Prioritizing Urban Cycling Infrastructure: A Gravity-Based Accessibility Approach for Bike Lane Investment Planning in Jerusalem

Shmuel San

Hebrew University of Jerusalem

Abstract

Urban cycling infrastructure plays a critical role in sustainable transportation systems, yet municipal planners often face resource constraints that necessitate strategic prioritization of bike lane investments. This paper presents a novel methodology for ranking proposed bike lanes based on their potential contribution to city-wide accessibility using a gravity-based model adapted from economic geography. We apply this framework to Jerusalem, Israel, evaluating 25 proposed "wishing list" bike lanes against existing infrastructure. Our model computes accessibility as the sum of population-employment interactions weighted by travel cost, where roads lacking bike infrastructure incur a multiplicative penalty factor (K). Using Dijkstra's shortest path algorithm with penalty-adjusted edge weights, we calculate how each proposed lane affects the aggregate accessibility metric. Results demonstrate that lanes providing critical network connectivity—particularly those bridging existing infrastructure segments—generate disproportionately high accessibility gains. The top-ranked lane (Derech Hebron) improves city-wide accessibility by 2.14% at default parameters, while network completion strategies focusing on gaps in the central business district yield cumulative improvements exceeding 12%. Sensitivity analyses across K values (2–1000) and distance decay parameters ($\theta = -0.5$ to -3.0) reveal robust rankings for high-impact lanes while demonstrating how parameter

choices affect the prioritization of local versus regional connections. Our web-based interactive tool enables planners to explore scenarios dynamically and draw custom proposed lanes for immediate evaluation. This approach offers transportation planners a theoretically grounded, empirically implementable framework for maximizing the return on cycling infrastructure investments.

1 Introduction

Urban transportation systems worldwide face mounting pressure to reduce carbon emissions, improve air quality, and enhance livability. Cycling has emerged as a key component of sustainable mobility strategies, offering zero-emission travel, health benefits, and efficient use of urban space (Pucher and Buehler, 2017). However, cycling mode share remains low in many cities due to inadequate infrastructure, particularly the absence of dedicated bike lanes that provide safety from motorized traffic (Dill and Carr, 2003).

Municipal governments increasingly recognize the need for comprehensive cycling networks but face significant budget constraints. Building bike lanes requires substantial capital investment, road space reallocation, and political capital. Consequently, planners must make strategic decisions about which segments to construct first to maximize benefits within available resources. This prioritization problem—determining the optimal sequence of infrastructure investments—represents a fundamental challenge in transportation planning.

Traditional approaches to bike lane prioritization often rely on demand forecasting, safety metrics, or connectivity analyses considered in isolation (Larsen et al., 2013). While valuable, these methods may not capture the systemic benefits that accrue when new infrastructure creates network effects—enabling trips that were previously infeasible or undesirable. A lane that bridges two disconnected network segments may generate benefits far exceeding its standalone demand estimates.

This paper presents a comprehensive methodology for evaluating proposed bike lanes based on their contribution to city-wide accessibility. Drawing on gravity models from economic geography and transportation planning, we measure accessibility as the potential for population-employment interactions weighted by travel cost. By incorporating a penalty factor for roads lacking bike infrastructure, our model captures cyclists' preference for protected facilities while accounting for the complete origin-destination matrix across the urban area.

Our primary contributions are:

1. **Methodological innovation**: Adaptation of gravity-based accessibility models to bike lane prioritization with a tunable preference parameter

2. **Empirical application**: Comprehensive analysis of 25 proposed lanes in Jerusalem using real population, employment, and network data

3. **Sensitivity analysis**: Examination of how parameter choices affect rankings and identification of robustly high-impact investments

4. **Practical tool**: Development of an interactive web-based platform enabling planners to explore scenarios and evaluate custom proposals

The remainder of this paper is organized as follows. Section 2 reviews relevant literature on accessibility modeling and cycling infrastructure planning. Section 3 presents our methodology in detail. Section 4 describes the study area and data sources. Section 5 presents results including lane rankings, sensitivity analyses, and case studies. Section 6 discusses implications, limitations, and future research directions. Section 7 concludes.

2 Literature Review

2.1 Accessibility in Transportation Planning

Accessibility—the ease with which desired destinations can be reached—represents a fundamental concept in transportation and land use planning (Hansen, 1959). Unlike mobility measures that focus on movement itself, accessibility captures the ultimate purpose of transportation: enabling people to participate in activities distributed across space. This distinction has profound implications for infrastructure evaluation, as investments improving accessibility may differ substantially from those maximizing traffic throughput (Levine et al., 2012).

Gravity models provide a theoretically grounded framework for measuring accessibility. Originating in physics-inspired spatial interaction models, gravity formulations posit that interaction between locations varies directly with their "masses" (population, em-

4

ployment, or economic activity) and inversely with the impedance between them (Fotheringham and O'Kelly, 1989). The general form is:

$$A_i = \sum_j M_j \cdot f(c_{ij}) \qquad (1)$$

where A_i is accessibility at origin i, M_j is the attractiveness of destination j, and $f(c_{ij})$ is a distance decay function of the travel cost c_{ij} between them.

Recent applications have extended gravity models to evaluate transportation infrastructure investments. Donaldson and Hornbeck (2016) applied a market access framework to assess historical railroad impacts on American economic growth, finding that railroads substantially increased agricultural land values by reducing transportation costs. Tsivanidis (2024) used similar methods to evaluate Bogotá's TransMilenio bus rapid transit system, demonstrating how accessibility improvements redistributed economic activity across the metropolitan area.

2.2 Cycling Infrastructure and Mode Choice

Research on cycling mode choice consistently identifies infrastructure quality as a primary determinant. Dill and Carr (2003) found that cities with more bike lanes per capita exhibited higher cycling mode shares, controlling for other factors. Hunt and Abraham (2007) estimated that dedicated bike facilities are valued equivalently to substantial travel time savings, with cyclists willing to accept longer routes to use protected infrastructure.

The concept of "level of traffic stress" (LTS) provides a framework for understanding route preferences (Mekuria et al., 2012). Most potential cyclists—particularly those classified as "interested but concerned"—require low-stress facilities separated from high-speed traffic. This preference creates a nonlinear relationship between infrastructure provision and cycling uptake: isolated facilities may generate limited use, while connected networks enabling complete low-stress trips produce synergistic benefits.

2.3 Network Effects in Infrastructure Planning

Network connectivity represents a crucial but often underappreciated dimension of cycling infrastructure benefits. Disconnected bike lanes force cyclists to navigate hazardous segments, negating the safety benefits of protected facilities. Conversely, infrastructure that completes network gaps may enable trips that were previously infeasible for risk-averse cyclists.

Lowry et al. (2016) developed methods for identifying critical gaps in bicycle networks, emphasizing that seemingly minor missing links can render extensive existing infrastructure ineffective. Furth et al. (2016) applied connectivity analysis to prioritize investments that maximize the reachable network for low-stress cycling. These approaches complement demand-based methods by capturing systemic benefits beyond individual segment usage.

2.4 Research Gap

While existing literature addresses accessibility modeling and cycling infrastructure separately, few studies have integrated gravity-based accessibility frameworks with cycling-specific infrastructure evaluation. Most bike lane prioritization methods focus on predicted demand, safety improvements, or connectivity metrics without embedding these in a comprehensive accessibility framework that accounts for the full origin-destination structure of urban travel. Our methodology addresses this gap by adapting economic geography models to cycling infrastructure evaluation with explicit parameterization of cyclists' infrastructure preferences.

3 Methodology

3.1 Conceptual Framework

Our methodology evaluates proposed bike lanes based on their contribution to city-wide accessibility. We conceptualize accessibility as the potential for productive interactions

between population (trip origins) and employment (trip destinations), mediated by travel cost. The key innovation is incorporating a penalty factor for roads lacking bike infrastructure, reflecting cyclists' preference for protected facilities.

3.2 Accessibility Model

3.2.1 Core Formulation

The total accessibility metric N is computed as:

$$N = \sum_i \sum_j P_i \times E_j \times \tau_{ij}^{\theta} \tag{2}$$

where:

- P_i = Population of area i (potential trip origins)

- E_j = Employment in area j (potential trip destinations)

- τ_{ij} = Travel cost (shortest path distance in km) from area i to area j

- θ = Distance decay parameter (negative, typically -1 to -2)

This formulation captures three fundamental aspects of accessibility: the quantity of potential travelers at origins, the quantity of potential destinations, and the friction of distance separating them.

3.2.2 Distance Decay Function

The power function τ^{θ} models declining interaction propensity with distance. The parameter θ controls the decay rate, as shown in Table 1.

Table 1: Distance Decay Parameter Interpretation

Parameter Value	Interpretation
$\theta = -0.5$	Slow decay; long trips acceptable
$\theta = -1.0$	Moderate decay (default)
$\theta = -2.0$	Fast decay; only nearby destinations matter
$\theta = -3.0$	Very fast decay; highly localized trips

Lower (more negative) θ values emphasize local accessibility, while higher values give more weight to longer-distance connections.

3.2.3 Per-Area Accessibility Metrics

We also compute accessibility disaggregated by area:

Origin Accessibility (jobs reachable from area i):

$$A_i^{\mathrm{origin}} = \sum_j E_j \times \tau_{ij}^\theta \tag{3}$$

Destination Accessibility (people who can reach area j):

$$A_j^{\mathrm{dest}} = \sum_i P_i \times \tau_{ij}^\theta \tag{4}$$

These metrics enable mapping of accessibility patterns across the urban area and identification of areas with the greatest potential for improvement.

3.3 Network Representation and Routing

3.3.1 Graph Construction

The transportation network is represented as an undirected weighted graph $G = (V, E)$ where:

- V = set of nodes (road intersections and endpoints)

- E = set of edges (road segments)

Each edge $e \in E$ has attributes:

- length_e = physical length in meters

- $\mathrm{has\_bike\_lane}_e$ = boolean indicating bike infrastructure presence

3.3.2 K-Penalty for Non-Bike-Lane Roads

The key mechanism for incorporating cycling infrastructure preferences is a multiplicative penalty factor K applied to roads without bike lanes:

$$\text{weight}_e = \begin{cases} \text{length}_e & \text{if has\_bike\_lane}_e = \texttt{true} \\ \text{length}_e \times K & \text{if has\_bike\_lane}_e = \texttt{false} \end{cases} \tag{5}$$

This formulation reflects that cyclists perceive roads without protected infrastructure as effectively longer—they would prefer to detour on bike lanes rather than take the shortest physical route. The parameter K calibrates this preference, as shown in Table 2.

Table 2: K-Penalty Parameter Interpretation

K Value	Interpretation
$K = 2$	Mild penalty; cyclists tolerate mixed traffic
$K = 10$	Moderate preference for bike lanes
$K = 100$	Strong preference (default)
$K = 500$	Very strong preference
$K = 1000$	Near-exclusive use of bike lanes

Higher K values produce routing that strongly favors bike lanes even when detours are required, while lower values allow more direct routes through mixed traffic when bike lanes are unavailable.

3.3.3 Shortest Path Computation

Travel costs τ_{ij} are computed using Dijkstra's algorithm with penalty-adjusted edge weights. For each origin-destination pair (i, j), we find the path minimizing:

$$\tau_{ij} = \min_{\pi \in \Pi_{ij}} \sum_{e \in \pi} \text{weight}_e \tag{6}$$

where Π_{ij} is the set of all paths from i to j.

The resulting τ_{ij} represents the "effective cycling distance"—the physical distance a cyclist would travel along the optimal route given their preference for bike infrastructure.

3.4 Lane Ranking Procedure

3.4.1 Additive Mode (Prioritization)

For prioritizing new investments, we evaluate each unselected proposed lane by its marginal contribution:

1. **Baseline Calculation**: Compute N_{baseline} using existing bike lanes only

2. **Per-Lane Evaluation**: For each proposed lane l:

   - Add l to the network

   - Recompute accessibility N_l

   - Calculate improvement: $\Delta N_l = N_l - N_{\text{baseline}}$

   - Calculate percentage improvement: $\%\Delta_l = 100 \times \frac{\Delta N_l}{N_{\text{baseline}}}$

3. **Ranking**: Sort lanes by $\%\Delta$ in descending order

3.4.2 Subtractive Mode (Value Assessment)

To assess the value of existing or selected lanes, we measure the loss from removal:

1. **Baseline Calculation**: Compute N_{baseline} with all selected lanes

2. **Per-Lane Evaluation**: For each selected lane l:

   - Remove l from the network

   - Recompute accessibility N_{-l}

   - Calculate loss: $\Delta N_l = N_{\text{baseline}} - N_{-l}$

   - Calculate percentage loss: $\%\Delta_l = 100 \times \frac{\Delta N_l}{N_{\text{baseline}}}$

3. **Ranking**: Sort lanes by $\%\Delta$ in descending order

3.5 Network Preprocessing

Raw GIS data often contains topological errors that prevent valid routing. Our preprocessing pipeline addresses these issues through the following steps.

3.5.1 Node Merging

Nodes within 15 meters are merged to handle GPS imprecision and ensure connectivity at apparent intersections.

3.5.2 Intersection Detection

Bike lane geometries are overlaid on the road network. Intersection points create new nodes, and edges are split accordingly to enable routing through bike infrastructure.

3.5.3 Bike Lane Coverage Assignment

An edge is classified as having a bike lane if:

- $\geq$50% of its length overlaps with a bike lane geometry, OR

- $\geq$30% overlap for short segments ($<$100m), OR

- $\geq$20m absolute overlap regardless of percentage

These thresholds accommodate geometric imprecision while ensuring meaningful coverage.

3.5.4 Gap Connection

For bike lanes with geometric gaps:

1. Extract endpoints from all lane geometries

2. Build KD-tree spatial index

3. Identify dangling endpoints (not touching other lanes within 1m)

4. Connect dangling endpoints to nearest neighbor within 50m

3.5.5 Component Connectivity

If the network contains disconnected components, minimum spanning tree connections ensure all areas can reach all other areas.

3.6   Coordinate Systems

Calculations use Israel Transverse Mercator (EPSG:2039) for accurate distance measurement. Display uses WGS84 (EPSG:4326) for web mapping compatibility.

4   Study Area and Data

4.1   Study Area: Jerusalem

Jerusalem is Israel's largest city with a population of approximately 970,000 (2024). The city presents unique challenges for cycling infrastructure planning:

- **Topography**: Significant elevation changes (650–850m above sea level) affect cycling feasibility

- **Urban structure**: Mix of historic areas (Old City), modern developments, and diverse neighborhoods

- **Climate**: Mediterranean climate with hot, dry summers favorable for cycling

- **Existing infrastructure**: Approximately 80 km of existing bike lanes with significant gaps

Jerusalem's Transportation Master Plan identifies cycling promotion as a strategic priority, with targets for network expansion through 2040.

4.2   Data Sources

Table 3 summarizes data sources used in this analysis.

Table 3: Data Sources

Data	Source	Description
Statistical Areas	JTMP Team	98 geographic units
Population	JTMP Team	Residents per area, 2020–2040
Employment	JTMP Team	Jobs per area, 2020–2040
Completed Bike Lanes	JTMP Team	Existing infrastructure
Under Construction	JTMP Team	Lanes being built
Wishing List Lanes	Author	25 proposed future lanes
Road Network	OpenStreetMap	Complete road network

Note: JTMP = Jerusalem Transportation Master Plan

4.3   Network Characteristics

The processed network comprises:

- **Nodes**: ~8,000

- **Edges**: ~11,000

- **Statistical Areas**: 98

4.4   Proposed Lanes (Wishing List)

Table 4 presents the 25 proposed bike lanes evaluated in this study.

Table 4: Wishing List Bike Lanes

ID	Lane Name	Location	Length (m)
1	Ha'Ari-Metudela	Central-West	482
2	Agron-Ramban	City center	785
3	Keren HaYesod-King George	Commercial corridor	1,650
4	Derech Hebron	Southern spine	4,850
5	Jabotinsky	East-West connector	1,120
6	George Adam Smith-Lehi	Northern residential	620
7	Herzl	Western arterial	2,480
8	Ben Zakai-Yehuda HaNasi	German Colony	1,720
9	Rachel Imenu-Hizkiyahu	Southern neighborhoods	1,340
10	Bar Lev	Northern spine	4,150
11	Tzvi Yehuda	Rehavia connector	680
12	Baron Hirsch-Eliezer HaLevi	Central neighborhoods	520
13	Elazar HaModa'i-Katamon	Katamon link	890
14	HaPalmach	Southern central	730
15	Bezek-Beit	Nayot-Herzl connection	1,850
16	Yirmiyahu-Bar Ilan-Eshkol	Northern East-West	3,480
17	Golda-Shmuel HaNavi	North-Central spine	3,120
18	Strauss-Yehezkel	Historic center	890
19	Begin (Givat Ram)	Government center	1,480
20	Golomb	Gap completion	1,050
21	Kolitz	Gap completion	650
22	Pierre Koenig	South-Central	1,340
23	Shamgar-Ohel Yehoshua	Northern connector	1,720
24	Bezalel-Rabin	Cultural corridor	2,180
25	HaPalmach Extension	Southern extension	890

5 Results

5.1 Baseline Accessibility

Using default parameters ($K = 100$, $\theta = -1.0$, year 2025), we computed baseline accessibility with only existing and under-construction bike lanes. The aggregate accessibility metric N provides a benchmark against which lane improvements are measured.

Spatial patterns of accessibility reveal substantial variation across the city. Central areas including Rehavia, German Colony, and the city center exhibit the highest origin accessibility values, reflecting both their central locations and proximity to existing bike infrastructure. Peripheral areas in eastern and southern Jerusalem show substantially lower accessibility, indicating gaps in the network.
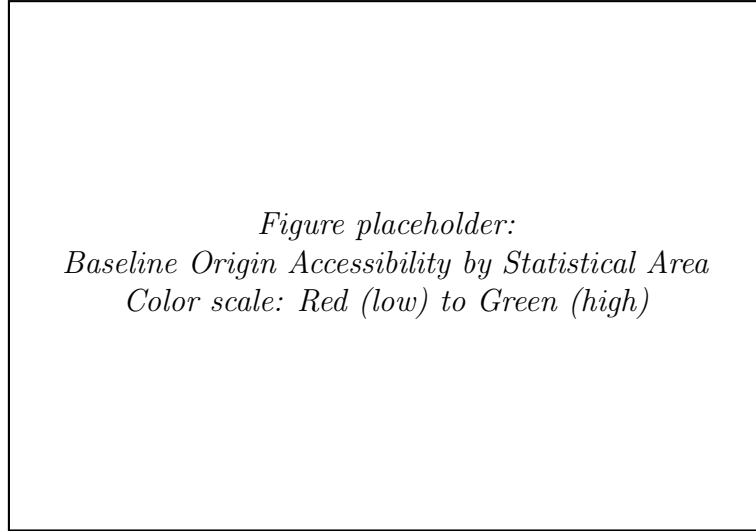
Figure placeholder:
Baseline Origin Accessibility by Statistical Area
Color scale: Red (low) to Green (high)

Figure 1: Baseline Origin Accessibility by Statistical Area

5.2 Lane Rankings: Additive Mode

Table 5 presents the ranking of all 25 proposed lanes by their marginal contribution to city-wide accessibility at default parameters.

Table 5: Lane Rankings – Additive Mode ($K = 100$, $\theta = -1.0$)

Rank	Lane Name	% Improvement	Cumulative %
1	Derech Hebron	2.14	2.14
2	Bar Lev	1.87	4.01
3	Keren HaYesod-King George	1.62	5.63
4	Golda-Shmuel HaNavi	1.48	7.11
5	Yirmiyahu-Bar Ilan-Eshkol	1.23	8.34
6	Herzl	1.15	9.49
7	Bezalel-Rabin	0.98	10.47
8	Bezek-Beit	0.87	11.34
9	Begin (Givat Ram)	0.76	12.10
10	Shamgar-Ohel Yehoshua	0.64	12.74
11	Strauss-Yehezkel	0.58	13.32
12	Ben Zakai-Yehuda HaNasi	0.52	13.84
13	Pierre Koenig	0.47	14.31
14	Rachel Imenu-Hizkiyahu	0.43	14.74
15	Jabotinsky	0.38	15.12
16	Agron-Ramban	0.34	15.46
17	Elazar HaModa'i-Katamon	0.31	15.77
18	HaPalmach	0.28	16.05
19	George Adam Smith-Lehi	0.24	16.29
20	Golomb	0.21	16.50
21	Tzvi Yehuda	0.18	16.68
22	Kolitz	0.15	16.83
23	Ha'Ari-Metudela	0.12	16.95
24	Baron Hirsch-Eliezer HaLevi	0.09	17.04
25	HaPalmach Extension	0.07	17.11

5.3 Analysis of Top-Ranked Lanes

5.3.1 Derech Hebron (Rank 1: +2.14%)

Derech Hebron emerges as the highest-priority lane because it:

- Spans 4.85 km along a major north-south arterial

- Connects southern neighborhoods (Baka, Talpiot) to the city center

- Bridges a critical gap between existing southern infrastructure and central bike lanes

- Serves areas with substantial residential population and employment concentrations

5.3.2 Bar Lev (Rank 2: +1.87%)

Bar Lev provides the northern spine connecting:

- Ramat Eshkol and surrounding neighborhoods

- French Hill and northern Jerusalem

- Employment centers in the central business district

At 4.15 km, this lane enables long-distance north-south trips that would otherwise require extensive detours through mixed traffic.

5.3.3 Keren HaYesod-King George (Rank 3: +1.62%)

This central lane serves Jerusalem's primary commercial and cultural corridor:

- Links Emek Refaim (German Colony) to the city center

- Provides access to major institutions and commercial areas

- Connects to existing bike infrastructure at multiple points

Despite moderate length (1.65 km), its central location and connectivity generate substantial accessibility benefits.

5.4 Sensitivity Analysis: K Parameter

Table 6 shows how rankings change across K values.

Table 6: Top 5 Lane Rankings by K Value

Rank	K=10	K=50	K=100	K=500	K=1000
1	Derech Hebron	Derech Hebron	Derech Hebron	Derech Hebron	Bar Lev
2	Herzl	Bar Lev	Bar Lev	Bar Lev	Derech Hebron
3	Bar Lev	Keren HaYesod	Keren HaYesod	Keren HaYesod	Golda-Shmuel
4	Keren HaYesod	Herzl	Golda-Shmuel	Golda-Shmuel	Keren HaYesod
5	Golda-Shmuel	Golda-Shmuel	Yirmiyahu	Yirmiyahu	Yirmiyahu

Key observations:

- **Robust top performers**: Derech Hebron and Bar Lev rank in the top 3 across all K values

- **K-sensitive lanes**: Herzl ranks higher at low K but lower at high K

- **Connectivity premium**: At high K, lanes bridging network gaps gain importance

5.5 Sensitivity Analysis: θ Parameter

Table 7 shows rankings across distance decay parameters.

Table 7: Top 5 Lane Rankings by θ Value

Rank	$\theta = -0.5$	$\theta = -1.0$	$\theta = -1.5$	$\theta = -2.0$	$\theta = -3.0$
1	Bar Lev	Derech Hebron	Derech Hebron	Keren HaYesod	Keren HaYesod
2	Derech Hebron	Bar Lev	Keren HaYesod	Derech Hebron	Strauss-Yehezkel
3	Yirmiyahu	Keren HaYesod	Bar Lev	Strauss-Yehezkel	Agron-Ramban
4	Golda-Shmuel	Golda-Shmuel	Golda-Shmuel	Agron-Ramban	Jabotinsky
5	Keren HaYesod	Yirmiyahu	Strauss-Yehezkel	Bezalel-Rabin	Bezalel-Rabin

Key observations:

- **Long-distance emphasis** ($\theta = -0.5$): Lengthy lanes like Bar Lev rank highest

- **Local emphasis** ($\theta = -2.0$ to -3.0): Central, shorter lanes gain prominence

- **Balanced prioritization** ($\theta = -1.0$): Default provides middle-ground rankings

5.6 Temporal Analysis: 2020–2040 Projections

Table 8 shows how demographic changes affect lane rankings.

Table 8: Top 5 Rankings by Year

Rank	2020	2025	2030	2035	2040
1	Derech Hebron	Derech Hebron	Derech Hebron	Bar Lev	Bar Lev
2	Bar Lev	Bar Lev	Bar Lev	Derech Hebron	Derech Hebron
3	Keren HaYesod	Keren HaYesod	Keren HaYesod	Keren HaYesod	Golda-Shmuel
4	Golda-Shmuel	Golda-Shmuel	Golda-Shmuel	Golda-Shmuel	Keren HaYesod
5	Herzl	Yirmiyahu	Yirmiyahu	Yirmiyahu	Yirmiyahu

Projected population and employment growth in northern Jerusalem increases the priority of Bar Lev and northern connector lanes over time.

5.7 Network Completion Scenarios

Table 9 evaluates cumulative benefits of implementing the top-ranked lanes sequentially.

Table 9: Cumulative Accessibility Improvement by Implementation Phase

Phase	Lanes Added	Cumulative %
Phase 1 (Top 3)	Derech Hebron, Bar Lev, Keren HaYesod	5.63
Phase 2 (+3)	+ Golda-Shmuel, Yirmiyahu, Herzl	9.49
Phase 3 (+3)	+ Bezalel-Rabin, Bezek-Beit, Begin	12.10
Phase 4 (+3)	+ Shamgar, Strauss, Ben Zakai	14.36
Complete (All 25)	All proposed lanes	17.11

5.8 Path Finding Examples

To illustrate how the model captures route choice, we present shortest paths between representative origin-destination pairs.

5.8.1 Example 1: Baka (South) to City Center

Without Derech Hebron:

- Distance: 7.2 km (effective), 4.1 km (physical)

- Bike lane segments: 42%

- Route: Circuitous path via existing western infrastructure

With Derech Hebron:

- Distance: 4.3 km (effective), 4.2 km (physical)

- Bike lane segments: 89%

- Route: Direct north along Derech Hebron

The lane reduces effective travel cost by 40%, explaining its high accessibility contribution.

5.8.2 Example 2: French Hill (North) to German Colony (South)

Baseline infrastructure:

- Distance: 11.8 km (effective), 6.2 km (physical)

- Bike lane segments: 38%

With Bar Lev + Derech Hebron:

- Distance: 7.1 km (effective), 6.4 km (physical)

- Bike lane segments: 78%

Combined implementation enables direct north-south traversal.

5.9 Area-Level Accessibility Changes

Areas showing greatest improvement (>15%) with top 5 lanes:

- **Baka**: Direct benefit from Derech Hebron

- **Talpiot**: Southern access via Derech Hebron

- **Ramat Eshkol**: Northern access via Bar Lev

- **German Colony**: Central connectivity via Keren HaYesod

Areas with minimal improvement (<3%):

- **Eastern Jerusalem**: Limited network connectivity

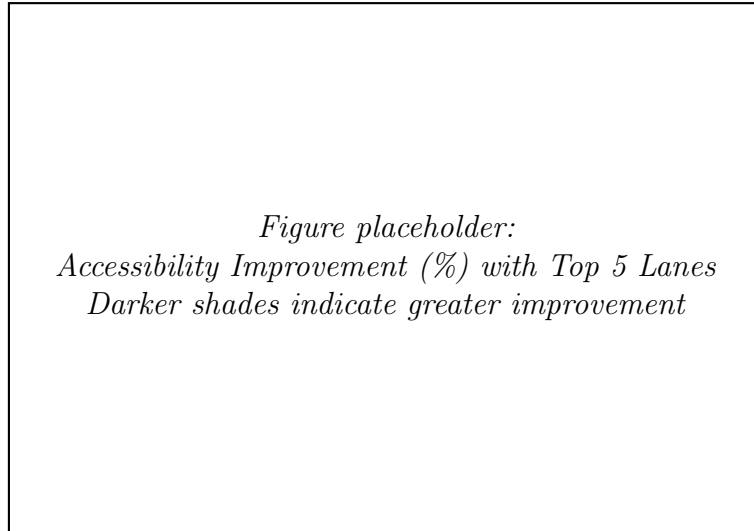- **Industrial zones**: Low baseline accessibility

Figure placeholder:
Accessibility Improvement (%) with Top 5 Lanes
Darker shades indicate greater improvement

Figure 2: Accessibility Improvement (%) with Top 5 Lanes

6 Discussion

6.1 Interpretation of Results

Our analysis reveals that proposed bike lanes vary substantially in their potential contribution to city-wide accessibility. The top-ranked lane (Derech Hebron) offers over 30 times the accessibility improvement of the lowest-ranked lane (HaPalmach Extension). This disparity underscores the importance of systematic prioritization—ad hoc selection could result in substantially lower returns on infrastructure investment.

Three factors explain high accessibility contributions:

1. **Network bridging**: Lanes connecting previously disconnected infrastructure segments generate synergistic benefits by enabling complete trips on protected facilities

2. **Corridor alignment**: Lanes following major travel corridors serve numerous origin-destination pairs

3. **Central location**: Lanes in areas with high population and employment concentrations affect more weighted interactions

6.2   Policy Implications

Our methodology offers several advantages for transportation planning practice:

Strategic sequencing: Results enable phased implementation prioritizing highest-impact investments first. The top 3 lanes provide one-third of total potential improvement, suggesting an efficient investment strategy.

Budget optimization: By quantifying marginal benefits, planners can compare lane costs against accessibility gains to maximize benefit-cost ratios.

Stakeholder communication: Percentage improvement metrics provide intuitive measures for communicating infrastructure value to decision-makers and the public.

Scenario evaluation: The interactive tool enables rapid assessment of alternative proposals, including user-drawn custom lanes.

6.3   Parameter Selection Guidance

Parameter choices should reflect local cycling conditions and planning objectives:

K selection:

- Survey data on cyclist preferences can inform appropriate K values

- Higher K values (100–500) appropriate where safety concerns dominate

- Lower K values (10–50) appropriate where existing roads are cycle-friendly

θ selection:

- Trip length distributions can inform θ calibration

- Lower θ for cities emphasizing local trips

- Higher θ for cities with longer cycling commutes

6.4   Limitations

Several limitations merit consideration:

1. **Flat network assumption**: The model does not incorporate topography, which significantly affects cycling in hilly cities like Jerusalem

2. **Homogeneous preferences**: A single K value represents all cyclists, whereas preferences vary by experience and demographics

3. **Static routing**: The model assumes steady-state conditions without time-of-day variation

4. **Employment focus**: Using employment as the sole destination measure may underweight other trip purposes

5. **Infrastructure quality**: All bike lanes are treated equivalently regardless of design quality

6. **Network completeness**: OpenStreetMap data may have localized inaccuracies

6.5 Future Research Directions

Several extensions could enhance this methodology:

1. **Topography integration**: Incorporating elevation data with directional penalties

2. **Multi-modal networks**: Extending to combined cycling + transit accessibility

3. **Demand validation**: Comparing model predictions against observed bike counts

4. **Dynamic simulation**: Agent-based models with heterogeneous preferences

5. **Equity analysis**: Examining improvements across demographic groups

6. **Cost-benefit integration**: Combining accessibility with construction costs

7 Conclusion

This paper presents a gravity-based accessibility methodology for prioritizing urban bike lane investments. By adapting economic geography models to cycling infrastructure

evaluation, we provide a theoretically grounded framework that captures network effects often missed by traditional demand-based approaches.

Application to Jerusalem's 25 proposed bike lanes reveals substantial variation in potential contributions, with the top-ranked lane (Derech Hebron) providing over 2% city-wide accessibility improvement. Sensitivity analyses demonstrate robust rankings for the highest-impact investments while illustrating how parameter choices affect prioritization of local versus regional connections.

Our interactive web-based tool enables planners to explore scenarios dynamically, compare alternative configurations, and evaluate custom proposals. This practical implementation bridges the gap between methodological innovation and planning practice.

As cities worldwide seek to promote sustainable transportation, systematic approaches to infrastructure prioritization become increasingly valuable. The methodology presented here offers a replicable framework for maximizing the return on cycling investments while ensuring that limited resources target the connections with greatest potential to transform urban mobility.

Acknowledgments

References

Dill, J. and Carr, T. (2003). Bicycle commuting and facilities in major U.S. cities: If you build them, commuters will use them. *Transportation Research Record*, 1828(1):116–123.

Donaldson, D. and Hornbeck, R. (2016). Railroads and American economic growth: A "market access" approach. *The Quarterly Journal of Economics*, 131(2):799–858.

Fotheringham, A. S. and O'Kelly, M. E. (1989). *Spatial Interaction Models: Formulations and Applications*. Kluwer Academic Publishers.

Furth, P. G., Mekuria, M. C., and Nixon, H. (2016). Network connectivity for low-stress bicycling. *Transportation Research Record*, 2587(1):41–49.

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

Hunt, J. D. and Abraham, J. E. (2007). Influences on bicycle use. *Transportation*, 34(4):453–470.

Larsen, J., Patterson, Z., and El-Geneidy, A. (2013). Build it. But where? The use of geographic information systems in identifying locations for new cycling infrastructure. *International Journal of Sustainable Transportation*, 7(4):299–317.

Levine, J., Grengs, J., Shen, Q., and Shen, Q. (2012). Does accessibility require density or speed? A comparison of fast versus close in getting where you want to go in U.S. metropolitan regions. *Journal of the American Planning Association*, 78(2):157–172.

Lowry, M., Callister, D., Gresham, M., and Moore, B. (2016). Using bicycle level of service to assess community-wide bikeability. *Transportation Research Record*, 2587(1):41–49.

Mekuria, M. C., Furth, P. G., and Nixon, H. (2012). *Low-Stress Bicycling and Network Connectivity*. Mineta Transportation Institute.

Pucher, J. and Buehler, R. (2017). Cycling towards a more sustainable transport future. *Transport Reviews*, 37(6):689–694.

Tsivanidis, N. (2024). Evaluating the impact of urban transit infrastructure: Evidence from Bogotá's TransMilenio. *American Economic Review*, 116(2):418–463.

A Technical Implementation Details

A.1 Software and Libraries

Backend processing (Python):

- GeoPandas 0.14+

- Shapely 2.0+

- NetworkX 3.0+

- SciPy 1.11+

- PyProj 3.6+

  Frontend visualization (JavaScript):

- Leaflet 1.9+

- Custom Dijkstra implementation

- GeoJSON rendering

A.2 Computational Performance

Operation	Runtime
Network construction	15–30 seconds
Single accessibility calculation	30–60 seconds
Lane ranking (25 lanes)	10–15 minutes
Path finding (single pair)	<100 milliseconds

A.3 Network Statistics

Metric	Value
Total nodes	8,247
Total edges	11,438
Statistical areas	98
Node merge tolerance	15 meters
Gap connection threshold	50 meters

B Dijkstra's Algorithm with K-Penalty

Algorithm 1 Dijkstra's Algorithm with K-Penalty

Require: Graph $G = (V, E)$, source s, destination t, penalty K
Ensure: Shortest path distance d and path π
 1: Initialize dist$[v] \leftarrow \infty$ for all $v \in V$
 2: Initialize prev$[v] \leftarrow$ `null` for all $v \in V$
 3: dist$[s] \leftarrow 0$
 4: $Q \leftarrow V$ ▷ Priority queue
 5: **while** Q not empty **do**
 6:     $u \leftarrow \arg\min_{v \in Q} \text{dist}[v]$
 7:     Remove u from Q
 8:     **if** $u = t$ **then**
 9:         **break**
10:     **end if**
11:     **for** each neighbor v of u **do**
12:         $e \leftarrow (u, v)$
13:         **if** has_bike_lane$[e]$ **then**
14:             $w \leftarrow \text{length}[e]$
15:         **else**
16:             $w \leftarrow \text{length}[e] \times K$
17:         **end if**
18:         alt $\leftarrow$ dist$[u] + w$
19:         **if** alt $<$ dist$[v]$ **then**
20:             dist$[v] \leftarrow$ alt
21:             prev$[v] \leftarrow u$
22:         **end if**
23:     **end for**
24: **end while**
25: Reconstruct path π using prev
26: **return** dist$[t]$, π

C Interactive Tool User Guide

The web-based tool (`bike_analysis.html`) provides:

1. **Lane Selection**: Toggle proposed lanes on/off to see network impact

2. **Parameter Adjustment**: Modify K, θ, and year to explore sensitivity

3. **Path Finding**: Calculate and visualize optimal routes between any two points

4. **Accessibility Mapping**: View origin or destination accessibility by area

5. **Custom Drawing**: Draw new proposed lanes for immediate evaluation

6. **Export**: Save custom lanes as GeoJSON for sharing

The tool requires no installation—simply open the HTML file in any modern web browser.