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Centrality-Driven Community Detection for Efficient Petroleum Distribution Planning

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INTRODUCTION & AIM

Background

- Petroleum distribution is essential for transportation, industry, and economic development of a country.
- Efficient network planning is necessary to ensure a reliable fuel supply and improve distribution efficiency.
- Various studies based on genetic algorithms, fuzzy relations, Dijkstra algorithm used to find the optimal routing in the literature.
- This study uses centrality measures to identify optimal depot locations in Gampaha District, Sri Lanka.

Aim

Analyze petroleum distribution network and determine the **optimal locations for establishing new depots** by minimizing travel distance.

Keywords: Centrality measures • Shortest path • Weighted graph • Network analysis • Spectral clustering

METHODOLOGY

Graph Construction:

Represented the network as an **undirected weighted graph** $G = (V, E, W)$ where $|V| = 66$ (Muthurajawela terminal and 65 Ceypetco stations).

- Edge weight w_{ij} = shortest road distance (km) from Google Maps.
- Adjacency matrix A, and normalised Laplacian $L_{norm} = I - D^{-\frac{1}{2}} W D^{-\frac{1}{2}}$.

Four Centrality Measures

Centrality Measure	Role in Distribution Network
Degree	Revealed highly connected hubs
Closeness	Identified locations reachable in shortest time
Betweeness	Identifies critical nodes whose failure may disrupt multiple routes.
Eigenvector	Identifies influential nodes connected to other important nodes.

Composite Priority Score S(v)

Centrality values normalised and combined:

$$S(v) = \Sigma w_i \cdot \tilde{C}_i(v) \quad \text{where } \Sigma w_i = 1, \tilde{C}_i(v): \textit{Normalised Centrality Score for Node } v$$

Node with highest $S(v)$ per cluster selected as priority node

Sensitivity Analysis Summary

Measure	Stability	Key Interpretation
Degree	★★★★★ Highest	Unaffected by small network changes
Eigenvector	★★★★ High	Influence consistent under perturbation
Closeness	★★★ Moderate	Rankings shift when structure is altered
Betweenness	★★ Lowest	**Most sensitive depends on shortest paths**

***Stability measured** by Spearman rank correlation: ±20% edge weight variation, 5% random edge removal.*

RESULTS & DISCUSSION

Table 1 — Top Nodes by Each Centrality Measure

Rank	Degree	Closeness	Betweenness	Eigenvector
1	Welisara 1	Welisara 1	Welisara 1	Katunayake
2	Minuwangoda	Welisara 2	Kadawatha 3	Negombo 4
3	Katunayake	Ragama 3	Gampaha 1	Negombo 1
4	Kadawatha 3	Ragama 2	Ja-Ela 5	Ja-Ela 7

Table 2 — Overall Priority Nodes (Top 10% by Composite Score)

Rank	Node	Station	Dominant	Score
1	M	**Muthurajawela (Terminal)**	Betweenness	1.0000
2	63	Welisara Station 1	Betweenness	**0.6302**
3	23	Kadawatha Station 3	Betweenness	0.4526
4	28	Katunayake	Eigenvector	0.4200
5	53	Ragama Station 3	Betweenness	0.3464
6	37	Minuwangoda	Betweenness	0.3101

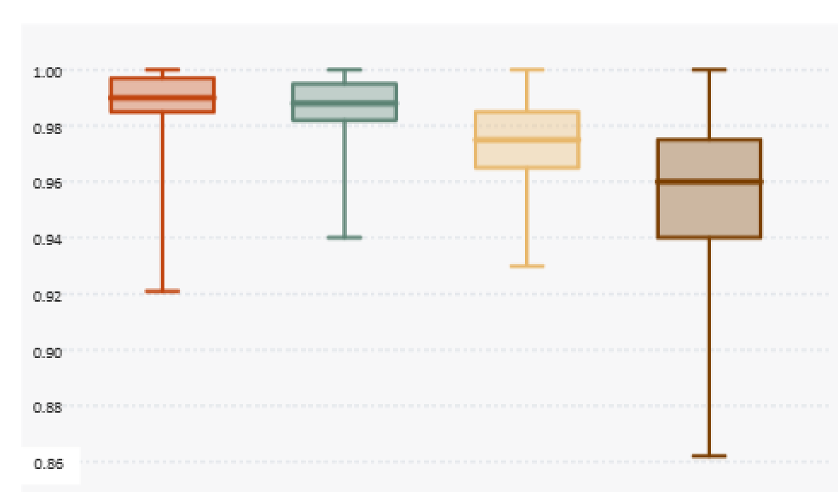

Figure 1 — Sensitivity Analysis: Spearman Rank Correlation Stability

Largest eigengap at index 4 → k = 4 optimal clusters

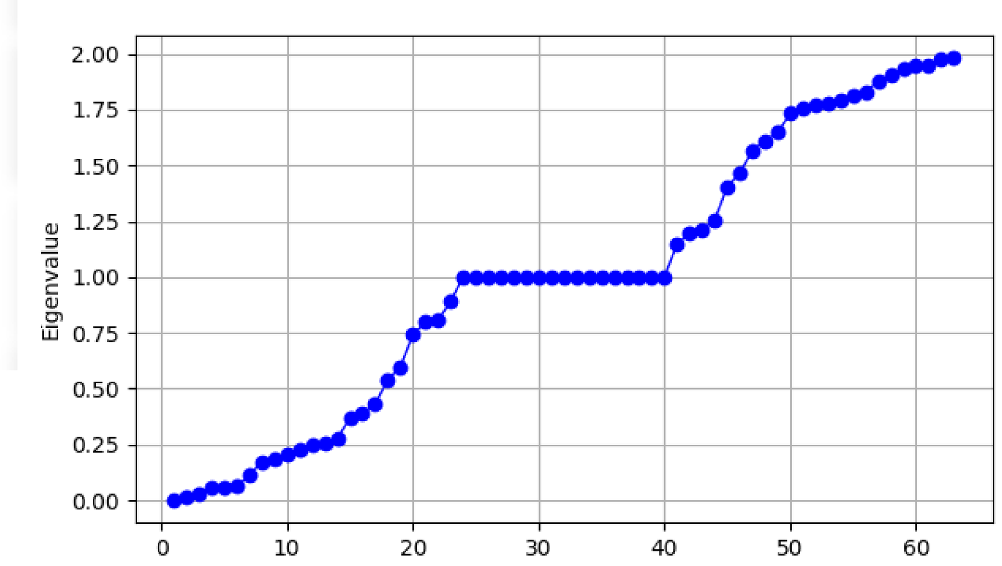

Figure 2 — Eigengap Heuristic: Optimal Number of Clusters k = 4

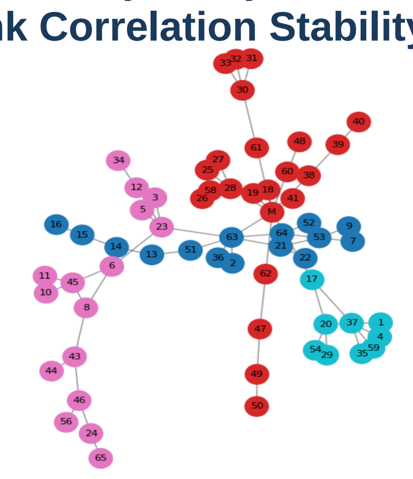

Figure 3— Clustering : Geographical Distribution

Table 3 — Cluster Priority Nodes & Distance from Muthurajawela Terminal

Cluster	Stations	Priority Node	Depot City	km
0	9	Ja-Ela Station 5 (Node 17)	**Ja-Ela**	13.9
1	15	Welisara Station 1 (Node 63)	**Welisara**	**6.0**
2	19	Gampaha Station 1 (Node 6)	**Gampaha**	13.9
3	22	Katunayake (Node 28)	**Katunayake**	**22.5**

CONCLUSION

- **Four centrality measures** were used to identify structural properties. Degree centrality was the most stable as confirmed by sensitivity analysis.
- **Four optimal clusters** identified via eigengap heuristic; most influential nodes per cluster determined.
- Accordingly, Welisara, Gampaha, Katunayake, and Ja-Ela are the most suitable cities for establishing new depots.
- Overall, the findings demonstrate that centrality-driven community detection is **helpful for the strategic planning of petroleum distribution systems.**

FUTURE WORK / REFERENCES

Future Work

- Integrate real-time traffic data
- Extend to other Sri Lankan districts
- Developing a software tool.

References

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