A Study on Luxembourg Public Transportation Network

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Introduction

Dataset: Official GTFS (General Transit Feed Specification) feed for Luxembourg (Nov–Dec 2025).

Motivation: Luxembourg's public transport affects the lives of residents in different areas in different ways. Analyzing this data, as a first step, can improve public transport planning and operations, as well as develop mobile applications for passengers and foster more efficient urban transport solutions.

The closer this analysis is to reality, the better the model performance will be. For example, GTFS schedules ignore walking transfers, yet pedestrians routinely walk up to 5 minutes between stops.

Objective: The larger goal of this study is to simulate the failure of hubs and core services (network resilience). The current results are baseline results and a first analysis to achieve the larger goal.

Definitions

Betweenness centrality measures how often a node lies on shortest paths between other nodes:

$$\text{betweenness}(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}.$$

High betweenness means structural bottleneck or key interchange.

Headway is the time interval between two services on the same route in the same direction.

Methods

Directed weighted graph from GTFS

Adding walking edges (200 m, 5 km/h speed).

Distance Calculated with `haversine` function.

Edge weight = travel time in seconds.

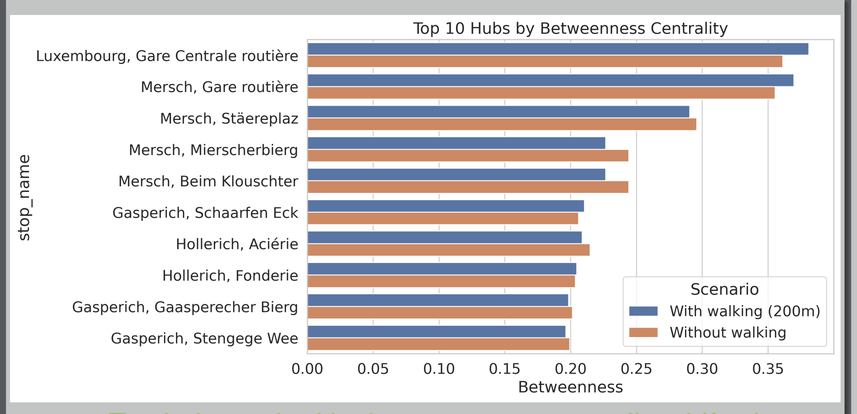
Centrality computed with `networkx.betweenness_centrality`.

Python stack: `gtfs-kit`, `geopandas`, `networkx`, `folium`, `tqdm`, `BallTree`.

Data Statistics (at the first glance)

Metrics	Statics
Stops	2 808
Scheduled trips	29 391
Routes	705
Transit edges	8 424
Walking edges (200 m)	3.15 million
Median headway	8.0 min
Stops with only 1 route	17.6%

Visual: Hub comparison bar chart

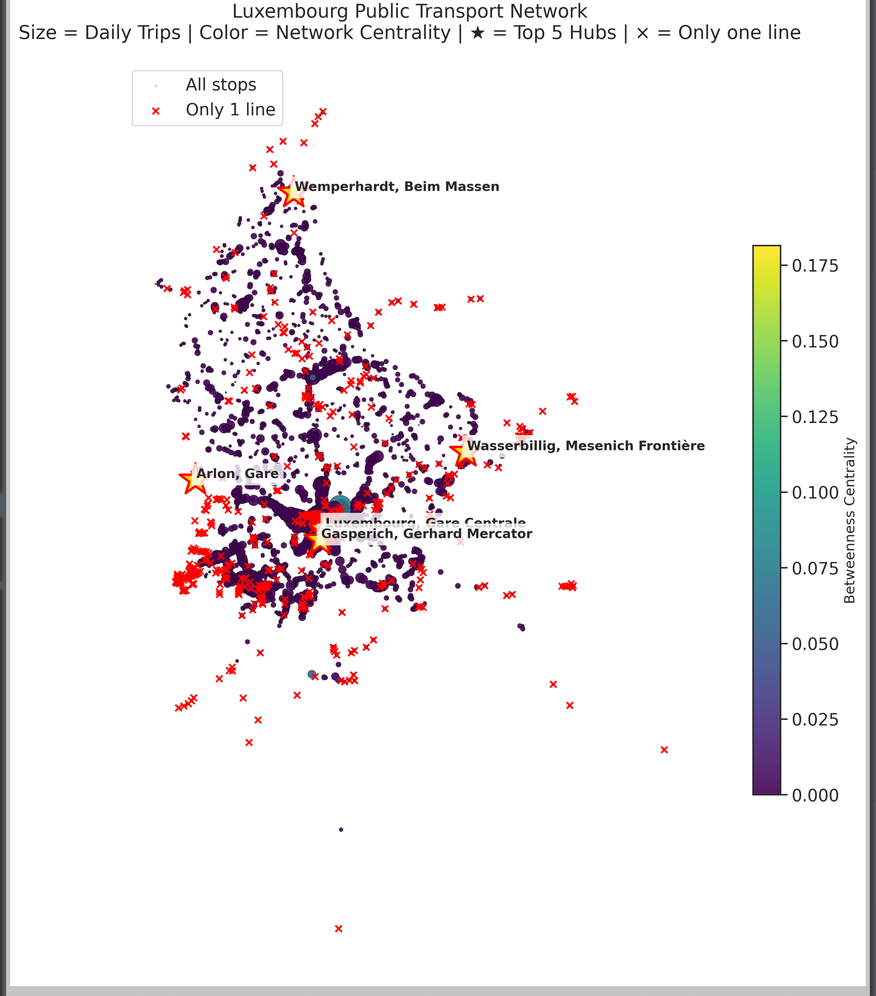


Top hubs ranked by betweenness centrality shift when walking is considered.

Busiest Stops

Rank	Stop Name	Trips/day
1	Hamilius (Bus)	4433
2	Luxembourg, Gare Centrale routière	4068
3	Centre, Fondation Pescatore	3471
4	Kirchberg, Gare routière Luxexpo	3086
5	Centre, F.D. Roosevelt	3030

Distribution of Stops

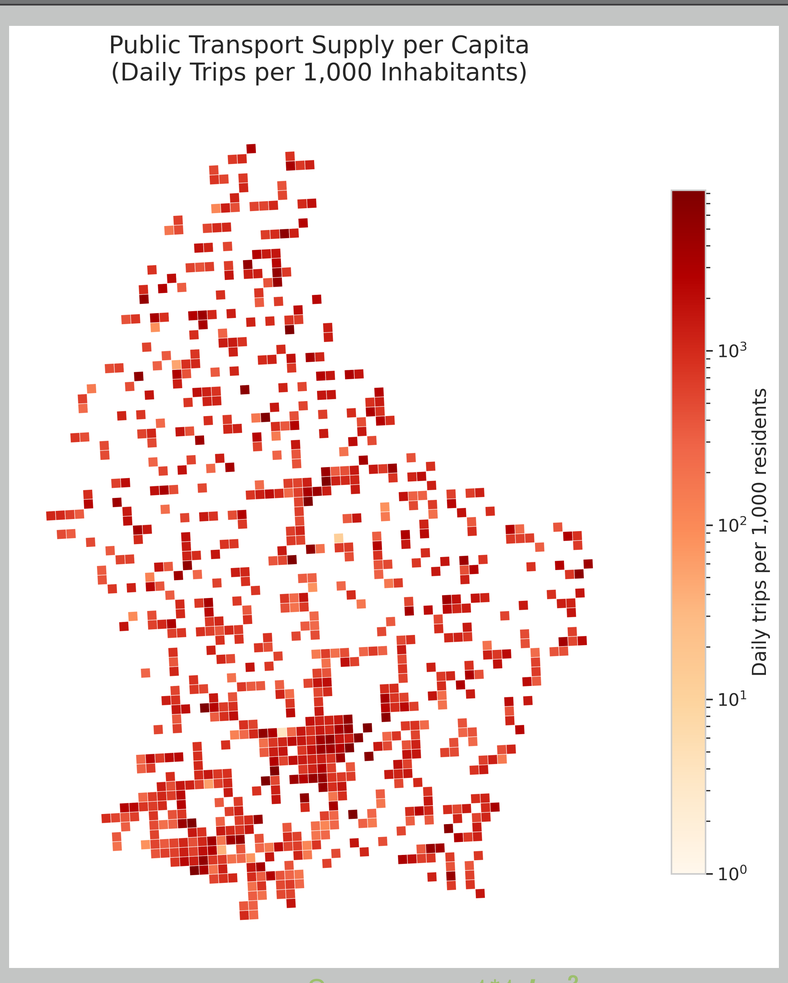


Only one service pass from most cross-border services.

Top stops by route diversity

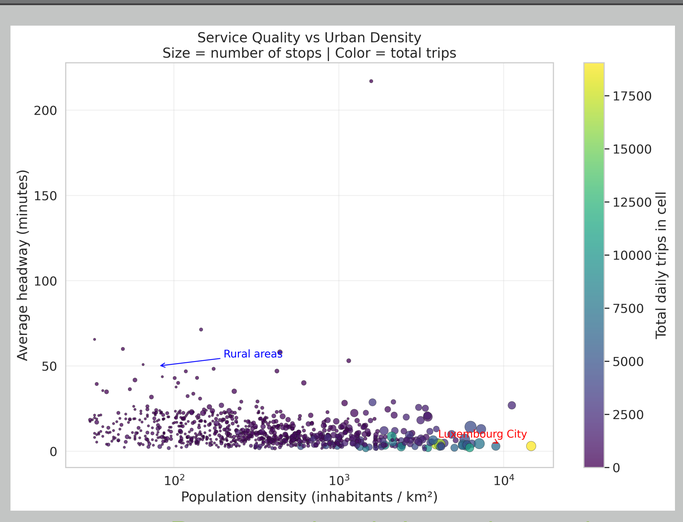
Rank	Stop Name	Number of routes
1	Limpertsberg, Theater (Bus)	50
2	Diekirch, Gare routière	49
3	Diekirch, op der Kluuster	47
4	Esch-sur-Alzette, Gare routière	47
5	Limpertsberg, Lycée de Garçons	46

Considering Population



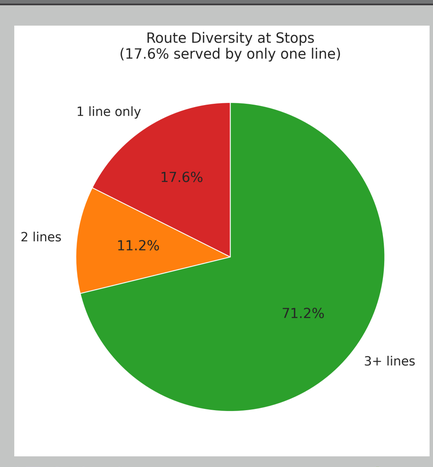
Squares are 1*1 km^2

Considering Population



Better services in Luxembourg city

Visual: Route diversity



17.6% of stops served by only one route.

Key Findings

Adding 200 m walking links changes results; some "bridge" stops lose importance.

Luxembourg, Gare Centrale routière becomes the clear #1 hub.

In reality, some stops, with the same name, have up to 200 meter distance.

Hamilius is the operationally busiest stop (4 433 daily trips) but it's not in the 10 top-hub list

17.6% of stops are served by a single bus/tram line → high vulnerability.

Median headway across the country is 8 minutes.

Conclusions & Outlook

Luxembourg's network is highly centralised around Gare Centrale when pedestrian behaviour is modelled.

Walking transfers are essential for realistic centrality analysis in dense urban areas.

The share of single-route stops are located in low dense area

GTFS-RT for delay-aware modeling and passenger counts is not available for Luxembourg.

Future work: node & service failure simulations, population impact assessment, integration of real-time delays (GTFS-RT when available).

GitHub Repository

More information on:

`Public_Transportation_Lux`