Integrating network science and public transport accessibility analysis for comparative assessment

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1. Introduction

An upward trend of applying complex network approaches to study transport systems can be observed over the past decades (Lin and Ban, 2013). This has particularly been the case for public transport networks (PTNs). The contribution of this study is twofold. First, we propose a new type of weighted space-of-service topological representation for PTNs which explicitly incorporates initial/transfer waiting times and in-vehicle travel times derived from scheduled timetables, i.e., General Transit Feed Specification (GTFS) data. We show that the farness centrality – which is the reciprocal of the closeness centrality (Bavelas, 1950) – can be efficiently computed using this new representation in terms of generalized travel costs, which consist of waiting times, in-vehicle travel times and transfer penalty costs. The resulting indicator provides a good way to quantify the impedance of each individual stop traveling to the rest of the network, thus can be used to assess the (stop-to-stop) accessibility in PTNs. Although GTFS data have been increasingly applied to study PT accessibility (e.g., Farber and Fu, 2017; Fayyaz S. et al., 2017), such complex network – instead of geographic information system (GIS) – based approaches for assessing PT accessibility are still missing to the best of our knowledge. Second, we apply the proposed methodology to eight tram networks worldwide, hence demonstrating how the method facilitates a comparative assessment. Such latitudinal comparative assessments can provide additional insights into network design, bench marking and planning, but are still scarce in the current literature.

2. Methodology

Our proposed methodology consists of four steps, which are sketched with simple examples in Figure 1.

2.1. Building the graph representation of PTNs from GTFS data

We first define that PTNs are comprised of two layers of networks: the infrastructure network (i.e., roads and rails) and the service network superimposed on the physical one (i.e., routes). Based on graph theory, a PTN is then represented as a directed graph which can be denoted by a triple $G = (V, E, R)$, where V, E, R represents the set of nodes, links and routes, respectively. Each node $v \in V$ represents a stop, while each link $e \in E$ is defined by an ordered pair of nodes (u, v), where u and v, respectively, denote the source and target nodes. Given the definition, PTNs are established from GTFS data.

2.2. Building topological network representations for PTNs

The second step is to build the **P**-space – which is coined as *space-of-service* in the context of PT (Luo et al., 2019)– topological representation based on the fundamental graph representation. In this case, a node represents an individual stop, and two nodes are linked if they are served by at least one common route. The neighbors of a node in this space are all stops that can be reached without performing a transfer.

2.3. Assigning travel time based weights to the space-of-service network

We further compute and assign weights based on travel times for each link. The link weight w is thus defined as follows:

$$w = \sum_{m=1}^{M} t_m^{iv} + t^{wait} \tag{1}$$

where t_m^{iv} denotes the in-vehicle travel time on the mth segment of a link, hence $\sum_{m=1}^{M} t_m^{iv}$ the total in-vehicle travel time for the link. t^{wait} represents the expected waiting time for this non-transfer ride at the beginning stop, which is estimated as the half headway determined by joint vehicle frequency.

2.4. Computing the centrality indicator based on generalized travel costs

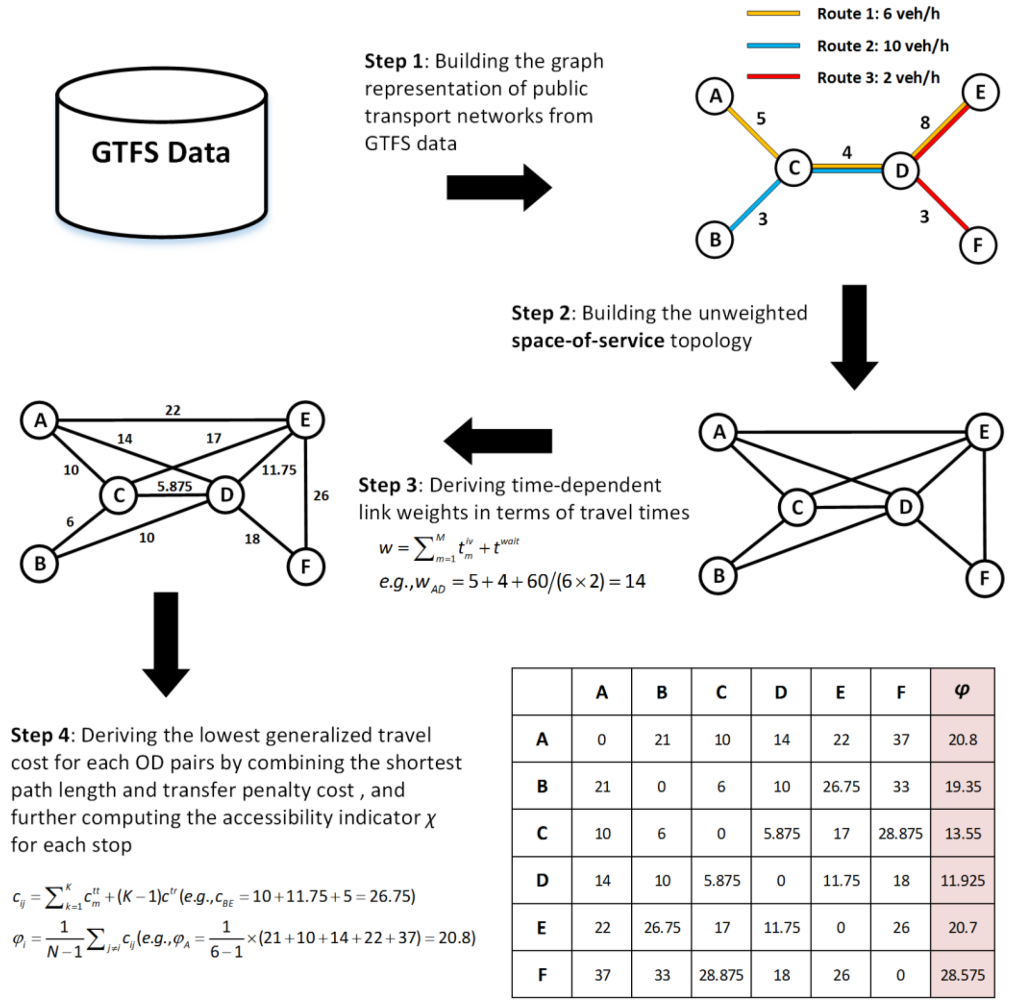
The generalized travel cost for each OD stop pair is measured in the time unit (minutes), which is comprised of total link travel times, waiting times for each ride (i.e., the initial waiting time and subsequent transfer waiting time), and transfer penalty cost for each transfer. The formula is shown as follows:

$$c_{ij} = \sum_{k=1}^{K} c_k^{tt} + (K-1)c^{tr} \tag{2}$$

where c_{ij} denotes the generalised travel cost from stop i to stop j. c_k^{tt} and c^{tr}denotes the kth ride's travel time cost and penalty cost for one transfer, respectively. K denotes the total number of rides for the shortest path from stop i to stop j. The transfer penalty cost set to be 5 minutes in this study. The centrality indicator, which serves as a proxy to stops' impedance/inaccessibility, is then computed as the average of all the travel cost from it to the rest stops in the entire network, which is specified as follows:

$$\varphi_i = \frac{1}{N-1} \sum_{j \neq i} c_{ij} \tag{3}$$

where φ_i indicates the travel impedance for node i to the rest of the network. N represents the total number of nodes in the network. c_{ij} denotes the minimal generalized travel cost from node i to node j. In this sense, the lower value a stop's indicator is, the more accessible it is to the rest of the network.



	A	B	C	D	E	F	φ
A	0	21	10	14	22	37	20.8
B	21	0	6	10	26.75	33	19.35
C	10	6	0	5.875	17	28.875	13.55
D	14	10	5.875	0	11.75	18	11.925
E	22	26.75	17	11.75	0	26	20.7
F	37	33	28.875	18	26	0	28.575

Figure 1. Illustration of the methodological workflow

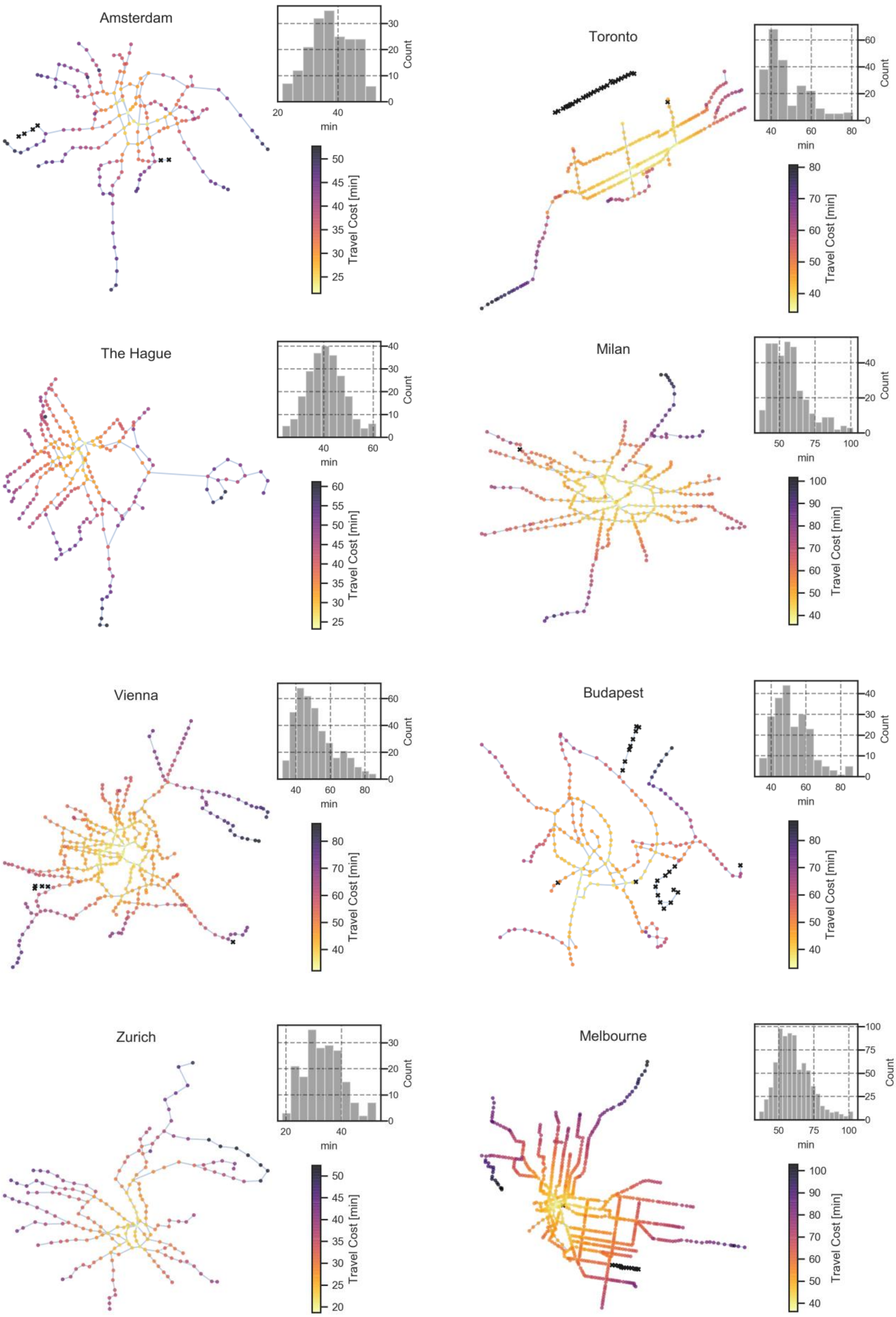


Figure 2. Visualizations of network-wide accessibility

3. Results

Eight tram networks from all over the world, including Melbourne (Australia), Vienna (Austria), Milan (Italy), Toronto (Canada), Budapest (Hungary), Zurich (Switzerland), Amsterdam and The Hague (The Netherlands), are selected for the accessibility analysis. Figure 2 presents the network-wide visualizations of stop accessibility for all the studied networks. Note that there are black "**x**" markers representing the stops disconnected to the rest of the network. This is due to the fact that the weighted network representations in this study, as mentioned before, are time dependent, and thus can be associated with no values when there are no scheduled services during the selected period (i.e., the morning peak from 8 am to 9 am). It can be observsed that the high accessibililty of those stops in the central area of the network turns out to be pronounced in both cases. Also, the accessbility gradually decays from the center to the edge for all the networks.

From Figure 3, it can be seen that the variability of a network's accessibility is proportional to its own size. As the median value of the accessibility indicator declines, the variability also decreases in a way that the range between the maximum and minimum shrinks. For large networks, such as Melbourne and Milan, they appear to have long tails on the top as a result of dramatic network sprawl from the center to suburbs. The opposite holds for some much smaller networks, including The Hague, Amsterdam and Zurich. Their shapes look much more compact in comparison to the others in the diagram.

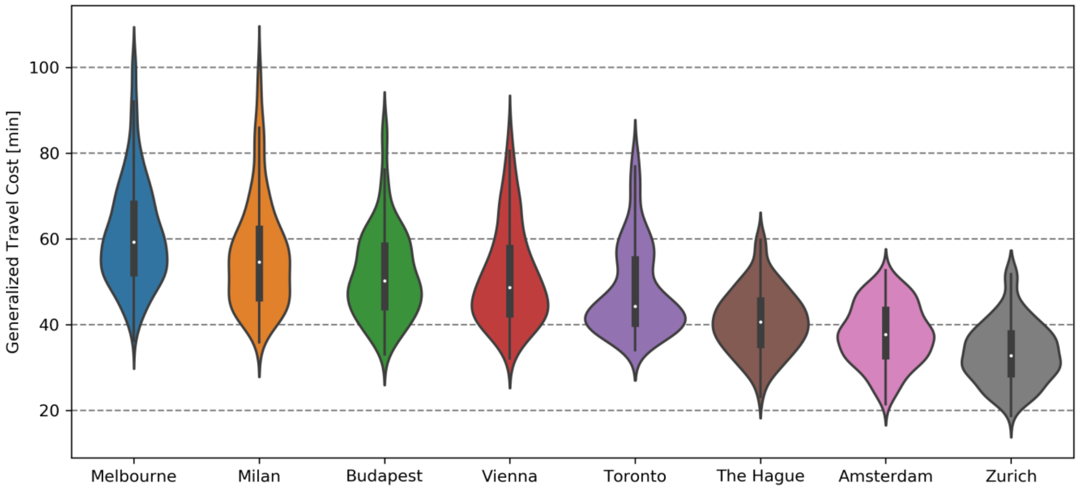


Figure 3. A violin plot illustrating the variability of the GTC based accessibility for the studied networks.

4. Conclusions

In this study, we propose an enhanced complex network representation of public transport which incorporates scheduled travel times as link weights. Based on this representation, an indicator that quantifies the travel impedance of individual stops in terms of generalized travel costs is efficiently computed. With GTFS data as the only input, this non GIS based method can be easily applied to assess various networks' accessibility. A case study of eight tram networks worldwide is presented. Our study makes an effort to further bridge the gap between complex network and transport research communities.

References

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