Sustainable Transportation

Homework 2: Transportation Accessibility Assessment

Qazvin City Job Accessibility Analysis

Using Gravity-Based and Cumulative Opportunities Methods

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Abstract

This report presents a comprehensive accessibility assessment for Qazvin City, Iran, evaluating transportation access to job opportunities across 61 zones grouped into 8 districts (Mantagheh). Two standard methodologies from transport and land-use planning are employed: (1) Gravity-Based Accessibility with a decay parameter $\beta = 0.1068$, and (2) Cumulative Opportunities Method with a 30-minute travel time threshold. Results reveal significant spatial inequalities in job accessibility, with central districts showing substantially higher accessibility values compared to peripheral areas. The analysis provides insights for urban planning and transportation policy recommendations to address accessibility disparities.

Keywords: Accessibility, Gravity Model, Cumulative Opportunities, Transportation Planning, Qazvin

1 Introduction

Transportation accessibility is one of the most critical indicators in sustainable transportation and land-use planning. It measures the ease with which people can reach destinations such as employment centers, services, and amenities using available transportation infrastructure.

This assignment evaluates job accessibility for residents of Qazvin City through public transportation modes. The assessment employs two widely recognized methodologies:

1. **Gravity-Based Accessibility Method**: Accounts for distance decay effects where opportunities farther away contribute less to accessibility.
2. **Cumulative Opportunities Method**: Counts all opportunities reachable within a specified time threshold.

1.1 Study Area

Qazvin is a major city in northwestern Iran with diverse urban zones. The study area comprises:

- **61 zones** (neighborhoods) with distinct population and employment characteristics
- **8 districts** (Mantagheh) for regional aggregation
- Origin-Destination travel time matrix including walking, waiting, and transfer times

2 Methodology

2.1 Data Sources

Three datasets were used for this analysis:

1. **Origin-Destination Travel Time Matrix**: Travel times between all zone pairs (in minutes), including walking time, transfer waiting time, and in-vehicle time.
2. **Geographic Data (GeoJSON)**: Zone boundaries with district assignments and identification numbers.
3. **Employment Data**: Number of jobs and population for each zone.

2.2 Gravity-Based Accessibility

The gravity-based accessibility for zone i is calculated as:

$$A_i^{grav} = \sum_j O_j \cdot e^{-\beta \cdot t_{ij}} \tag{1}$$

Where:

- A_i^{grav} = Gravity-based accessibility for zone i
- O_j = Number of job opportunities in zone j
- t_{ij} = Travel time from zone i to zone j (minutes)
- β = Distance decay parameter (0.1068 as specified)

The exponential decay function reflects the diminishing attractiveness of opportunities as travel time increases. With $\beta = 0.1068$, opportunities at 30 minutes travel time contribute approximately 4% of their full value.

2.3 Cumulative Opportunities Method

The cumulative opportunities accessibility for zone i with threshold T is:

$$A_i^{cumul} = \sum_j O_j \cdot \mathbf{1}(t_{ij} \leq T) \tag{2}$$

Where:

- A_i^{cumul} = Cumulative accessibility for zone i
- T = Time threshold (30 minutes)
- $\mathbf{1}(\cdot)$ = Indicator function (1 if condition is true, 0 otherwise)

This method counts all jobs reachable within 30 minutes, treating all accessible opportunities equally regardless of exact travel time.

3 Results

3.1 Task 1: Accessibility Indicators by Zone and District

Table 1 presents the mean accessibility indicators aggregated by district (Mantagheh).

Table 1: Accessibility Indicators by District (Mean Values)

District (Mantagheh)	Gravity-Based	Cumulative (30-min)
Yakhchal (5)	24,139	126,391
Balaghi (2)	21,269	98,994
Navab South (3)	20,195	111,978
Shisheh Chi (1)	17,729	90,209
Navab North (4)	14,607	72,606
Molla Sadra South (6)	12,497	62,103
Molla Sadra North (7)	6,670	27,025
Kowsar (8)	5,353	15,838

Table 2: Summary Statistics for Accessibility Indicators (All Zones)

Statistic	Gravity-Based	Cumulative (30-min)
Count	61	61
Mean	15,770	77,771
Std Dev	9,248	52,969
Min	2,918	2,690
25%	7,125	25,740
Median	15,711	74,130
75%	23,429	120,840
Max	35,192	188,210

3.2 Task 2: Accessibility Maps

Figure 1 presents choropleth maps of both accessibility indicators across Qazvin's zones.

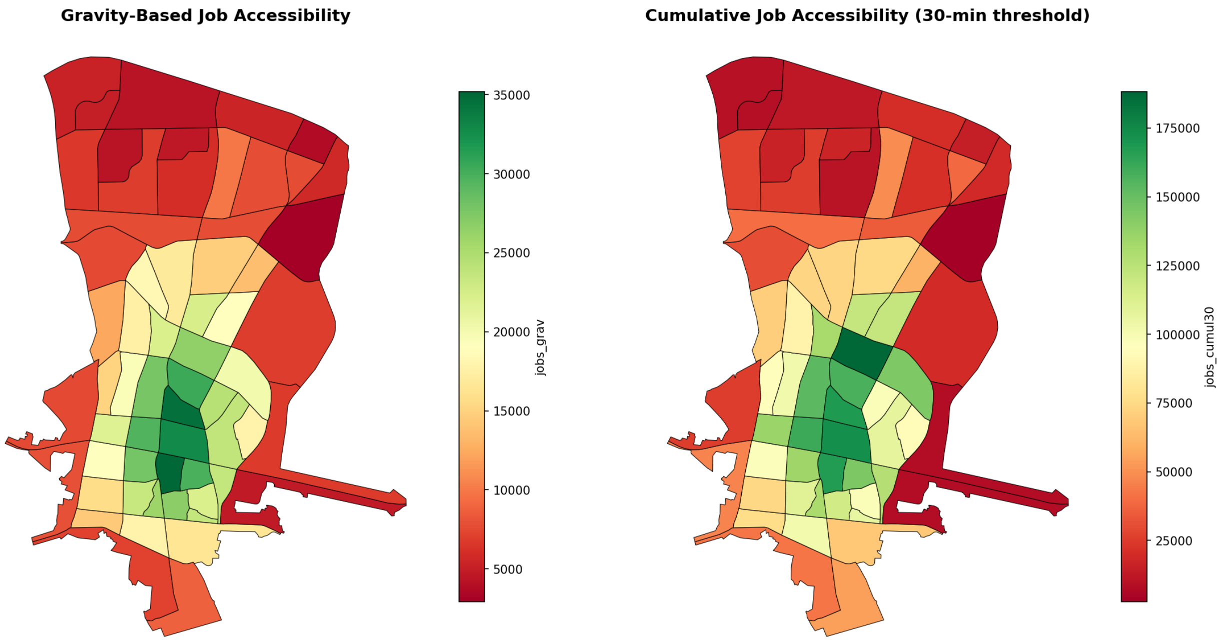

Figure 1: Accessibility Maps: (Left) Gravity-Based Job Accessibility, (Right) Cumulative Job Accessibility with 30-minute threshold. Green indicates high accessibility; red indicates low accessibility.

3.3 Task 3: Method Comparison

3.3.1 Which Method is More Appropriate?

Both methods capture accessibility but differ fundamentally in their assumptions:

Table 3: Comparison of Accessibility Methods

Aspect	Gravity-Based	Cumulative (30-min)
Distance Sensitivity	Continuous decay with distance	Binary (accessible/not accessible)
Behavioral Realism	More realistic (people prefer closer jobs)	Less realistic (ignores time differences within threshold)
Interpretation	Weighted job potential	Total jobs within reach
Policy Use	Investment prioritization	Service coverage assessment
Sensitivity to Threshold	Less sensitive (smooth decay)	Highly sensitive to threshold choice

Recommendation: The **Gravity-Based Method** is more appropriate for this analysis because:

1. **Behavioral realism**: It reflects actual travel behavior where people prefer closer destinations, even within acceptable travel times.
2. **Continuous sensitivity**: Small improvements in travel time translate to proportional accessibility gains, enabling nuanced policy evaluation.
3. **No arbitrary threshold**: The cumulative method's results change dramatically with threshold selection (e.g., 25 vs 30 vs 35 minutes), while gravity-based results are more stable.
4. **Better for planning**: It identifies zones that benefit most from marginal travel time improvements.

However, the **Cumulative Method** remains useful for:

- Communicating accessibility in intuitive terms ("X jobs within 30 minutes")
- Setting minimum service standards
- Equity assessments comparing districts

3.4 Task 4: Geographic Pattern Analysis

3.4.1 Observed Patterns

The accessibility analysis reveals distinct spatial patterns:

1. **Central-Peripheral Gradient**: Central districts (Yakhchal, Balaghi, Navab) show 3-4x higher accessibility than peripheral districts (Kowsar, Molla Sadra North).
2. **Employment Concentration Effect**: Districts with high job density (Balaghi with 10,600 jobs in one zone) serve as accessibility attractors for surrounding areas.
3. **Network Connectivity Impact**: Zones along major transit corridors show consistently higher accessibility regardless of their own employment levels.
4. **Edge Effects**: Northwestern zones (Kowsar district) suffer from limited connectivity, with cumulative accessibility as low as 2,690 jobs.

3.4.2 Why Are Certain Areas More Accessible?

- **High-Accessibility Areas** (Yakhchal, Balaghi, Navab South):
  - Central location minimizing average travel time to all destinations
  - Dense employment concentrations nearby
  - Better public transit connectivity
  - Historic city center with mixed land use
- **Low-Accessibility Areas** (Kowsar, Molla Sadra North):
  - Peripheral location on city edges
  - Primarily residential with few local jobs
  - Limited public transit service
  - Recent development outpacing infrastructure

3.4.3 Inequality Analysis

The Coefficient of Variation (CV) indicates substantial inequality:

- Gravity-Based CV: $\frac{9{,}248}{15{,}770} = 58.6\%$
- Cumulative CV: $\frac{52{,}969}{77{,}771} = 68.1\%$

The ratio between highest and lowest district accessibility exceeds 4:1, indicating significant spatial disparity in job access.

3.5 Task 5: Recommendations for Improvement

Based on the analysis, the following recommendations are proposed to increase accuracy and reliability in accessibility assessment, while addressing observed inequalities:

3.5.1 Recommendation 1: Incorporate Mode-Specific Travel Times

Current limitation: The analysis uses aggregate travel times that may not reflect modal choices.
Improvement:

- Separate accessibility calculations for different modes (walking, cycling, bus, car)
- Weight by mode share to create composite accessibility index
- Enable mode-specific policy evaluation

3.5.2 Recommendation 2: Account for Competition Effects

Current limitation: The gravity model assumes all jobs are equally available to all job seekers.
Improvement:

- Implement a doubly-constrained gravity model or Hansen-based measure
- Include labor force size as a denominator to account for job competition
- Formula modification: $A_i = \sum_j \frac{O_j}{P_j^\alpha} \cdot e^{-\beta t_{ij}}$ where P_j is the competing population

3.5.3 Recommendation 3: Time-of-Day Sensitivity

Current limitation: Static travel times do not capture peak/off-peak variations.
Improvement:

- Calculate peak-hour accessibility (relevant for work trips)
- Include reliability measures (travel time variability)
- Weight by typical work arrival time distributions

3.5.4 Recommendation 4: Validate with Observed Behavior

Current limitation: The decay parameter $\beta = 0.1068$ may not reflect local behavior.
Improvement:

- Calibrate β using observed commute data from household travel surveys
- Compare actual commute distances/times with accessibility predictions
- Segment analysis by income level, car ownership, and job type

3.5.5 Additional Policy Recommendations

To address the observed accessibility inequality:

1. **Transit Investment**: Prioritize bus route extensions to Kowsar and Molla Sadra North districts
2. **Employment Decentralization**: Incentivize job creation in low-accessibility areas
3. **Transfer Optimization**: Reduce transfer times at major hubs to improve gravity-based accessibility
4. **Targeted Development**: Mixed-use development in peripheral zones to increase local job availability

4 Conclusion

This accessibility assessment of Qazvin City reveals significant spatial inequality in job accessibility across the city's 8 districts. Key findings include:

1. Central districts (Yakhchal, Balaghi) exhibit 4x higher accessibility than peripheral areas (Kowsar)
2. The gravity-based method provides more behaviorally realistic results than cumulative opportunities
3. Geographic patterns reflect the combined effects of employment concentration, transit connectivity, and urban form
4. Substantial room exists for policy intervention to reduce accessibility disparities

The analysis demonstrates the value of accessibility metrics for identifying underserved areas and prioritizing transportation investments. Future work should incorporate mode-specific analysis, competition effects, and behavioral calibration to improve assessment accuracy.

References

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A Appendix: Complete Zone-Level Results

The complete accessibility results for all 61 zones are available in the supplementary CSV file: `zone_accessibility_results.csv`

Key zones with highest and lowest accessibility:

Table 4: Top 5 and Bottom 5 Zones by Gravity-Based Accessibility

Rank	Zone Name	Gravity-Based	Cumulative
1	Balaghi	35,192	167,450
2	Malek Abad	29,852	144,360
3	Tanoorsazan	26,785	116,940
4	Khayam	25,956	124,460
5	Khiaban	25,933	130,480
57	Elahieh	4,377	8,950
58	Vali Asr	4,776	8,060
59	Kabol Alborz	6,872	25,740
60	Minoodar	2,918	2,690
61	Pamchal	3,635	7,360