Network Analysis of Road networks for Dark Store Placement Optimization

ES 404

Shashank Ghosh, Jainam Chhajer

Department of Mechanical Engineering, Department of Civil Engineering

1. Introduction

- Quick commerce demands faster and more efficient last-mile delivery infrastructure.
- Dark stores are essential micro-warehouses designed for rapid order fulfillment.
- This project uses network science to find optimal dark store locations.
- Real road network data is analyzed for traffic, connectivity, and accessibility.
- Centrality and community detection identify key nodes for logistics efficiency.
- Well-placed dark stores enhance delivery speed, customer satisfaction, and business growth

2. Research Questions

- Can centrality measures from network science predict ideal locations for dark stores?
- Which centrality measures (PageRank, Eigenvector, Betweenness, etc.) best align with actual store placements?
- Can we generalize a rule or algorithm to identify future dark store sites?

3. Datasets

- Our network data is taken from OpenStreetMaps. The processing of road network is done via a python library OSMnx.
- Store locations are validated via visiting offline stores marking them on OpenStreetMaps
- Centrality Measures are calculated via library called Networkx.

Nodes (**N**) = 8314

Edges (**E**) = 11550

Average Degree <**k**> = 1.44

Clustering Coefficient = 0.044

Modularity Score = 0.94

4. Methodology

- **Graph Construction:** Road network as a graph: nodes = intersections, edges = road segments.
- **Edge Weights:** Based on travel time (distance / assumed speed, increased on trunk roads).
- Travel time based on the edge's geometric length and road class (Trunk,highway, etc).
- Louvain Algorithm for community detection

Centrality Measures Used:

  - PageRank
  - Eigenvector Centrality
  - Betweenness Centrality
  - Closeness Centrality
- **Validation:**
  - Distance between predicted top nodes and actual store locations.
  - Overlap analysis between model predictions and real placements.

5. Results

- Predicted node located just **550m** from actual Blinkit dark store in Kudasan, demonstrating model accuracy
- Top 3 predicted nodes fall within **350m** radius of Blinkit store in Raysan area, validating network science approach
- Community detection successfully partitions Kudasan into optimal neighborhood clusters for strategic store placement
- **PageRank** algorithm identified as most accurate predictor, closely matching actual Blinkit store locations

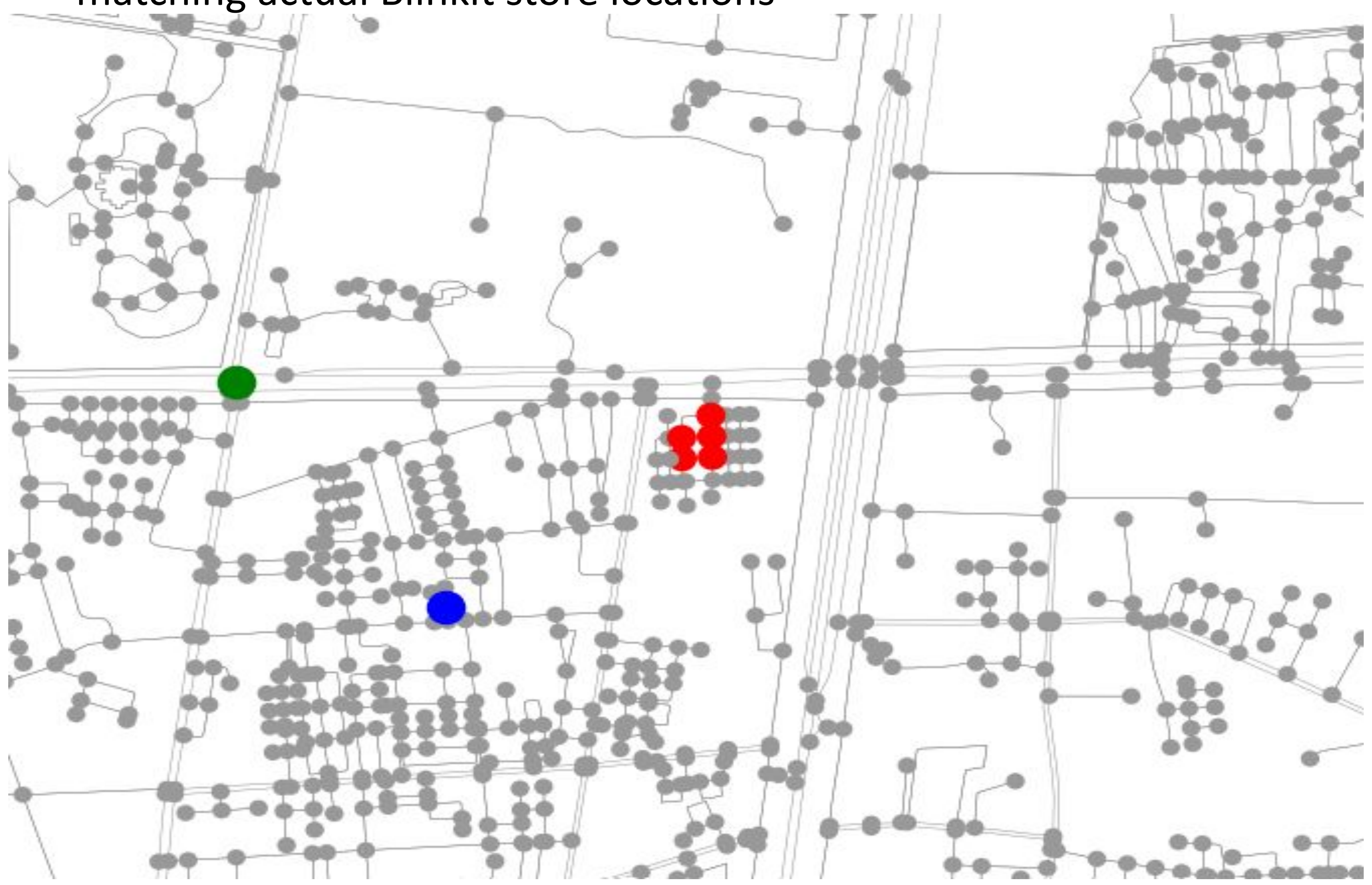

Fig.1 - EigenVector node(in red) , actual location(in blue), Reliance circle(in green)

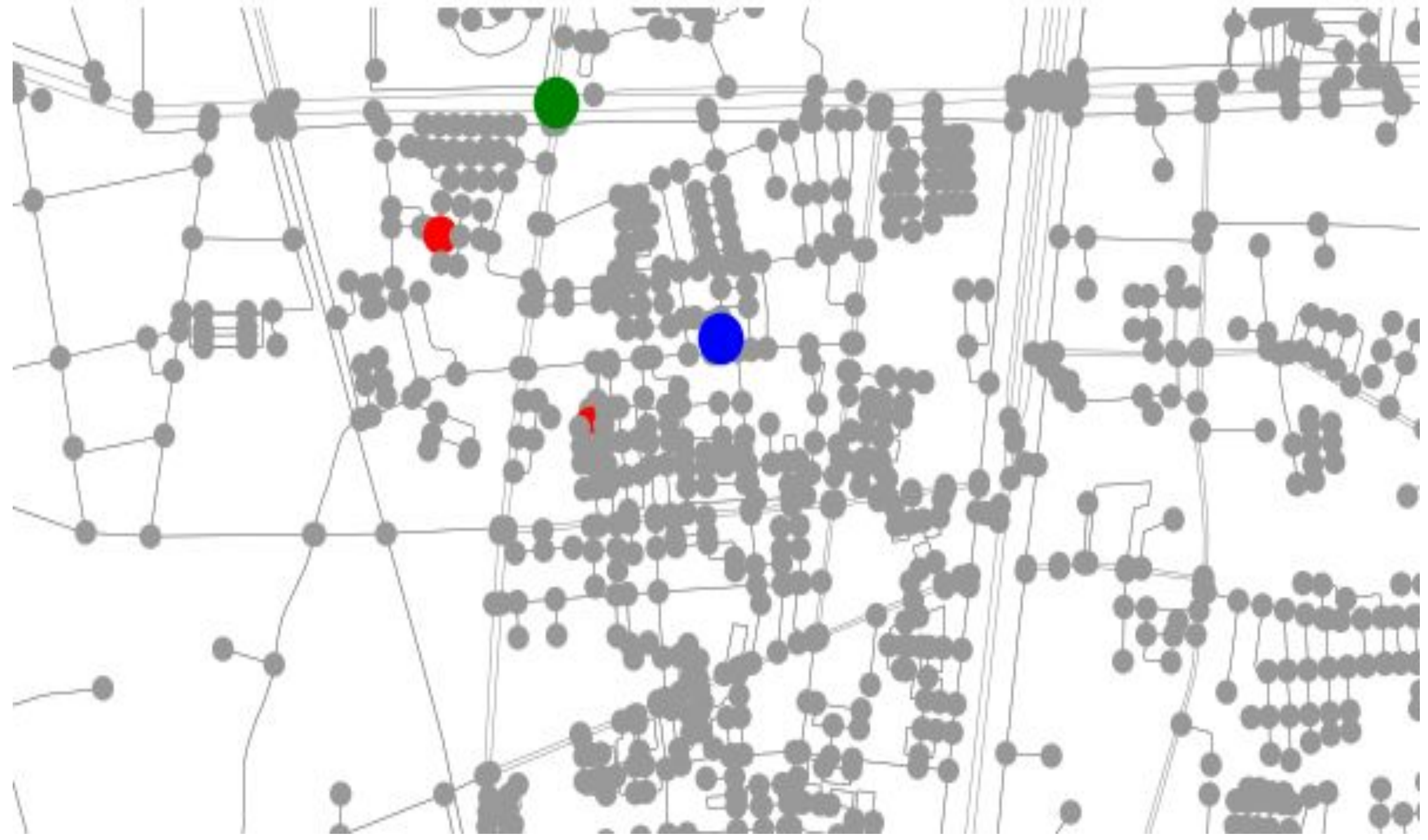

Fig.2 - Pagerank node(in red) , actual location(in blue), Reliance circle(in green)

Fig.3- Community Detection

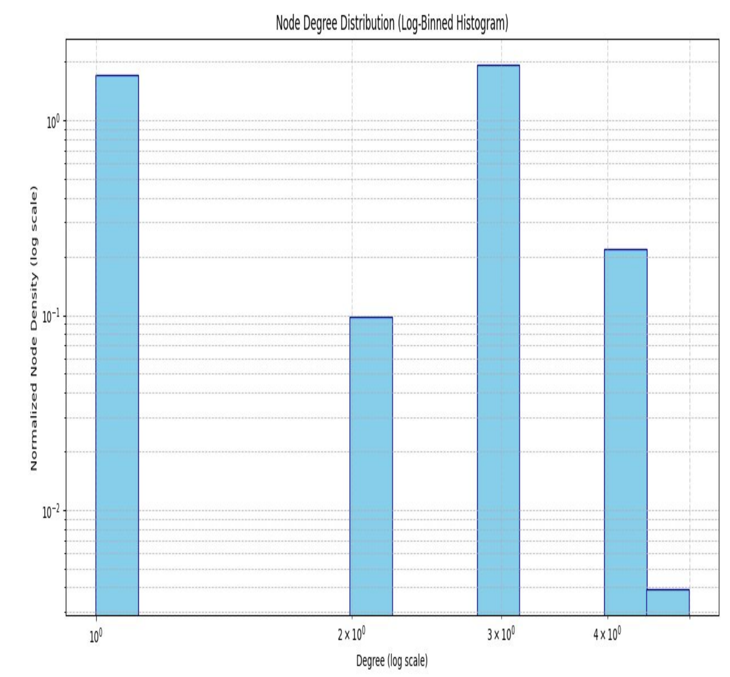

Fig.4- Degree Distribution

6. Conclusion

- Network science enables optimal dark store placement through graph-based centrality measures like eigenvector, betweenness and pagerank.
- The model's predicted locations closely match existing infrastructure, validating its real-world applicability.
- **Traffic-weighted edges** and Louvain community detection enhance accuracy while ensuring balanced coverage.
- The approach offers a scalable solution to improve last-mile efficiency in both established and emerging delivery economies.

7. References

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- Blondel, V.D. et al. (2008). Fast unfolding of communities in large networks. J. Stat. Mech.

ghoshshashank@iitgn.ac.in, chhajerjainam@iitgn.ac.in