Optimizing Dark Store Placement in Urban Networks

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Abstract

A dark store is a facility meant solely for processing online orders, not for customer visits. These stores function more like warehouses, optimized for picking and packing rather than browsing. Typically located in urban or suburban settings close to high-density areas, dark stores enable fast deliveries—often within 10 to 15 minutes.

1 Introduction

As e-commerce continues to grow, placing dark stores in optimal locations is crucial for reducing last-mile delivery times. This study develops a framework using network science to determine the best placement of dark stores within an urban road network. The model uses road data and accounts for traffic fluctuations by assigning dynamic weights to roads. Additionally, it integrates network centrality measures, community detection, and real-world constraints such as zoning and budgets to enhance logistics and ensure equitable urban coverage.

1.1 Dataset Overview

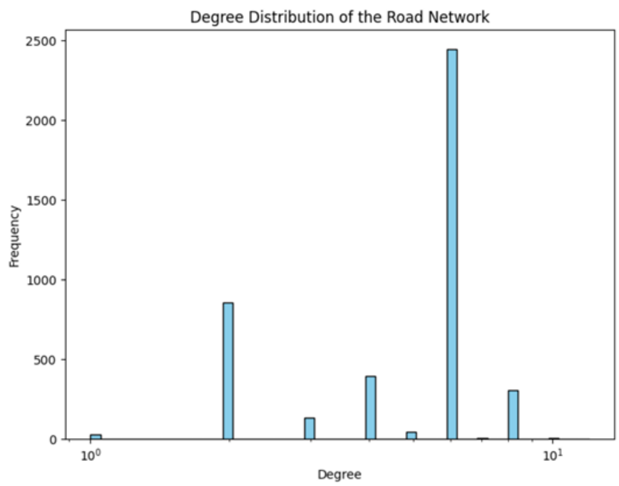
- **Nodes:** Represent intersections or key points in the road network.
- **Edges:** Represent road segments between nodes, weighted by travel time.
- **Source:** Extracted from OpenStreetMap via the OSMnx library.

1.2 Preprocessing

Minimal cleaning was required. Isolated nodes were removed, and weights were adjusted to reflect peak-time traffic.

1.3 Initial Metrics

- Nodes: 4217
- Edges: 10576



2 Centrality Analysis

2.1 Eigenvector Centrality

Identifies well-connected nodes based on their neighbors' connections. Top nodes are highlighted on a map of Kudasan, Gandhinagar.

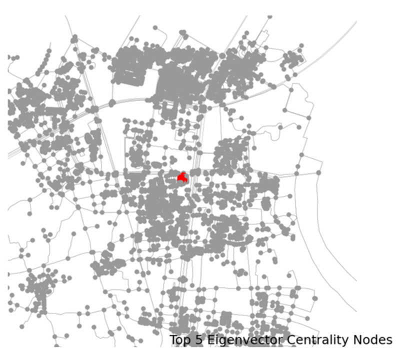


Figure 1: Top 5 Eigenvector Nodes, Map of Kudasan, Gandhinagar

2.2 Katz Centrality

Evaluates nodes based on direct and indirect paths with a damping factor. High Katz nodes often lie at critical intersections

Figure 2: Top 5 Katz Centrality Nodes(in Red), Map of Kudasan, Gandhinagar

2.3 Betweenness Centrality

Measures how often nodes appear on shortest paths, highlighting key transit points in the network.

Figure 3: Top 5 Betweenness Centrality Nodes(in red)

2.4 Closeness Centrality

Reflects how quickly a node can reach all other nodes. Useful for positioning vital infrastructure.

Figure 4: Top 5 Closeness Centrality nodes(in red)

2.5 HITS Algorithm

- **Authority Nodes:** Receive links from many hubs; often major destinations.
- **Hub Nodes:** Link to many authorities; important for traffic flow.

Figure 5: HITS nodes

3 Community Detection

Louvain algorithm was used to find clusters in the network. The modularity score was 0.94, indicating strong community structures.

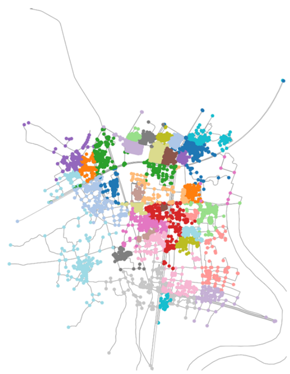


Figure 6: Louvain Community Detection, Modularity = 0.94

4 Assortativity and Degree Correlation

The network shows neutral assortativity (Pearson coefficient: 0.007), indicating that node connections are not influenced by node degree.

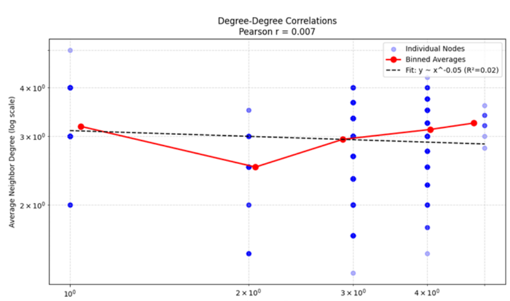


Figure 8: Degree-Degree Correlation Plot

Figure 7: Degree-Degree Correlation Plot

5 Clustering Coefficients

5.1 Global Clustering Coefficient

Measured at 0.0437, reflecting the tree-like, hierarchical nature of road networks.

5.2 Local Clustering

Sample values:

Node ID	Degree	Local Clustering Coefficient
3469607001	5	0.0000
4038755388	5	0.0000
6621517666	5	0.1000
6390642252	5	0.2000

clusteringg is very low in random graphs

Links to Code and Results

- Problem 1
- Problem 2
- Problem 3
- Problem 4
- Problem 5