Integrating network science and public transport accessibility analysis for comparative assessment

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Research gap & Objective

Research gap
Many studies only apply network science to perform topological analyses of public transport networks (PTNs) without incorporating service properties fundamental to transport systems.

Research objective
To integrate network science and public transport accessibility analysis for comparative assessment across multiple public transport networks.
### Topological representations of public transport networks

#### Space-of-infrastructure (L-space)
- Each node represents a stop.
- Two nodes are linked if they are adjacent on at least one infrastructure segment (i.e. road or rail).

#### Space-of-service (P-space)
- The nodes represent stops.
- Two nodes are linked if they are served by at least one common route.
Computing generalized-travel-cost-based (GTC-based) travel impedance metric

- Scheduled timetables from GTFS
- Total in-vehicle travel times + expected waiting times
- Half of the headway determined by the joint service frequency of all direct services (synchronization across routes not considered)

Step 1: Building the graph representation of public transport networks from GTFS data.

Step 2: Constructing the unweighted space-of-service network.

Step 3: Computing and adding travel times as weights to the space-of-service network.

\[ w_{ij} = t^*_i + t^*_j \text{ (e.g., } w_{AD} = 5 + 4 + \frac{60}{6 \times 2} = 14) \]

Step 4: Deriving the lowest generalized travel cost for each stop pairs, and further computing the average travel impedance per stop.

\[ w_i = \sum w_{ij} + i(K-1) \text{ (e.g., } w_{AG} = 10 + 11.75 + 5 = 26.75) \]

\[ t_i = \frac{\sum w_{ij}}{|V|-1} \text{ (e.g., } t_A = \frac{1}{5-1}(21 + 10 + 14 + 22 + 37) = 20.8) \]

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<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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- Total in-vehicle travel times.
- Total waiting times (i.e., the initial waiting time and subsequent transfer waiting times).
- Time-equivalent penalty per transfer.
Assessing the accessibility of tram networks worldwide

- Tram as a major mode
- Availability of GTFS data
- Weekday morning peak schedules (8 am - 9 am)
- Transfer penalty = 5 min
- networkx (python 3)
Benchmark metric

How?

- Computed using the **unweighted space-of-infrastructure** representation.
- Travel impedance determined based on minimal number of links between stop pairs traversed **without considering transfers**.
- Completely from a **topological** perspective.

Why?

- Simple and intuitive.
- Comparable with existing topological analyses of PTNs
Comparison between benchmark and GTC-based metrics

How?
• The gap between two metrics is quantified by the residual of a linear regression model.
• The dependent variable: GTC-based metric.
• The independent variable: Benchmark metric.
• The bigger the residual, the larger the gap.

Visualization of travel impedance
• Blue spots: benchmark metric > GTC-based metric.
• Red spots: benchmark metric < GTC-based metric.
• Residuals shown in the scatter plot with the Pearson correlation coefficient $r$. 
The spatial disparity in the travel impedance is more remarkable according to the GTC-based metric.
• Some stops on the periphery of the network display largely underestimated impedance by the benchmark metric.

• GTC-based ones better capture this aspect.
  ❖ Waiting times
  ❖ # Transfers
  ❖ Physical inter-stop space
I ncorporating PT service properties leads to:

- more realistic spatial disparity in accessibility analysis
- more pronounced differences in accessibility across different networks.

![Complementary cumulative distributions of the travel impedance for the studied tram networks. (a) The benchmark metric; (b) The GTC-based metric.](image)
Variance analysis

- Impedance is proportional to the spatial scale;
- Larger networks show higher travel impedance on average (Melbourne = 2x Zurich);
- The in-vehicle travel time is similar to the overall GTC;
- Waiting and transfer times are very different (Median values ~ 15 min)
Main conclusions
- Easy implementation based on only GTFS data (no local knowledge required);
- Considering service properties matters when assessing PT accessibility;
- Larger networks show higher total travel impedance due to longer in-vehicle travel times;
- Median value of waiting and transfers costs for the morning peak is roughly 15 minutes.

Future works
- Incorporate O-D demand when computing the travel impedance;
- Adopt the multilayer network concept.
Thank you!

Questions?

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