Network Analysis of the Karachi Public Transit System

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Introduction

This report presents a comprehensive network analysis of the Karachi Bus Network. The dataset contains the city's public transit system including both BRT and minibus routes. In this network, each node represents a unique bus stop and a directed edge represents a direct connection from one stop to the next. By applying network analysis techniques, we want to uncover the structural properties of this transit system, identify its most critical hubs, and understand the overall efficiency and dynamics of public transportation in Karachi.

Global-Level Analysis

A global-level analysis provides a high-level overview of the network's structure. We examined several key metrics to understand the overall connectivity and topology of the bus network.

Network Size

The network consists of 572 bus stops (nodes) and 1139 connections (edges).

Density

The network density is approximately 0.0035. This extremely low value indicates a sparse network, which is expected for a real-world transit system. The value is far smaller than the clique.

Clustering Coefficient

The global clustering coefficient is approximately 0.14. This value measures the tendency for bus stops to form connected clusters. It suggests the presence of localized zones, like neighborhoods, where stops are more interconnected than the other parts of the network.

Average Path Length

The average path length is 8.08. This means that on average a passenger needs to travel between 8 and 9 stops to get from any random stop to another. A low average path length is a key indicator of an efficient network.

Small-World Properties

The combination of a relatively low average path length and the given clustering coefficient suggests that the Karachi bus network exhibits small-world properties, as a passenger could move from one stop to another quickly even though the network is sparse. This structure enables both effective local transit within neighborhoods and rapid travel across the city.

Degree Distribution

The network's degree distribution follows a "long-tail" pattern, which is characteristic of a scale-free network. This says that the network's structure is dominated by a small number of major hubs that hold the system together. For example, major hubs like NIPA Chowrangi and Tower dominate the system. For any long distance travel, passengers are almost certain to pass through one of these central hubs. While this is efficient it also introduces vulnerability, as a disruption at a major hub could significantly impact a large portion of the network.

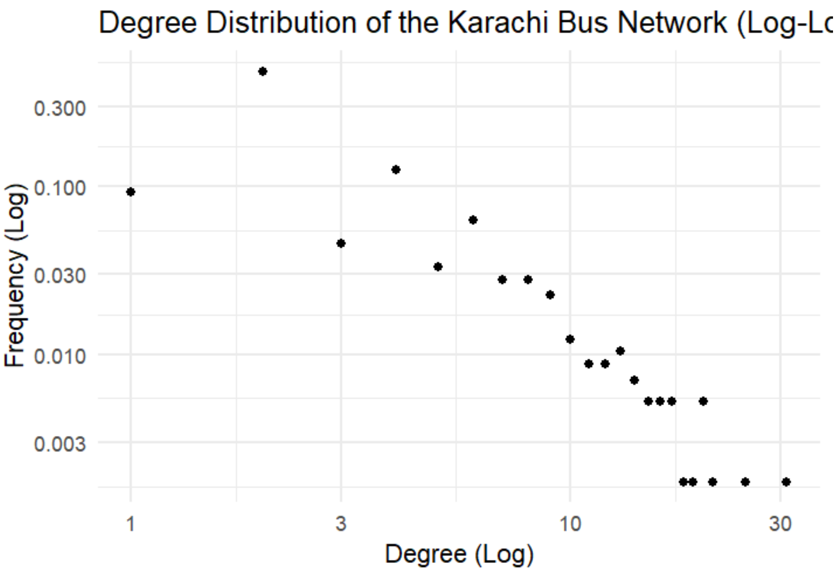

Figure 1: Log-scale Degree Distribution.

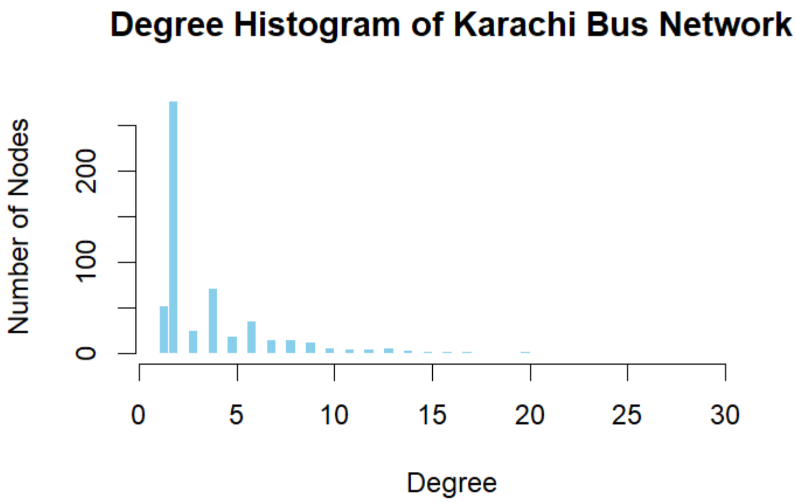

Figure 2: Degree Histogram showing degree distribution.

Centrality Analysis

Centrality analysis helps us identify the most influential bus stops in the network. Since the network is directed, we can analyze how stops function as destinations, departure points, or important transfer hubs. We analyzed three different centrality measures to understand the various roles these key stops play.

Degree Centrality

Degree centrality measures the number of direct connections a node has. In a directed network, we distinguish between incoming (in-degree) and outgoing (out-degree) connections.

Total Degree Centrality

Total Degree Centrality identifies the overall busiest bus-stops. A high total degree means a stop serves numerous bus routes, making it a major intersection or terminal.

Stop Name	Total Degree
NIPA Chowrangi	31
Tower	25
Sohrab Goth	21
M.A. Jinnah Road	20
Gurumandir	20

These stops are among the most active connection hubs. NIPA Chowrangi is clearly the network's busiest single point. Tower, Sohrab Goth, and others are also major transport centers where the highest number of bus routes converge, allowing passengers to switch between many different routes easily.

In-Degree Centrality

In-Degree Centrality measures the number of incoming routes. Stops with high in-degree are prominent destinations or transfer points that many routes lead to.

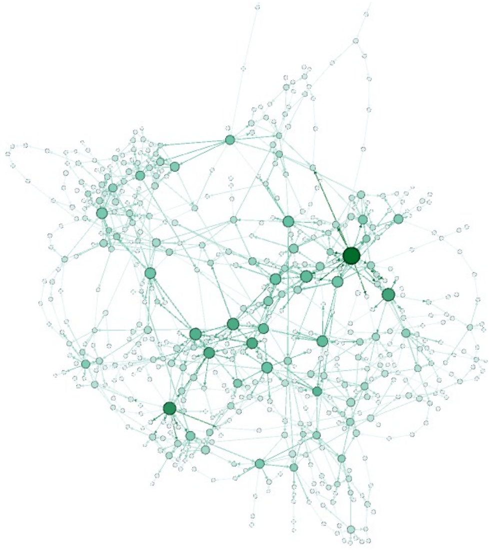

Figure 3: Bus Network based on Total degree.

Stop Name	In-Degree
NIPA Chowrangi	15
Tower	14
M.A. Jinnah Road	11
Petrol Pump	11
Gurumandir	11

These top stops, including NIPA Chowrangi and Tower, are major destinations within the city. A high number of routes terminate or pass through them, indicating they are key commercial, residential, or social centers.

Out-Degree Centrality

Out-Degree Centrality measures the number of outgoing routes. Stops with high out-degree are major origin points from which passengers can access a wide variety of destinations.

Stop Name	Out-Degree
NIPA Chowrangi	16
Sohrab Goth	11
Tower	11
Saddar	10
Purani Sabzi Mandi	10

NIPA Chowrangi is both a top destination and a top departure point. Sohrab Goth, as a major inter-city bus terminal, logically ranks high as an origin point for trips starting within Karachi.

Betweenness Centrality

Betweenness centrality measures how often a node appears on the shortest path between other nodes. A stop with a high betweenness score is a crucial "bridge". Its absence would disrupt travel between different parts of the city.

Stop Name	Betweenness
Jinnah Hospital	0.113709
Tower	0.109999
M.A. Jinnah Road	0.106502
Labour Square	0.106235
Saddar	0.097840

These stops are critical for the flow of traffic across the city. While some are also high-degree hubs like Tower and Saddar, others like Jinnah Hospital and Labour Square may have fewer direct routes but are strategically located, connecting large sections of the network. Disrupting service at these stops would severely impact the ability to travel between different parts of the city.

Eigenvector Centrality

Eigenvector centrality identifies nodes that are connected to other highly influential nodes. A stop can have a high eigenvector score not just by having many connections, but by being connected to other important stops. It measures a node's overall influence within the network.

Stop Name	Eigenvector
NIPA Chowrangi	1.0000000
Purani Sabzi Mandi	0.6545293
University Road	0.5490336
Hassan Square	0.5146106
Numaish	0.4691159

NIPA Chowrangi's top score confirms it is not just busy, but it is also centrally connected to other important hubs, making it the most influential stop in the network. Stops like Purani Sabzi Mandi and University Road form part of the city's core transit corridor, linking to other strategic locations and increasing their importance.

Conclusion

Our analysis of the Karachi Bus Network reveals a complex system that operates as a sparse, scale-free, and small-world network.
This structure is defined by a few highly connected hubs that provide overall efficiency (low average path length) while also supporting localized transit clusters.

The centrality analysis highlights a clear hub-and-spoke structure. NIPA Chowrangi stands out as the single most critical node, with highest numbers in total degree, in-degree, out-degree, and eigenvector centrality. Tower and Saddar also function as major terminals where passengers transfer routes daily.

Stops like Jinnah Hospital and M.A. Jinnah Road, with their high betweenness centrality, are essential for connecting different parts of the city, even if they aren't the busiest hubs overall. The directed analysis also shows that some stops are primary departure points (e.g., Sohrab Goth), while others are major destinations (e.g., M.A. Jinnah Road), reflecting the city's daily commuter flow.

The system's efficiency is heavily reliant on all these key hubs. This also reveals an important vulnerability. Disruptions like traffic jams or protests at these few central locations can create bottlenecks that cause cascading delays throughout the entire transit system. This analysis provides a foundational understanding for city planners to optimize routes, identify potential points of failure, and build a more resilient public transportation network for the future.