Core-Periphery Pattern in Public Transport Accessibility

A Study of the Warsaw Metropolitan Area

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Plan of the presentation I

About this presentation

Objectives

- comprehensive analysis of public transport accessibility in the Warsaw metropolitan area
- main focus: spatial and temporal disparities
- assessment of public transport provision

Methods

- gravity-based model
- basic spatial unit: 1×1 km grid square
- population density as a proxy for destination attractiveness
- new measure: accessibility gain related with public transport operation

Theoretical framework

Definition of accessibility

Hansen (1959):

> *Potential of opportunites for interaction*

Ingram (1971):

> *inherent characteristic (or advantage) of a place with respect to overcoming some form of spatially operating source of friction (for example, time and/or distance)*

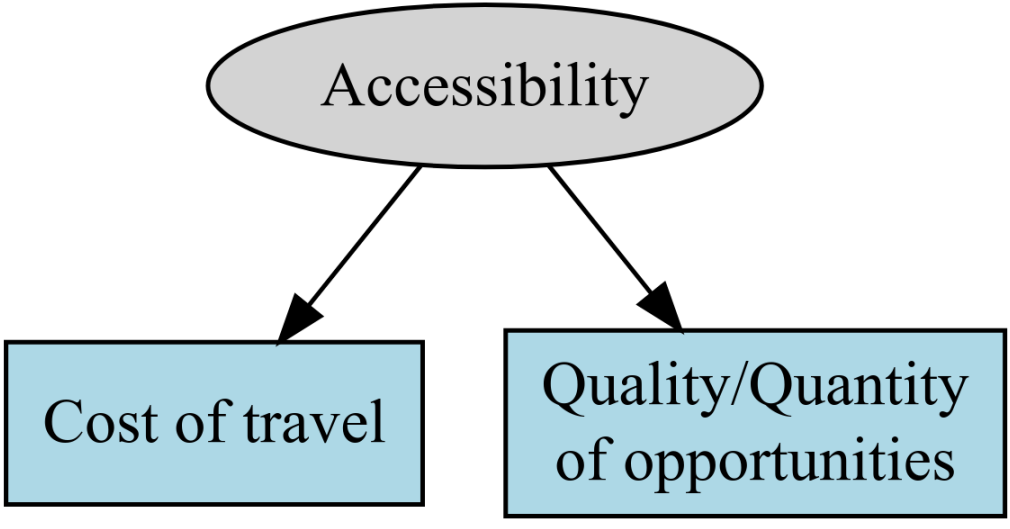
Geurs and Ritsema van Eck (2001):

> *The extent to which the land-use transport system enables individuals or goods to reach activities or destinations by means of transport modes.*

Accessibility

Ease of reaching potential destinations, considering their attractiveness and cost of travel.

Components of accessibility



Gravity-based measure

General formula for accessibility (A_i) in point i:

$$A_i = \sum_{j \neq i} a_j \, \mathrm{f}(t_{ij})$$

where:

- a_j is an attractiveness of destination j
- t_{ij} is travel time between an origin i and a destination j
- $f(t)$ is an impedance function representing the resistance or effort associated with traveling between points

Impedance function

- represents the difficulty (cost) of reaching destination
- reflects commuters' travel preferences
- its parameters should be carefully chosen
- most common formulas:
  - exponential function

$$f(t_{ij}) = \exp(-\beta t_{ij})$$

  - gaussian function

$$f(t_{ij}) = \exp(-\beta t_{ij}^2)$$

  - step function

$$f(t_{ij}) = \begin{cases} 1 & \text{if } t_{ij} \leq T \\ 0 & \text{if } t_{ij} > T \end{cases}$$

Impedance function - visualisation

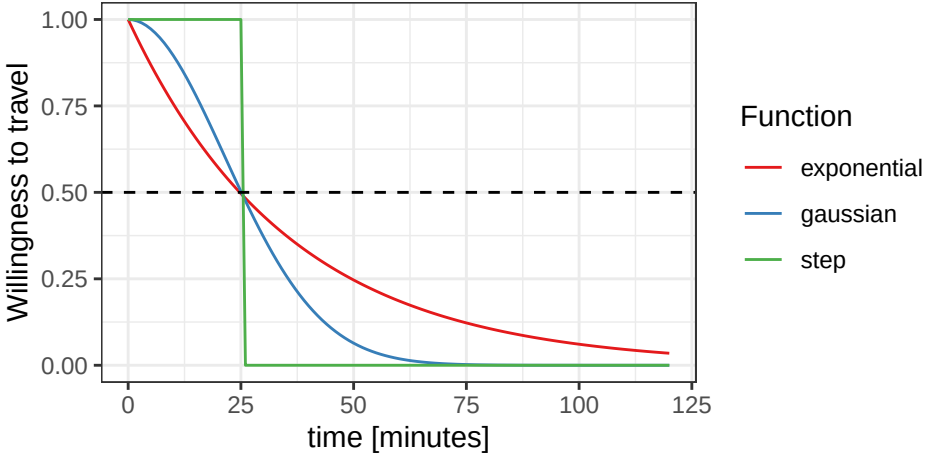


Figure 1: Major types of decay functions with half-life of 25 min (own work)

Case study: Warsaw metropolitan area

Study area

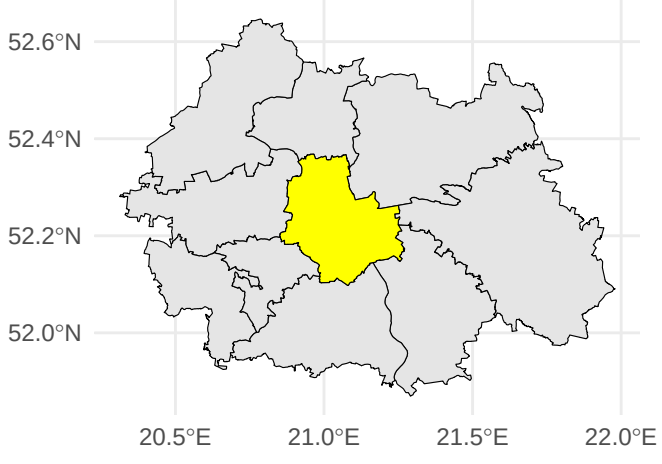


Figure 2: Counties belonging to the Warsaw metropolitan area (own work)

Data sources

Table 1: Gravity model parameters

Parameter	Notation	Case Study	Data Source
Destination attractiveness	a_i	Population in 1 km grid	National Census 2021
Impedance function	$f(t_{ij})$	Parameters estimated from residents' travel patterns	Warsaw Transport Survey 2015
Travel times	t_{ij}	Own elaboration of travel time matrix	Public transport schedules (GTFS) and road network (OSM)

Population density

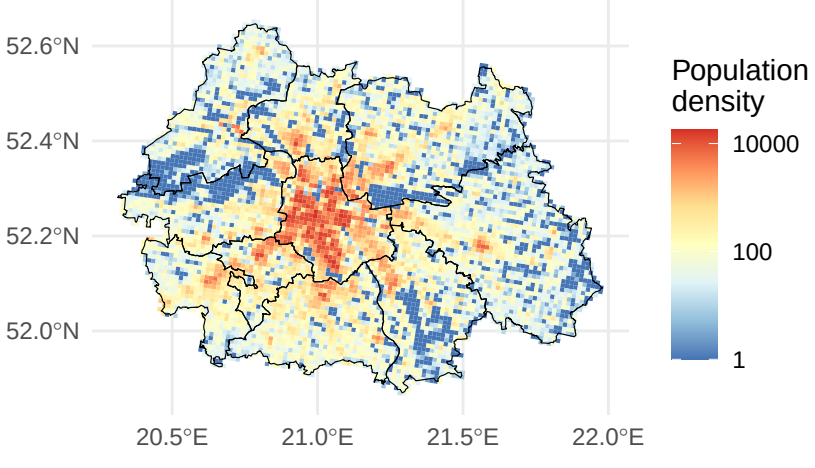
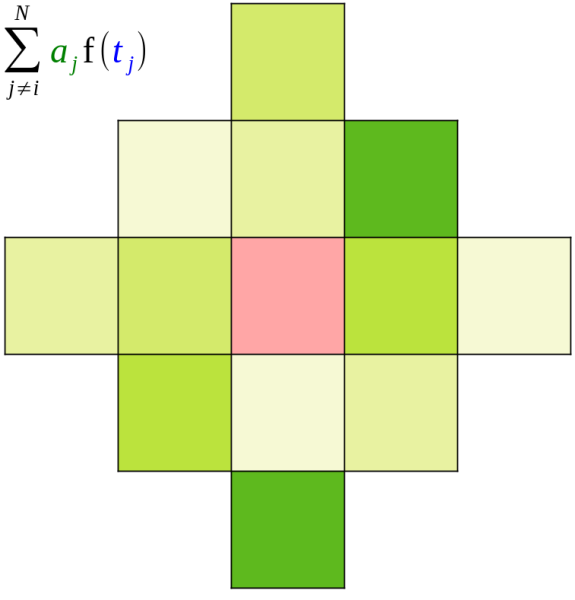


Figure 3: Population density in 1km census grid

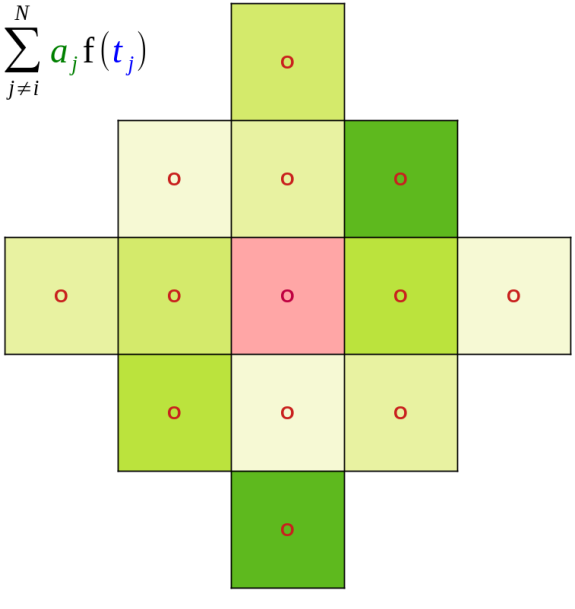
Accessibility calculations (1)

$$A_i = \sum_{j \neq i}^{N} a_j \, \mathrm{f}(t_j)$$



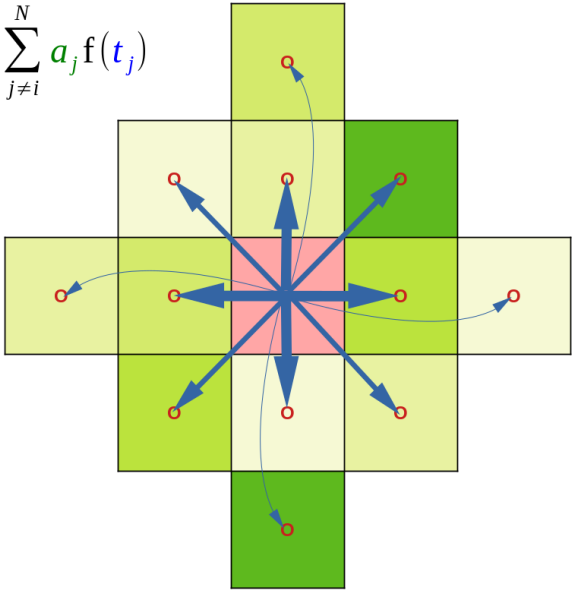
Accessibility calculations (2)

$$A_i = \sum_{j \neq i}^{N} a_j \, \mathrm{f}(t_j)$$



Accessibility calculations (3)

$$A_i = \sum_{j \neq i}^{N} a_j \, \mathrm{f}(t_j)$$



Travel time calculations - r5r[1] package

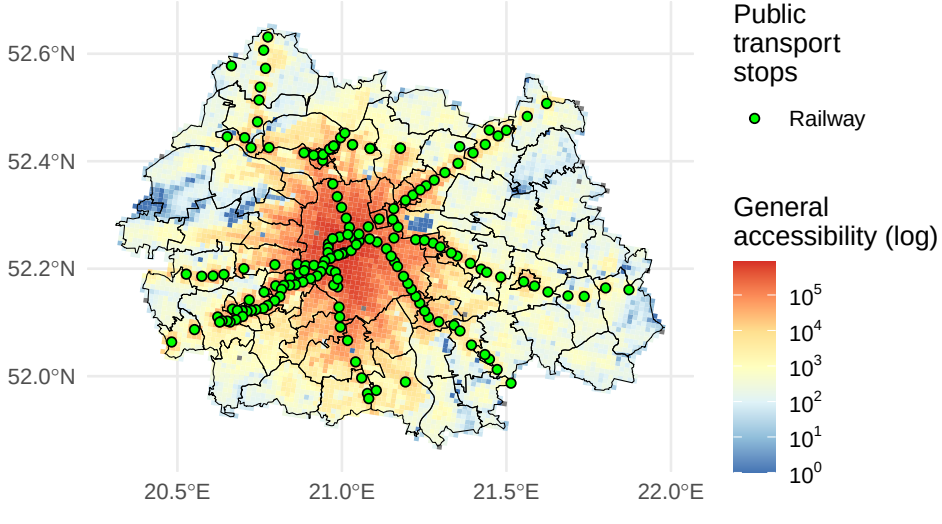
What is r5r?

- An R package for rapid accessibility analysis and travel time calculations.
- Uses **GTFS (public transit) and OpenStreetMap (road network) data**
- Designed for multimodal transport (walking, cycling, transit, driving).
- Computes **travel time matrices** for large-scale urban networks

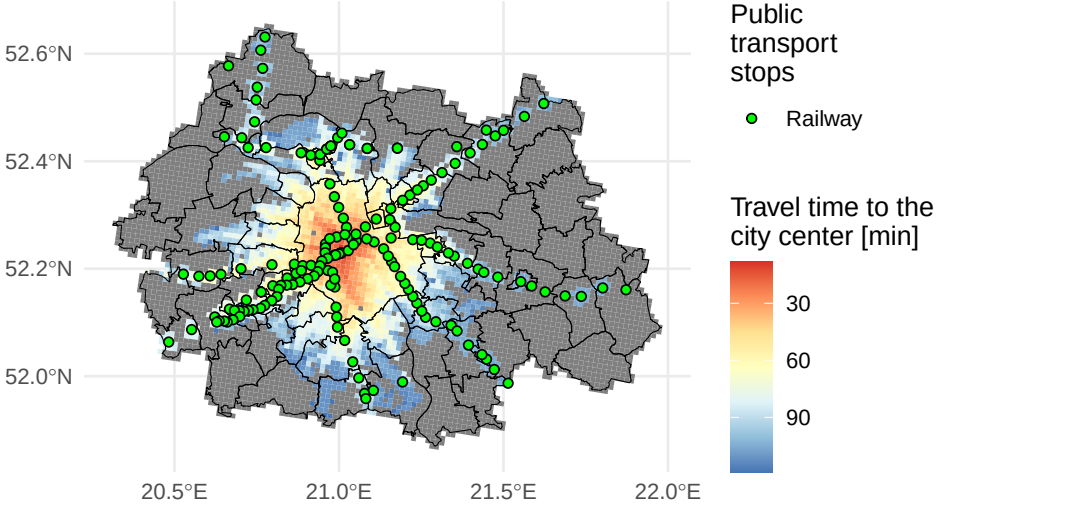
[1] Pereira et al. (2021)

Results

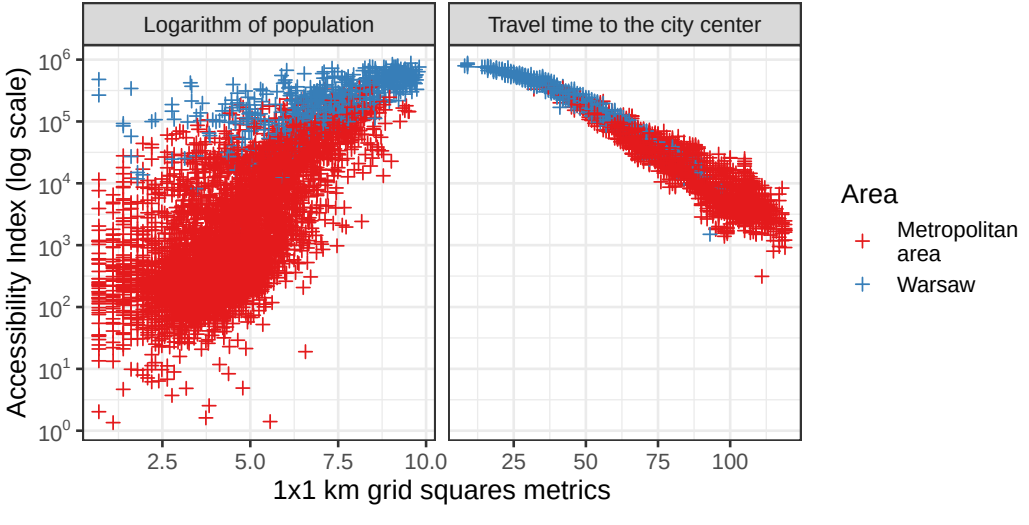
General public transport accessibility



Centrality (1)



Centrality (2)



Accessibility gain – new proposed measure

Formula:

$$A_{\text{gain}} = 1 - \frac{A_{walk}}{A_{\text{PT}}}$$

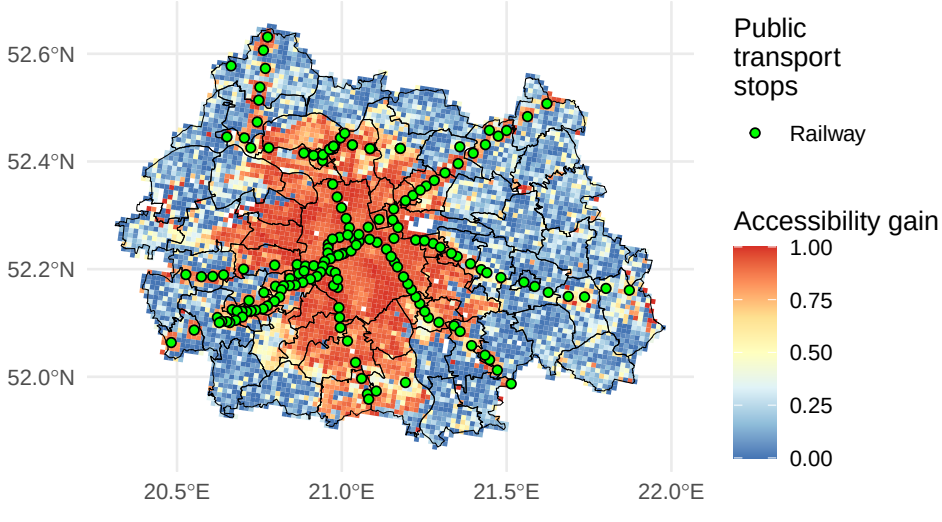
Interpretation

Indicator A_{gain} informs what proportion of total accessibility can be attributed to the operation of public transportation

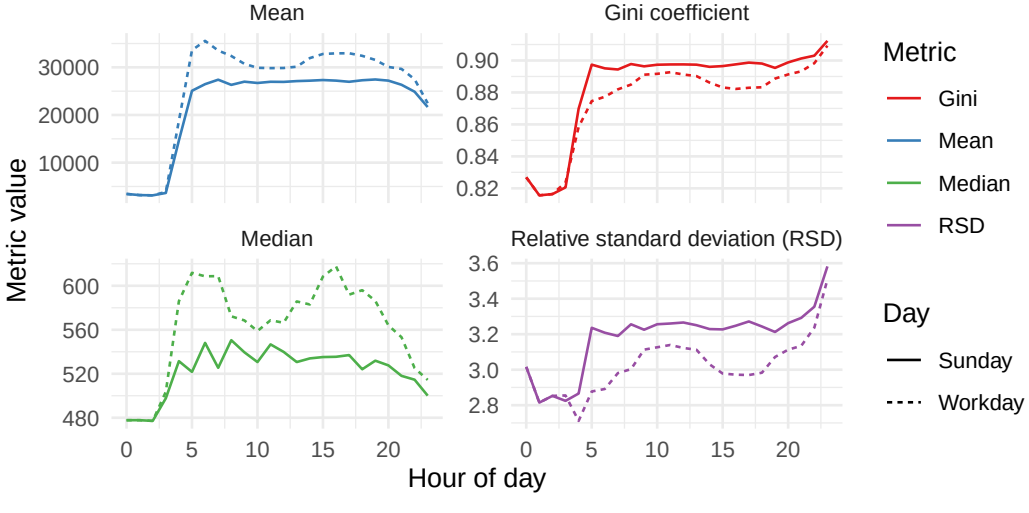
Advantages

- ease of interpretation
- standardized indicator
- values in the range $[0, 1]$

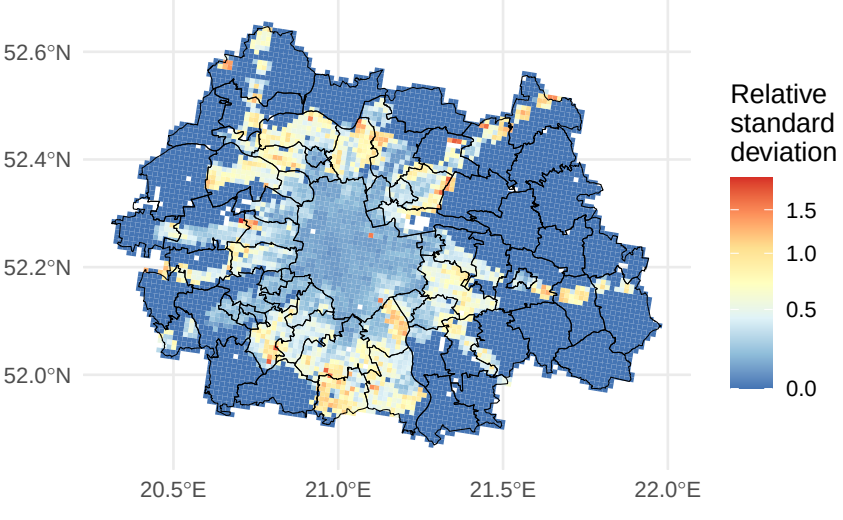
Accessibility gain – map



Temporal variations of accessibility



Temporal variability - map



Conclusions

Conclusions

Key findings

- Accessibility exhibits core-periphery structure
- Travel time to the city centre is a near-perfect predictor of accessibility score
- rail lines play crucial role in bridging the gap for peripheral residents
- Temporal variability of PT services is higher in the peripheral municipalities

Limitations

- Not all carriers provide schedules in GTFS format $\Rightarrow$ they are not included in the analysis
- Population density might not be an ideal proxy for destination attractiveness

Thank you!

Bibliography

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