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Advanced Public Transport Network Analyser

Jan Nykl and **Michal Jakob** and **Jan Hrncir** [1]

Abstract. We present a web-based tool for a fine-grained analysis of the quality of public transport coverage. Employing an efficient graph-based transport network representation and a fast, modified Dijkstra-based journey planning algorithm, the tool calculates four public transport accessibility indices: journey duration, service frequency, the number of transfers, and a combined, overall index. Together, the indices give an accurate picture of the user-perceived accessibility by public transport in the area and time of interest.

1 Introduction

Public transport is an essential part of urban transport infrastructure and plays an indispensable role in the daily lives of urban citizens, in particular in larger cities. Consequently, the quality of public transport is under constant scrutiny, both from passengers and the authorities responsible for public transport development and operation.

The factors affecting passengers' perception of public transport quality have been thoroughly studied by transport researchers. Besides the more subjective factors, such as perceived comfort and safety, factors directly related to the routing and timetabling of public transport services have been found to play a significant role [1].

The existing research on public transport network analysis, however, focuses on the methods that analyse public transport networks from the perspective of structural graph-theoretic properties, such as node degree or betweenness [3, 4]. Although computationally inexpensive and useful for determining certain properties important from the network design and service operation perspective, such as the importance of stops or the occupancy of network links, graph-structural analysis reveals little about the quality factors considered important by public transport users.

We therefore take a different approach. Instead of directly analysing a simplified graph model of the public transport network, our analyser examines the properties of the public transport network by executing a very high number of simultaneous journey planning queries on the full-detail transport network model (see the next section). This allows the analyser to evaluate properties related to the detailed timing and interdependencies of connections, which play an important role in users' perception of public transport service quality.

Recently, applications for analysing public transport quality from the passengers' perspective have emerged, such as Mapnificent[2] or Helsinki HSL's Travel time map[3]. Although similar in purpose to our analyser, these applications provide limited functionality (focusing only on travel time and not considering transfers or service frequencies) and less accurate results due to a simplified model of the public transport network. Our analyser is therefore the first publicly available tool that offers fine-grained multi-criteria analysis of public transport service quality from users' perspective.

2 Problem Description

The analysis of accessibility is performed on a public transport network represented by a directed *time-dependent* graph $G_{\text{TD}} = (V, E, f)$, where V is a set of stops, E is a set of directed edges representing links between stops and $f : E \times \mathbb{N}_0 \mapsto \mathbb{N}_0$ is a function which, given an arrival time $\tau \in \mathbb{N}_0$ (in seconds) to the edge's head node, specifies how many seconds it takes to travel to the edge's tail node. See [2] for a detailed definition of the time-dependent graph structure.

The basis of the analysis are *one-to-one* metrics which assess a certain aspect of public transport accessibility between specific pairs of locations (termed the *analysis origin* and the *analysis destination*) and for specific times of travel (termed *the analysis time*). We use three primary metrics and one derived, overall accessibility metric. The three primary one-to-one accessibility metrics are:

- *Travel time* μ_T – the time, walking included, required to reach the analysis destination from the analysis origin.
- *Number of interchanges* μ_I – the minimal number of transfers required to reach the analysis destination from the analysis origin.
- *Frequency* μ_F – the number of non-dominated connections between the analysis origin and the analysis destination in the next 20 minutes (from the analysis time).

In order to facilitate mutual comparison and aggregation of the primary metrics, we discretize their values into five quality levels: *worst, bad, average, good, and best*. This allows us to define the derived *Overall* μ metric representing the overall service quality between the analysis origin and the analysis destination; the value of the Overall metric is the worst quality level of the three primary metrics.

Based on the one-to-one metrics, we define and calculate higher-level aggregate measures. The first of them are the *one-to-many accessibility indices* – a one-to-many accessibility index of a location is calculated as an average value of the corresponding one-to-one metric between the location and all other locations in the transport network; the average is weighted by the importance of each destination location measured as the number of people travelling from/to the location. The accessibility indices represent the aggregate accessibility of a given location in terms of the four accessibility metrics.

By aggregating further, *many-to-many accessibility indices*, again one for each metric, can be calculated for the *whole* network. A many-to-many accessibility index is calculated as the average of the respective one-to-many accessibility index over all locations in the public transport network; again the average is weighted by the importance of each location.

[1] Agent Technology Center, Faculty of Electrical Engineering, Czech Technical University in Prague, Czech Republic, emails: {nykl | jakob | hrncir}@agents.fel.cvut.cz.
[2] http://www.mapnificent.net/
[3] http://mak.hsl.fi/

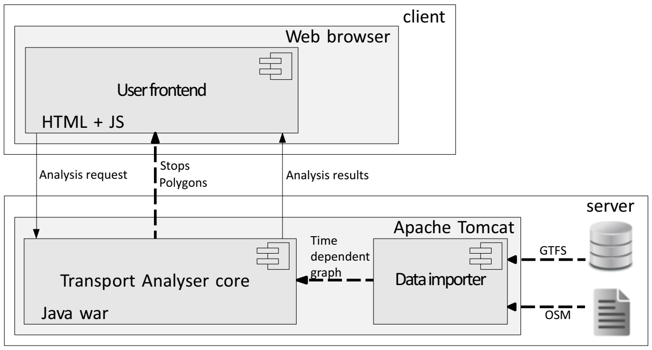

Figure 1. Architecture of the Transport Network Analyser.

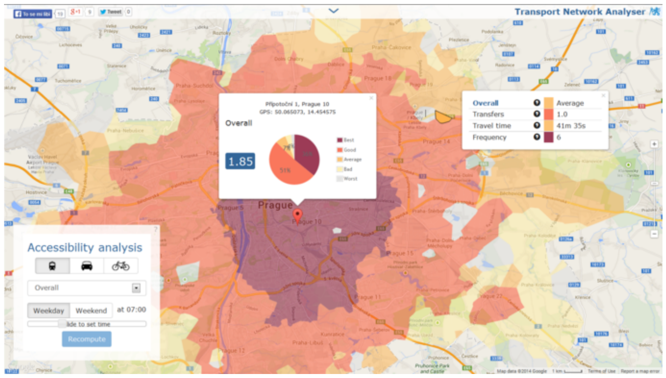

Figure 2. Web-based frontend of the Transport Network Analyser. Color-coded polygons are used to display the values of the selected one-to-one metric for different locations of the network along with basic statistics about the proportion of each quality level; the interface also displays selected one-to-many accessibility index for the chosen analysis origin.

3 System Description

The Transport Network Analyser system consists of a server backend and a web browser frontend. The frontend and the backend communicate via an HTTP protocol using JSON-based RESTful APIs. The architecture of the system is shown in Figure 1.

3.1 Data Importer

An essential part of the system is the data import and preparation module. The module reads external map and timetable data and uses them to build the time-dependent graph representing the analysed public transport network. The analyser uses the General Transit Feed Specification (GTFS)[4] format for timetables and OpenStreetMap (OSM) [5] format and data for map and footpath data. The interchanges between public transport stops are precomputed using the OSM data. Depending on the size of the city, the resulting time-dependent network graph contains up to tens of thousand nodes.

3.2 Transport Analyser Core

The Analyser Core implements the core network analysis algorithms. Given a user's request specifying the analysis origin and time, the core performs the analysis and returns the result to the client. The result returned contains the values of all four one-to-one metrics between the analysis origin and all other locations in the network together with the value of accessibility indices for the analysis origin.

The evaluation of all one-to-one metrics corresponds to executing tens of thousands of journey plan searches. The analyser avoids executing such a very high number time-consuming searches by employing a modified Dijkstra's algorithm extended to work on time-dependent graphs and to take restrictions on maximum walking distance into account. The Dijkstra's algorithm is used because of its ability to efficiently compute shortest paths from the analysis origin node to every other node in the graph. This way, the calculation of all one-to-one metrics between an analysis origin and all other destinations can be done using just 11 runs of the modified Dijkstra's algorithm configured to use either travel time or the number of interchanges as the search criteria. The calculation takes approximately 400 ms on a lower-end server for the city of Prague, whose planning graph (covering the area of 496 km^2) contains approximately 15,000 nodes and 50,000 of time-dependent edges.

[4] http://developers.google.com/transit/gtfs/
[5] http://wiki.openstreetmap.org/wiki/Main_Page

3.3 Web-based User Frontend

The web-based frontend, implemented in HTML and Javascript, allows the user to specify analysis parameters and explore analysis results. After setting the analysis origin, time of the day and the day of the week (weekday vs. weekend), the frontend displays results in an interactive map-based interface (see Figure 2).

4 Real-World Deployment and Experience

Several thousand people used the analyser web application since it was made publicly available in November 2013. During the peak period, the application, deployed on a single lower-end server, served more than 10 users simultaneously without noticeable performance degradation. The average response time stayed under 1s.

In their feedback, users most often stated the comparison of different locations for the purpose of property rental / purchase as the reason for using the application. Beyond general public, the tool also attracted attention from the expert audience, including urban planners and public transport operators.

We currently work on an extended, multi-modal version of the analyser which can also calculate car-, walk- and bike-specific accessibility metrics. The latest version of the tool is available at http://transportanalyser.com.

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