Strategic Planning of Cycling Infrastructure Through Built Environment Analysis and Network Optimization

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Project Overview

This project addresses the challenge of implementing micro-mobility infrastructure within urban environments by developing a data-driven system to aid city planners in strategic bike path development. Our approach focuses on identifying and addressing "bike lane deserts"—areas with high potential for bicycle use but lacking connected cycling routes.

Problem Statement and Context

Cycling adoption varies dramatically across countries and cities. The Netherlands leads globally with approximately 36% of its population using bicycles as their primary transportation mode, supported by extensive infrastructure and cultural integration. Denmark follows with 23% of trips made by bicycle, while Germany and Sweden maintain notable cycling populations at 10% and 12% respectively. In contrast, the United States sees much lower adoption rates, typically in the low single digits.

Urban areas often demonstrate significantly higher cycling rates than national averages. For example, Copenhagen achieves over 50% bicycle commuting for work and school trips, highlighting the impact of targeted urban planning and cycling culture on transportation choices.

Project Objectives

Rather than simply drawing paths between points, our system will function as an "infrastructure planner" that:

1. **Diagnoses** current cycling infrastructure to identify underserved areas
2. **Analyzes** urban environments using objective clustering methods
3. **Proposes** strategic new bike lanes that maximize connectivity impact
4. **Optimizes** connections between isolated zones and existing networks

Technical Approach

Module 1: Urban Feature Extraction and Characterization

This module collects and processes neighborhood-level data using OSMnx to build detailed urban area profiles. Key functions include:

- Quantifying existing infrastructure density
- Extracting relevant urban characteristics
- Creating standardized feature sets for analysis

Module 2: Underdeveloped Area Identification (Clustering)

This module applies unsupervised machine learning to identify "bike lane deserts" through analysis of urban profiles and detection of mismatches between cycling potential and infrastructure availability.

Algorithms:

- **K-Means Clustering:** Segments the city into typologies (e.g., "well-served commercial," "residential with bike lanes," "underserved residential")
- **DBSCAN:** Identifies anomalies and complex-shaped clusters, particularly effective for detecting disconnected infrastructure gaps

Module 3: Infrastructure Proposal (Network Optimization)

This module designs strategic solutions to enhance urban bike-friendliness by identifying high-impact new bike lane locations.

Algorithms:

- **Shortest Path Analysis (Dijkstra's Algorithm):** Finds direct candidate routes from underserved zones to existing bike networks using OSMnx implementation
- **Betweenness Centrality Analysis:** Evaluates network flow importance by simulating route additions and measuring connectivity improvements
- **Custom Impact Scoring:** Ranks proposals based on:
  - Residential population connected in underserved areas
  - Number of newly accessible points of interest (POIs)
  - Construction feasibility (considering street width and speed limits)

Course Topic Integration

Heuristic Search: Implementation of A* and Dijkstra algorithms for route optimization over road network graphs, incorporating heuristics such as Euclidean or Manhattan distance.

Classification: Application to predict street characteristics (congestion levels, cycling suitability) based on attributes like population density, speed limits, and connectivity.

Clustering: Central to identifying underserved areas using K-Means and DBSCAN algorithms to group areas with similar transportation characteristics.

Regression: Prediction of continuous variables including travel time, traffic levels, and cycling density based on network attributes.

Expected System Behaviors

The system will demonstrate the following capabilities:

1. **Identification:** Detect underserved urban zones lacking proper bike lane access through unsupervised clustering based on OpenStreetMap features
2. **Optimization:** Propose efficient infrastructure connections including:
    - Shortest paths between underserved areas and existing networks
    - Routes maximizing network connectivity through betweenness centrality improvements
3. **Classification:** Determine street suitability for cycling based on road attributes using models like Random Forests

Anticipated Challenges

Data Quality and Completeness

OpenStreetMap data varies in detail and accuracy across cities, requiring robust preprocessing and validation methods to ensure consistent, usable features.

Scalability of Graph-Based Algorithms

Memory requirements for loading entire road networks may challenge large-scale implementations, necessitating efficient data structures and algorithm optimization.

Clustering Interpretability

Selecting appropriate features and parameters (cluster numbers for K-Means, density thresholds for DBSCAN) significantly impacts the reliability of identified underserved zones.

Multi-Criteria Optimization

Moving from diagnosis to realistic proposals requires balancing conflicting objectives:

- **Maximize coverage:** Benefit the largest population
- **Improve connectivity:** Integrate effectively with existing networks
- **Ensure feasibility:** Consider real-world construction constraints

The primary challenge involves incorporating practical constraints into proposals, considering factors beyond geometric shortest paths including speed limits, street types, and road width for safe, implementable solutions.

Key Resources

Boeing, G. (2025). *Modeling and Analyzing Urban Networks and Amenities With OSMnx.* Geographical Analysis. https://doi.org/10.1111/gean.70009

- Updated OSMnx capabilities guide for bike lane data extraction, network metric calculation, and result visualization

Senturk, I. F., & Kebe, G. Y. (2019). *A novel shortest path routing algorithm for wireless data collection in transportation networks.* IEEE Conference on Computer Science and Engineering.

- Addresses the "Traveling Salesman Problem with Neighborhoods" (TSPN) with practical heuristics for connecting underserved regions to existing networks

Task Distribution

Task	Nelson	Marston
Project proposal	✓	✓
Load OSMnx data		✓
Exploratory Data Analysis (EDA)	✓	
K-Means Clustering Algorithm		✓
DBSCAN Clustering Algorithm	✓	
Dijkstra's Algorithm		✓
Betweenness Centrality Analysis	✓	
Custom Impact Scoring Function	✓	✓
Final report compilation	✓	✓
Project presentation recording	✓	✓

Note: While individual leadership is designated for specific components, both team members will collaborate across all tasks to ensure comprehensive understanding and implementation.