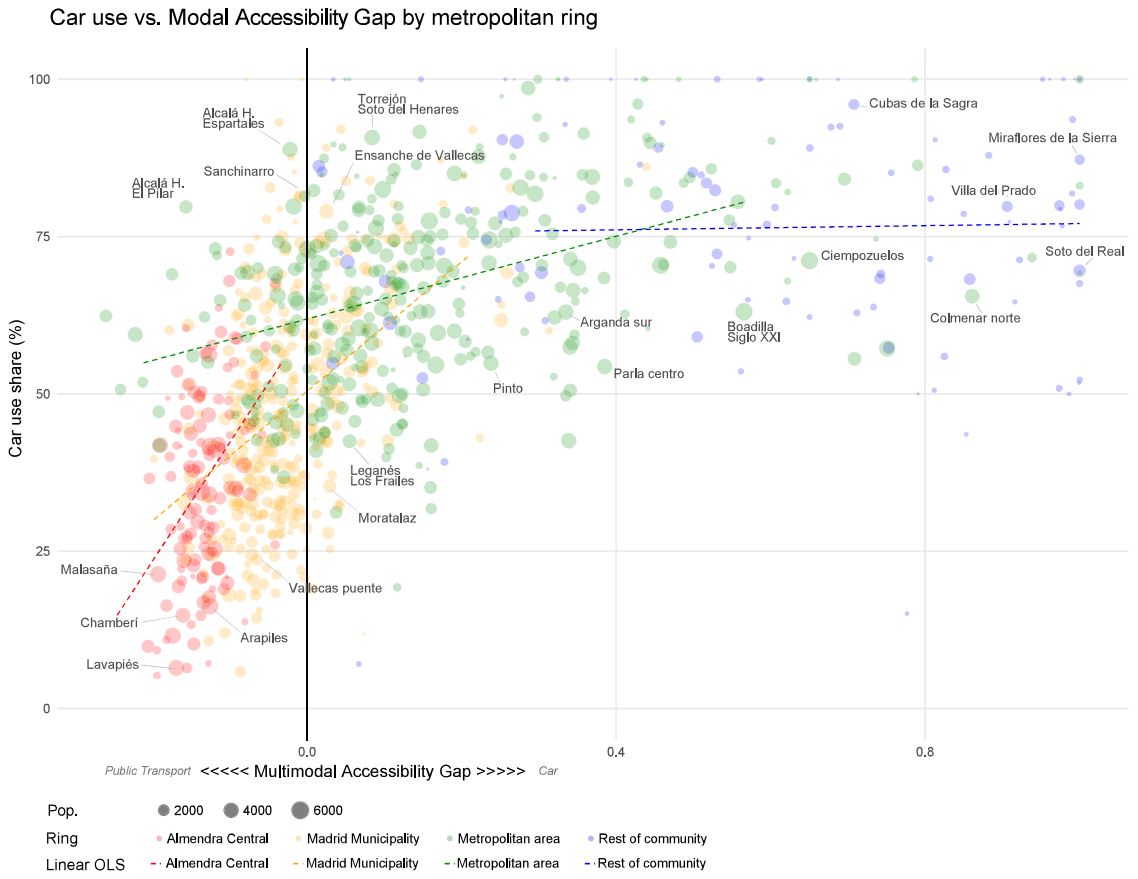


Figure 2: Car use share vs. mSPAV-based MAG by metropolitan ring, with linear OLS fit per ring. Bubble size proportional to zone population.

4 Conclusions

This paper demonstrates that MAG, operationalised through population-group-neutral mSPAV, is a viable predictor of car modal share at the zonal level in a major European metropolitan area. The multivariate model achieves $R^2 = 0.658$ using only three variables derivable from open or standard planning data sources.

The approach is data-efficient, operationally simple, and theoretically grounded in random utility theory, offering a meaningful alternative to individual-based mode choice models in data-scarce or upstream planning contexts. It is particularly suited to metropolitan areas with heterogeneous densities and multimodal networks. Key limitations include the use of 2018 survey data, the restriction to motorised modes, and residual spatial autocorrelation. Future work should explore mobile phone OD data as input, extend the framework to soft modes, and replicate the analysis in other metropolitan contexts.

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References

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy*, *15*(2), 73–80.

Ben-Akiva, M., & Lerman, S. R. (1985). Discrete choice analysis: Theory and application to travel

demand. *MIT Press*.

Geurs, K. T., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, *12*(2), 127–140.

Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners*, *25*(2), 73–76.

Kawabata, M., & Shen, Q. (2006). Job accessibility as an indicator of auto-oriented urban structure: a comparison of Boston and Los Angeles with tokyo. *Environment and Planning B: Planning and Design*, *33*(1), 115–130.

Kwok, R. C. W., & Yeh, A. G. O. (2004). The use of modal accessibility gap as an indicator for sustainable transport development. *Environment and Planning A*, *36*(5), 921–936.

Levinson, D., & Krizek, K. J. (2020). *Metropolitan transport and land use: Planning for place and plexus* (2nd ed.). Routledge.

McNally, M. G. (2008). The four-step model. In D. A. Hensher & K. J. Button (Eds.), *Handbook of transport modelling* (pp. 35–53). Emerald.

Ortúzar, J. d. D., & Willumsen, L. G. (2001). *Modelling transport* (3rd ed.). Wiley.

Pereira, R. H. M., Saraiva, M., Herszenhut, D., Braga, C. K. V., & Conway, M. W. (2021). r5r: Rapid realistic routing on multimodal transport networks with R5 in R. *Findings*. doi: 10.32866/001c.21262

Shen, Q. (1998). Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. *Environment and Planning B: Planning and Design*, *25*(3), 345–365.

Soukhov, A., & Páez, A. (2024). Multimodal spatial availability: A singly constrained measure of accessibility. *Environment and Planning B: Urban Analytics and City Science*. (In press)

Soukhov, A., Páez, A., Higgins, C. D., & Mohamed, M. (2023). Introducing spatial availability, a singly constrained measure of accessibility. *PLOS ONE*, *18*(1), e0278468.

Williams, H. C. W. L. (1977). On the formation of travel demand models and economic evaluation measures of user benefit. *Environment and Planning A*, *9*(3), 285–344.

Yang, J., Guo, A., Li, X., & Huang, T. (2017). Study of the impact of a high-speed railway opening on China's accessibility pattern and land use. *Journal of Transport Geography*, *61*, 151–162.