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ACCESSIBILITY VIA PUBLIC TRANSPORT THROUGH GRAVITY MODELS BASED ON OPEN DATA

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Efficient urban facility access is crucial for enhancing residents' well-being and quality of life. This study examines public transport accessibility to essential facilities in Rome, such as high schools and hospitals, using gravity models based on open data sources, like OpenStreetMap and GTFS. Two versions of the gravity model are compared: an origin constrained and a doubly constrained. The latter can consider the capacity of facilities as a strict constraint, offering thus a more realistic assessment of accessibility. The findings highlight the correlation of public transport quality and urban accessibility, showing how variations in public transport supply affect the weighted average time to reach services like healthcare, education, and leisure. This approach reveals specific zones needing improvement and provides a valuable tool for predicting the impact of future changes in the transport network with respect to social equity. An online platform has been developed to allow a readily available application of this methodology to boost active citizenship and proactive decision making.

Keywords: Urban mobility, public transport accessibility, open data, GTFS

1. Introduction

Accessibility is paramount in sustainable transport and urban development, emphasizing the ease with which various amenities and activities can be reached from a given origin, typically a residential area (Geurs and van Wee, 2004). This core concept encompasses accessing spatially separated amenities and activities, serving as a crucial indicator of opportunity availability and destination reachability. Understanding accessibility and its measurement methodologies not only sheds light on travel behaviour and spatial organization but also paves the way for creating more inclusive and efficient urban environments. Beyond physical proximity, it encompasses temporal and social dimensions, crucial for inclusive urban planning. Understanding accessibility illuminates spatial resource distribution and informs infrastructure optimization. Technological advancements in GIS and big data enable accessibility analysis. Prioritizing accessibility in transportation planning fosters economic vitality, social equity, and resilient communities during urban growth.

Researchers have dedicated significant efforts to devising methodologies for measuring accessibility within urban structures, resulting in a plenty of approaches with varying levels of data requirements and analytical complexity (Geurs and van Wee, 2004; Lee and Miller, 2018; Liu and Zhu, 2004). These diverse methods can be broadly classified into five major approaches, each offering unique insights into accessibility patterns and spatial organization.

Utility-based approach represents a cross-disciplinary measure to accessibility assessment, drawing upon a diverse array of data sources including economic indicators, social demographics, land use patterns, and transportation networks. By integrating these factors, researchers can estimate the value of opportunities within a given area, providing valuable insights into the accessibility landscape (Geurs and van Wee, 2004).

Space-time approaches extend the analysis beyond mere spatial dimensions, incorporating temporal variations to capture how accessibility evolves over time (Lee and Miller, 2018). By considering factors such as peak travel times, changes in service availability, and commuting patterns, these methods offer a more comprehensive understanding of accessibility within urban environments.

Person-based approaches delve into the nuanced behaviour of individuals, recognizing that travel decisions are influenced by factors such as trip-chaining behaviour and interpersonal variations in time

budgets (Liu and Zhu, 2004). By focusing on individual preferences and constraints, these measures provide insights into the complex interplay between travel behaviour and accessibility.

The Opportunity-based approach quantifies accessibility in terms of reachable opportunities within specified travel costs or the total cost required to access a predetermined number of opportunities. This method provides a practical framework for evaluating the efficiency of transportation networks and identifying areas with limited access to essential services (Geurs and van Wee, 2004).

Lastly, Gravity-type approach, rooted in Hansen's Gravity Model (1959), offer a foundational understanding of accessibility by normalizing travel costs between origin and destination based on distance or time decay functions. By quantifying the attractiveness of destinations and the impedance of travel, these measures facilitate comparisons across different locations and modes of transport, informing urban planning decisions and transportation policy (Lee and Miller, 2018).

Gravity indices offer a robust approach to assessing accessibility by leveraging various attraction measures such as retail floor space or household numbers, while impedance functions play a crucial role in modelling travel costs through inverse power or negative exponential functions of distance or travel time, addressing competition challenges among methodologies (Bunel and Tovar, 2014). However, concerns arise regarding the rapid decay of impedance functions near the origin, necessitating refinement to align theoretical models with real-world observations (Ingram, 1971).

In the Gravity-type approach, the flow of individuals or goods from one zone (i) to another zone (j) is determined by a combination of factors, including the opportunities available at the destination zone (e.g., employment) and the demand originating from the origin zone (e.g., population), weighted by a cost function denoted as $f(c_{ij})$ (Duccio Piovani *et al.*, 2018). Here, the cost c_{ij} represents the expected time of travel using public transportation from zone i to zone j. This cost function is typically modelled as an exponential decay of the form $e^{-\beta c_{ij}}$, where β is a parameter calibrated using empirical data. Traditionally, this modelling approach is applied to analyse journey-to-work trip distribution, where the total number of commuters is constrained (outflow) along with the number of employees arriving at work (inflow), thus constituting the doubly constrained model. By normalizing travel costs between origin and destination based on distance or time decay functions, this approach provides a fundamental understanding of accessibility within urban environments, facilitating comparisons across different locations and transportation modes.

However, the effectiveness of these metrics hinges on behavioural data to estimate functional parameters, such as decay factor (β), which may lack easily communicable or meaningful units (Levine *et al.*, 2012). While the interpretation often revolves around the notion of the "number of opportunities easily reachable", the term "easily" requires further clarification and elucidation. Levine *et al.* (2012) highlight a pertinent theoretical limitation concerning the use of such estimation procedures for accessibility measures, emphasizing the intricate relationship between willingness to travel and the availability of opportunities. They argue that the willingness to travel is contingent upon the spatial distribution of opportunities. Regions with numerous nearby destinations and few distant ones may exhibit greater reluctance to travel, implying a higher value for β . Conversely, areas with few nearby destinations and many distant ones may witness a propensity for long trips due to the limited availability of nearby options, potentially leading to an overestimation of accessibility compared to regions where long-distance travel is less necessary. This nuanced understanding underscores the importance of considering spatial context and travel behaviour when interpreting accessibility metrics and highlights the need for more refined estimation methodologies to capture the complexities of accessibility within urban environments.

Despite the advocacy for incorporating competition into accessibility measures, planners and policymakers often favour simpler approaches like cumulative opportunities, which may oversimplify accessibility calculations and overlook spatial complexities (Bunel and Tovar, 2014). Consequently, there is a growing need for more sophisticated methodologies that capture the multifaceted nature of accessibility and its implications for urban development. In our investigation, we're delving into the complex aspects of urban accessibility. To unravel these complexities, we've opted for the doubly constrained gravity model as our methodological framework. This choice reflects a thoughtful consideration of the multifaceted interplay between origin-destination interactions and the spatial distribution of opportunities within urban landscapes.

2. Methodology

Our methodological core centres on the mathematical formulation of the doubly constrained gravity model. This model comprises a set of equations designed to represent how different areas within a city

interact. It considers factors like cost, capacity of the opportunities (supply), and population of different zones (demand).

2.1. Calculation of accessibility

The gravity model, traditionally used in geographical and transportation studies, is a potent method for quantifying accessibility. It leverages the concept that the interaction between locations diminishes with increasing distance, similar to Newton's law of universal gravitation. This model is particularly effective because it not only evaluates potential access based on the demand for services and opportunities but also incorporates the competitive landscape, acknowledging that multiple users may compete for the same resources.

To further refine this approach and incorporate competitive effects, the model has been extended to include a doubly constrained mechanism, which enhances its accuracy and applicability. This advanced version simultaneously addresses constraints on both the supply and demand sides. It considers the capacity of opportunities (supply) and the needs or desires of the population (demand). By integrating these dual aspects, the doubly constrained gravity model provides a more nuanced and realistic assessment of accessibility. To fully grasp the doubly constrained model, it is necessary to first understand the three key principles that underpin flow calculations:

- *Origin Constrained*: This concept is used when the destination has no capacity limits, and the only constraint is the demand from the origin. This means that the flow from an origin zone is limited by the population or demand originating from that zone, but there are no restrictions on the number of people that a destination can accommodate.
- *Destination Constraint*: This concept is applied when the destinations have capacity limits, but the origins have no demand constraints. Here, the flow to a destination is restricted by the capacity of that destination to handle demand, irrespective of the demand originating from the origin zones.
- *Doubly Constrained*: This approach is used when both the capacity of the destinations and the demand from the origins are limited. It provides a more balanced and realistic assessment of accessibility by ensuring that the total flow into any destination matches the total flow out of each origin, given the supply and demand constraints.

In our study we are using doubly constrained method which calculates the accessibility of each Point of Interest (POI) by closely examining both the capacity of each POI within a zone and the number of people competing for them. This comprehensive approach ensures that accessibility is not merely determined by the geographical or transportation costs from each zone to a POI. Instead, it incorporates a more detailed analysis that includes both demand and supply factors. By doing so, the model accounts for the intensity of demand, how many are seeking the same opportunities, and the availability of these opportunities, reflecting a real-world scenario of competition and resource limitation. For this purpose, the balancing factors of Wilson's doubly constrained spatial interaction model (Wilson, 1970, 1971) have been used. This model employs balancing factors that adjust for both the attraction of the destination and the generation of the origin, thus ensuring that the total flow into any destination matches the total flow out of each origin, given the supply and demand constraints.

This method involves a two-step iterative process. First, the supply side constraints are adjusted to reflect the capacity limits of the opportunities available. Second, the demand side constraints are updated to account for the population's needs and desires. Through successive iterations, the model converges to a solution that balances both constraints, offering a robust measure of accessibility.

The balancing factors a_i and b_j in this model can be interpreted as measures of accessibility that are adjusted to account for the effects of competition, as noted by Williams and Senior in 1978. These balancing factors are formulated based on the assumption of the negative exponential demand function, as the following forms:

- *Balancing Factor a_i* : This factor adjusts for the supply side constraints and is calculated for each origin zone i . It ensures that the total demand generated from each origin zone matches the available capacity across facilities. Mathematically, it can be expressed as:

$$a_i = \sum_{j=1}^n \frac{1}{b_j} D_j e^{-\beta c_{ij}} \quad (1)$$

Where n is the number of destinations, D_j is the capacity of the facility, c_{ij} is the cost between origin zone i and destination j , β is the parameter representing the effect of distance on demand, and b_j is the balancing factor for the destination j .

- **Balancing Factor b_j :** This factor adjusts for the demand side constraints and is calculated for each destination j . It ensures that the total demand absorbed by each destination matches the demand generated from all origin zones. Mathematically, it can be expressed as:

$$b_j = \sum_{i=1}^m \frac{1}{a_i} O_i e^{-\beta c_{ij}} \tag{2}$$

Where m is the number of origin zones, O_i is the demand (population or number of potential users) at origin zone i , c_{ij} is the cost between origin zone i and destination j .

The iterative calculation of these balancing factors a_i and b_j continues until they converge to stable values, ensuring that the model accurately reflects the constraints on both the supply and demand sides. This iterative process helps achieve a balanced distribution of flows that match the observed data, making the doubly constrained gravity model a robust tool for accessibility analysis in urban planning and transportation studies.

In operational terms, the model utilizes variables a_i and b_j to moderate the flows between origins and destinations. These weights are adjusted iteratively, reflecting the balance of demand and opportunity between the zones and POIs. The operational steps of the model include:

- **Initial Calculation:** Assigning initial values to the balancing factors a_i and b_j . The initial value of b_j is set to 1 and a_i has been calculated based on this assumption.
- **Iterative Adjustment:** In the iterative adjustment process, the model updates the factors a_i and b_j to ensure that the total demand from each origin zone is appropriately distributed across all POIs. For each origin zone i , the factor a_i is recalculated using the current values of b_j , while for each destination j , the factor b_j is recalculated using the updated values of a_i .
- **Flow Computation:** During each iteration, the flow from each origin zone to each POI is computed based on the formula 3.

$$q_{ij} = \sum_{i=1}^m \sum_{j=1}^n \frac{O_i}{a_i} \times \frac{D_j}{b_j} \times e^{-\beta c_{ij}} \tag{3}$$

- **Iteration Until Convergence:** During each iteration, a_i , b_j , and the corresponding flow (q_{ij}) are computed. The iteration process persists until the discrepancy between two consecutive flow values falls below the predefined tolerance threshold. This criterion ensures that the system approaches an equilibrium state, characterized by minimal changes in flow. Consequently, the total outgoing flows from each zone match the total incoming flows to each destination according to their respective demand and capacity constraints.

Once the model converges within this tolerance, signifying a minimal difference in values between iterations, the values of flows, along with the resulting flow matrix, are deemed final. These outputs represent a stable state of the model, wherein the calculated values optimally mirror the real-world accessibility conditions from each origin zone to each destination. Within the model's formulation, the concept of opportunity is integral, defined by the capacity of each POI. These capacities dictate the ability of POIs to cater to the population, serving as attractors in our model and exerting a profound influence on the overall accessibility pattern. Conversely, demand is quantified based on the potential users within each origin zone, reflecting the potential need for access to each POI. Moreover, the variable (c_{ij}) represents the cost of travel from each zone to each POI. This cost matrix is meticulously developed by computing the shortest paths from each zone to each POI, leveraging the public transportation data provided by GTFS. The resultant cost matrix, integral to our analysis, encapsulates the travel costs, measured in terms of time, associated with accessing each POI. Additionally, β which is the decay factor, which quantifies the decrease in interaction with increasing distance or cost. For the purposes of this study, β has been set to 0.1, reflecting a moderate decline in interaction as cost increases. This setting helps to model the realistic impact of spatial separation on accessibility.

The final step in computing active accessibility involves utilizing the completed flow matrix. Accessibility for each origin is calculated according to Formula 4, which determines the expected value of the cost by taking a weighted average of the product of flow values q_{ij} from origin i to each destination j and the corresponding travel costs c_{ij} .

$$Acc_i = \frac{\sum_{j=1}^n c_{ij} \times q_{ij}}{\sum_{j=1}^n q_{ij}} \tag{4}$$

Together, the calculated data form the analytical backbone of our doubly constrained model, enabling a nuanced examination of how effectively the urban infrastructure meets the residents' needs and guiding targeted improvements to enhance city-wide accessibility. This comprehensive approach allows us to identify areas where accessibility may be lacking or where resources are underutilized, providing valuable insights for urban planners and policymakers to make informed decisions about infrastructure development and resource allocation. By understanding the interactions of demand, supply, and travel costs, we can work towards creating more equitable and efficient urban environments that better serve the needs of all residents.

2.2. Case study

We applied the aforementioned methodology through a case study focusing on Rome, Italy. As the capital, Rome comprises 1187 zones, each represented by a unique segment of the city with distinct numbers of potential demand. These zones are illustrated in Figure 1, where darker zones signify higher values: for high schools, darker shades indicate zones with a higher student population, and for hospitals, darker areas reflect zones with more total residents. We gathered comprehensive population data from these zones, analysing demographic profiles and socio-economic indicators to understand the city's diverse population characteristics. Our aim was to explore how effectively Rome's public transport supply meets the needs of its residents and identify areas for potential improvement. In our analysis, we included crucial types of POIs to urban living: hospitals and high schools. When quantifying opportunities for hospitals and high schools, we considered their capacity, the number of users they can accommodate or serve simultaneously. This capacity-based approach ensures that our assessment reflects the practical limitations of these POIs in meeting the needs of the population. By considering these factors, our analysis provides a comprehensive understanding of accessibility, catering to the diverse needs and activities of residents in Rome.

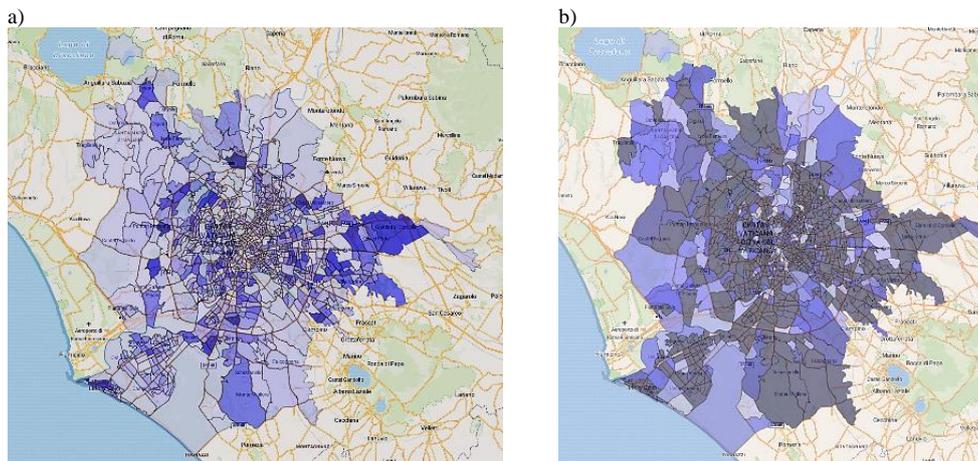


Figure 1. Studied zones considering their potential demand for a) high schools and b) hospitals

Data Collection and Preparation

Before embarking on our accessibility analysis in Rome, meticulous efforts were undertaken to collect and prepare the necessary data. The success of our study hinged upon the accuracy and comprehensiveness of the datasets utilized, which encompassed various dimensions of urban infrastructure, population distribution, and transportation networks.

- **Population Data:** We obtained detailed population data from authoritative sources such as the Italian National Institute of Statistics (ISTAT) and municipal government databases. This data provided insights into the demographic composition of Rome, including population density, age distribution, and socio-economic indicators.
- **POI Locations:** The locations of POIs, including hospitals and high schools were essential components of our analysis. To ensure accuracy, we compiled this information from reliable sources such as public health databases, and educational institutions. Geospatial techniques were employed to geocode POI addresses and accurately represent their spatial distribution within Rome. Figure 2 illustrates the distribution of these facilities in Rome, where darker zones indicate a higher capacity of the respective POI.

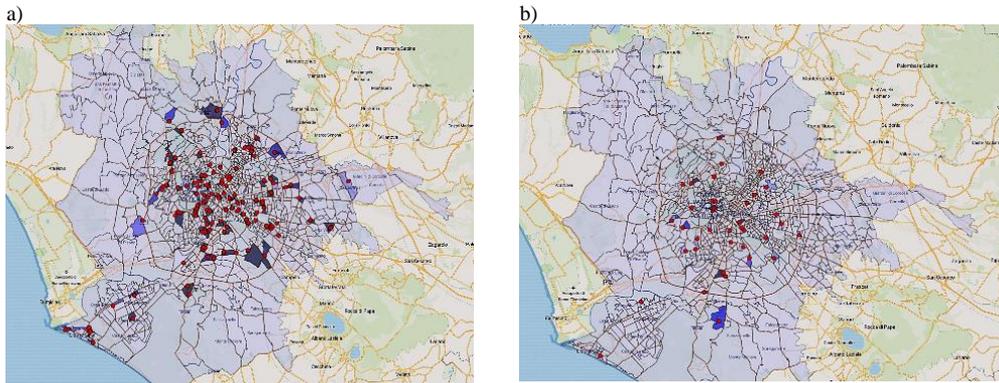


Figure 2. Distribution of target POIs considering their capacity: a) High Schools, B) Hospitals

- **Transportation Networks:** A comprehensive understanding of Rome's transportation infrastructure was vital for assessing accessibility. We leveraged publicly available data from the GTFS to capture the spatial layout and service frequencies of public transit routes, including buses, trams, and metro lines, as shown in Figure 3. This rich dataset facilitated the computation of travel times and distances between origin and destination, serving as a critical input for our accessibility analysis.

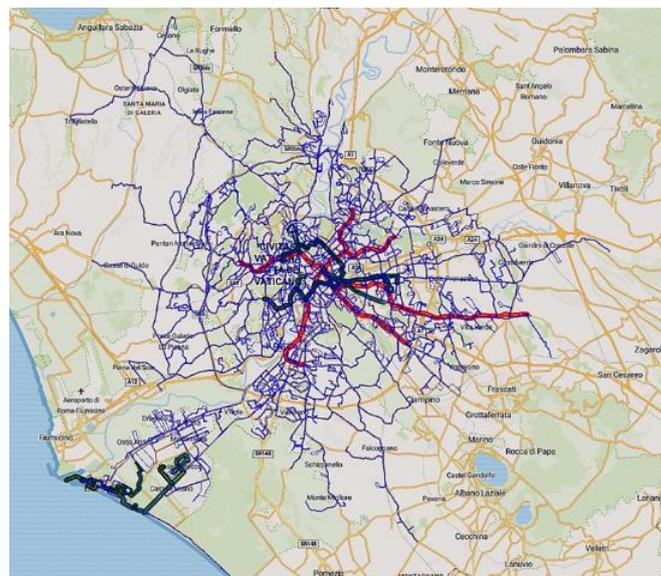


Figure 3. Public transport network in Rome

Platform Description

To facilitate the comprehensive data collection, preparation, and analysis required for our study, we developed an online platform. This platform, built using JavaScript, integrates various datasets and performs the necessary calculations to assess urban accessibility. Below, we provide an overview of the platform's features and capabilities.

Data Handling

The platform is designed to handle various types of data, including GeoJSON and csv files for population and POI data, as well as GTFS data for transportation networks. Key features include:

- **Data Upload and Validation:** Users can upload files for population and POI data, with automatic validation.
- **GTFS Integration:** Incorporates GTFS data to model public transportation networks, computing travel times and distances.

Analytical Capabilities

The platform implements the doubly constrained gravity model and computes accessibility metrics, allowing users to input parameters and perform calculations for detailed insights into POIs access across origin zones.

Visualization and Output

- *Interactive Maps*: Display accessibility levels across the city with customizable parameters.
- *Charts and Graphs*: Summarize accessibility metrics and key findings.

3. Results and findings

3.1. Accessibility to Hospitals

The accessibility analysis for hospitals in Rome is depicted in Figure 4. Figure 4a shows the initial accessibility calculation, while Figure 4b illustrates the accessibility calculation by using doubly constrained model after convergence. The analysis reveals that central areas exhibit the highest accessibility levels, marked by darker green shades, due to a dense public transport network and proximity to multiple hospital facilities, providing quick and easy access for residents. Surrounding these central areas, zones with medium-high accessibility (lighter green) maintain good access to hospitals, supported by reasonably well-connected public transport. In contrast, peripheral zones, indicated by yellow shades, display lower accessibility levels due to longer travel distances. The application of the doubly constrained model results in a redistribution of accessibility of the POIs, reflecting the impact of increased competition for limited healthcare resources and as can be seen since the model accounts for both supply and demand factors, it leads to a more realistic representation of accessibility.

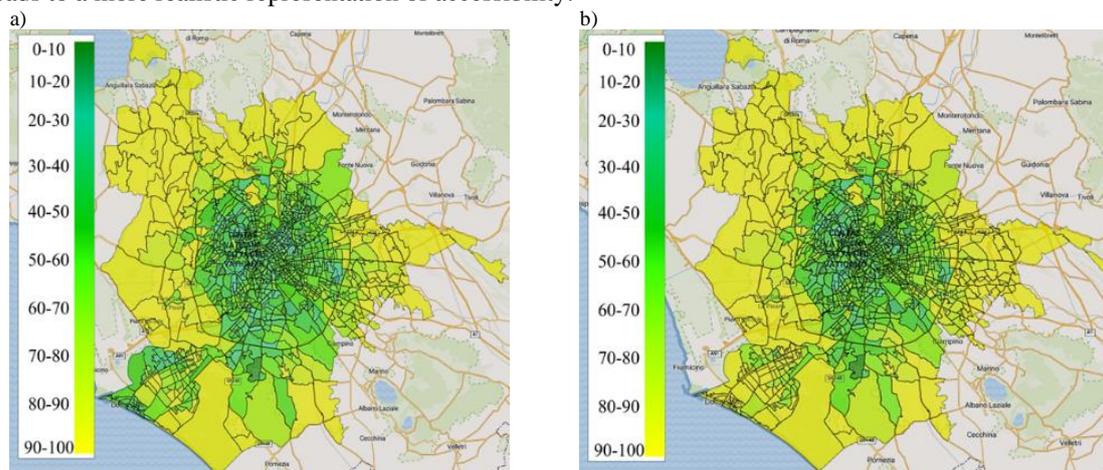


Figure 4. Hospital accessibility in minutes calculated by a) Origin Constrained and b) doubly constrained

The evolution of hospital accessibility in Rome has been illustrated in Figure 5. Initially, the central areas of Rome display high levels of accessibility, contrasting starkly with the more remote outskirts. However, upon implementing the doubly constrained model, a noticeable decrease in accessibility is observed in these central areas, indicating an overestimation in the initial evaluations. Conversely, areas on the outskirts, particularly in the northern parts, experience an increase in accessibility, providing a more accurate reflection of access to hospital services.

Analysis reveals that areas with a high density of hospitals, primarily in central Rome, experienced a decrease in accessibility (marked in red) after the application of the model. This suggests that initial assessments likely overlooked real-world constraints. On the other hand, some suburban areas with less hospital density witnessed increased accessibility (marked in blue), suggesting that initial estimates might have underestimated the accessibility of hospitals, due to efficient transport systems. This analysis highlights the gap between the physical concentration of hospitals and the actual accessibility experienced by residents, emphasizing the need to incorporate comprehensive data that includes transportation and population needs.

By incorporating these elements, the doubly constrained model provides a refined and more accurate depiction of accessibility across Rome, adjusting for both overestimations and underestimations that were previously hidden by less nuanced models.

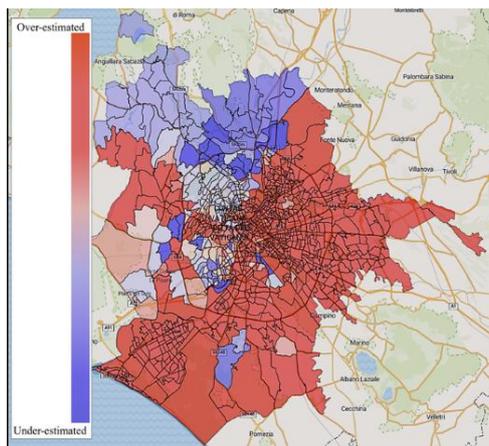


Figure 5. Evolution (Delta) of calculated accessibility in Hospitals

As illustrated in the subsequent series of images (Figure 6), the zones experiencing the most significant improvement and the greatest reduction in accessibility are both marked in yellow for hospitals.

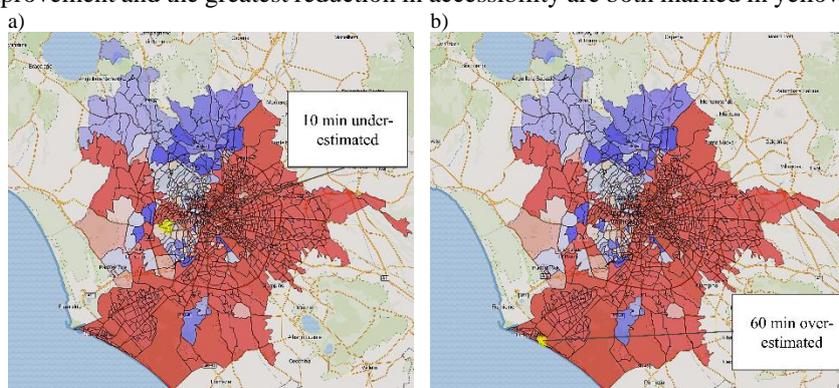


Figure 6. The most over and under-estimated hospital accessibilities

3.2. Accessibility to High Schools

The analysis of accessibility to high schools in Rome shows clear differences across various city areas, as illustrated by the initial gravity model (Figure 7a) and doubly constrained model (Figure 7b). Initially, the central regions demonstrate the highest accessibility levels, supported by an extensive public transport network and the close presence of numerous high schools. The surrounding areas also enjoy fairly high accessibility. However, when the doubly constrained model is applied, there's a shift in accessibility, especially in the outer areas. While central areas continue to have high accessibility, this model points out the effects of heightened competition for educational resources. The outer areas, particularly in the northwest, east, and south, show reduced accessibility due to longer travel times and less frequent public transport options.

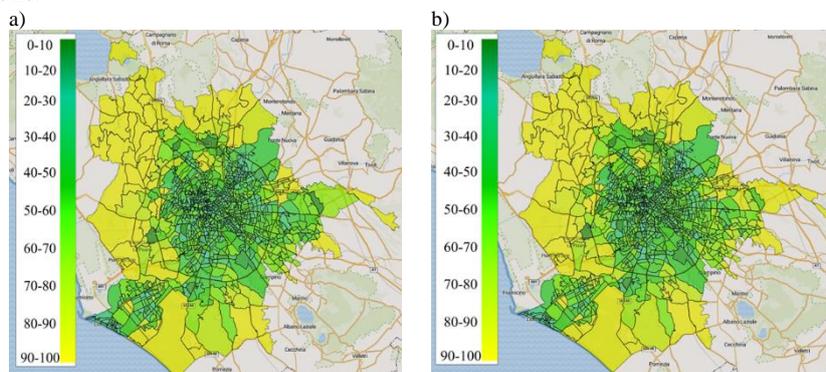


Figure 7. High school accessibility calculated in minutes by a) origin constrained and b) doubly constraint

The analysis visualized through Figure 8 illustrates the evolution of accessibility to high schools in Rome before and after the application of the doubly constrained model. Initially, accessibility appears more evenly distributed across central zones, with peripheral areas significantly underserved. After applying the doubly constrained model, the revised map indicates a nuanced shift in accessibility: a decrease (shown in red) is primarily observed in peripheral areas, suggesting that initial estimates there were overestimated. Conversely, increases in accessibility (shown in blue) are seen in some northern, southern, and central areas, reflecting a more realistic assessment that accounts for supply and demand factors.

By comparing these changes, it becomes apparent that areas with a high concentration of schools often experienced a reduction in accessibility ratings post-model application. This trend suggests that initial accessibility might have been overestimated due to optimistic assumptions about transport efficiency or demographic reach. On the other hand, some peripheral areas with fewer schools witnessed increases in accessibility, indicating that initial estimates might have overlooked the effectiveness of transport systems that enhance school accessibility. This relationship underscores that while the physical presence of high schools is a critical factor in determining accessibility, the interplay with public transport and demographic data provides a more comprehensive picture. The doubly constrained model plays a crucial role in refining these estimates by considering not just the location of the schools but also the capacity of them to efficiently connect students from their residences to schools.

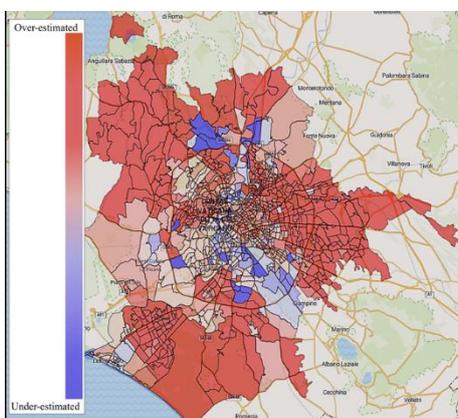


Figure 8. Evolution (Delta) of calculated accessibility in high Schools

As illustrated in the subsequent series of images (Figure 9), the zones experiencing the most significant improvement and the greatest reduction in accessibility are both marked in yellow for high schools.

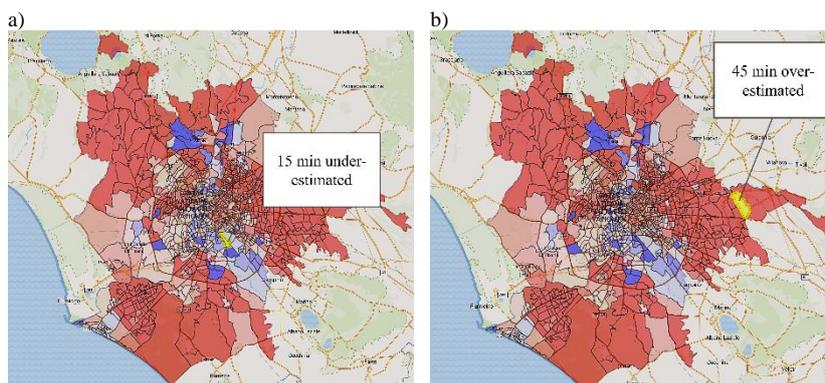


Figure 9. The most over and under-estimated high school accessibilities

4. Conclusion

This study highlights the critical role of advanced analytical models in understanding urban accessibility and mobility. By employing the doubly constrained gravity model, our research into Rome’s public transport accessibility illustrates how such tools can offer comprehensive insights into the spatial variations of cities. This approach enriches our understanding of how urban residents access essential

services, providing a broader picture that transcends the specific conditions of any single city. The doubly constrained model, by accounting for both origins and destinations, has shown a good effect in assessing accessibility according to realistic values, further validating its applicability in urban studies.

Our analysis revealed intricate patterns of accessibility that vary significantly across different urban zones, clearly indicating that while central areas benefit from robust public transport links and proximity to essential services, peripheral regions lag significantly, plagued by inadequate public transport services and longer travel times. The disparities between central and peripheral areas underscore the urgent need for targeted public transport improvements in these underserved areas to balance the accessibility scales. The model's capacity to account for both supply and demand factors enhances its utility, allowing for a deeper exploration into the multifaceted nature of city living. The application of such models is pivotal for advancing our comprehension of urban environments globally. As urban populations continue to grow, the importance of understanding and improving accessibility through informed analysis becomes increasingly clear. This type of research is crucial for academics, urban developers, and even residents seeking to grasp the challenges and opportunities within their urban landscapes.

Future research should focus on expanding the scope of models like the doubly constrained gravity model by refining zones down to the census block level to enhance the model's accuracy. Other suggestions for further investigation include calibrating β over different values and using real-time data to validate the findings of this research. There is a critical need to apply these models to a variety of urban settings, from densely populated megacities to smaller, less-dense environments, to validate and refine their applicability and accuracy. This expansion would enable researchers to compare how different urban forms and governance structures impact accessibility. Additionally, integrating real-time data streams could improve the model's responsiveness to immediate changes in urban conditions, such as construction, policy shifts, or sudden demographic changes.

As we reflect on the implications of this research, it becomes clear that the challenges and solutions identified in urban mobility and accessibility are universally relevant, yet uniquely manifested in each city's fabric. Ultimately, this research serves as a reminder of the power of data-driven insights and innovative modelling techniques in shaping the future of urban living, paving the way for more resilient and adaptable urban environments worldwide.

In conclusion, the use of sophisticated modelling in urban studies not only clarifies the current state of urban accessibility but also sets the stage for future research. It prompts a more nuanced discussion about how cities can evolve to meet the needs of their diverse populations. By continuing to refine these models and apply them in various contexts, we can enhance our strategic approach to urban development, making cities more liveable and accessible for everyone.

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