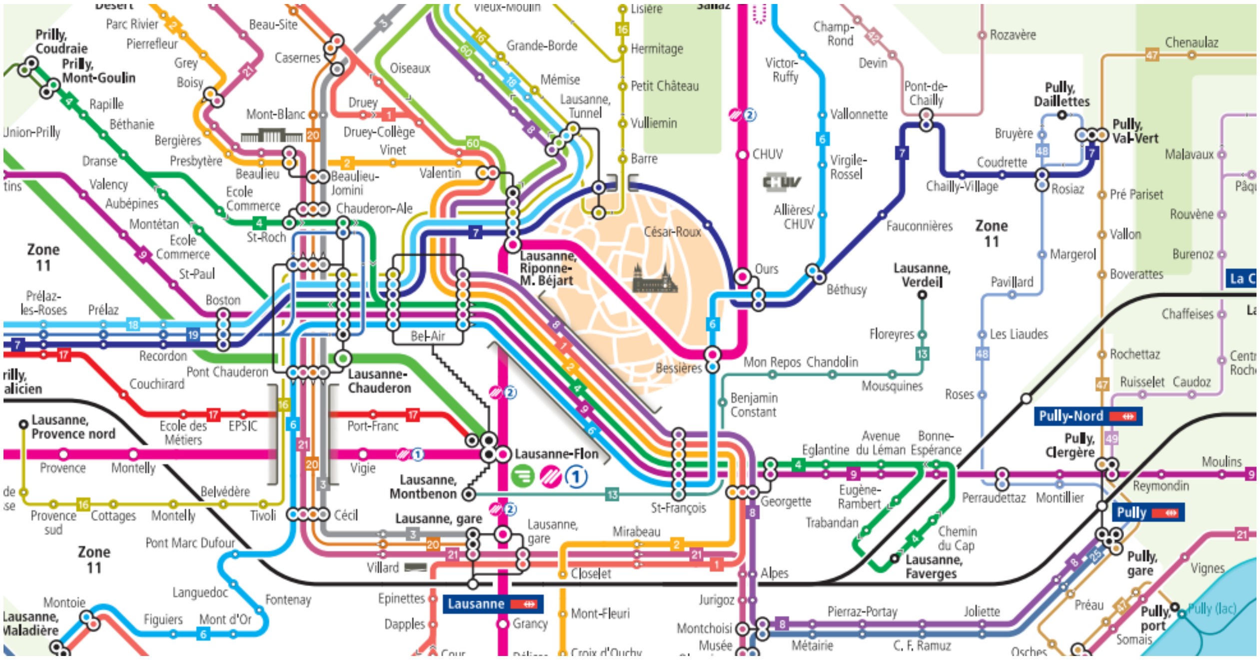
Assignment 2:
Network Design and Passenger Flow Distribution



Important dates:

- Submit written report by **Monday, 5th June**

For any questions concerning this assignment, please contact the responsible Teaching Assistants: Renzo Massobrio (r.m.massobrio@tudelft.nl) and Nejc Geržinič (n.gerzinic@tudelft.nl).

Purpose:

To understand, analyse and discuss the interactions between demand and supply of public transport systems. The case study requires estimating travel demand based on network topography, conducting a network assignment exercise, performing robustness analysis experiments, and analysing network performance. The discussion reflects on obtained demand patterns, network utilisation levels, network functionality under disruptions and suggestions for improving service performance.

General instructions:

In this assignment, you will continue studying the public transport network you analysed in Assignment 1 (list available in Appendix A) and continue working with the same teammate and the same peer review group.

You are asked to prepare an advisory report to support local policy makers in assessing passenger flow distribution, identifying bottlenecks, carrying out a robustness analysis and proposing service improvements.

Guidelines:

Step 1: Create an origin-destination matrix

In order to assess passenger flow distribution, you will need to create an origin-destination matrix. This should be constructed based on the following gravitation model. Let x_{ij}, the number of passengers traveling from station i to station j, be calculated as follows:

$$x_{ij} = \frac{a_j \cdot f_{ij}}{\sum_{j \in S; j \neq i} a_j \cdot f_{ij}} \cdot q_i$$

where q_i is the number of passenger trips originating from station i, a_j is the number of passenger trips destined to station and S is the set of all stations in the network. f_{ij} denotes the impedance function of traveling between i and j. The impedance function is defined as:

$$f_{ij} = \alpha \cdot e^{-\beta t_{ij}}$$

where t_{ij} is the travel time between stations i and j. Let $\alpha = 5, \beta = 0.5$. For the total production and attraction assume that the total production and attraction per station is directly proportional to the share of stations' closeness centrality out of the sum of closeness centrality as follows:

$$q_i = a_i = \frac{c_i}{\sum_{i \in S} c_i} \cdot Q$$

Where c_i is the closeness centrality value of station i. Finally, assume that the average number of public transport trips per resident of the case study area per day is 0.8 and that 10% of all public transport trips take place between 8-9 AM.

Step 2: Passenger assignment

Once you have created an OD matrix, you will perform a passenger assignment for the morning peak period (8-9 AM). Consider the demand between each O-D pair and assign the demand onto the network. Assume that passengers perform a probabilistic route choice among k-shortest paths, where k = 3. For route choice, assume that passengers use a random utility maximization approach with the following utility function:

$$U = \beta_I \cdot I + \beta_W \cdot W + \beta_T \cdot T$$

where I is the in-vehicle time, W is the waiting time and T is the number of transfers passengers need to make. You may assume that $\beta_I = -0.1$. You should specify the remaining utility function coefficients and provide arguments for how you have chosen to set their values.

You may use the provided code in helping you determine the k-shortest paths in your network. In the code, you will need to specify the waiting time and transfer time penalty in relation to the in-vehicle time penalty ($\frac{\beta_W}{\beta_I}$ and $\frac{\beta_T}{\beta_I}$ respectively).

Step 3: Determine the optimal vehicle capacity

Having performed the passenger assignment, determine the vehicle capacity. To aid you in this, you should first **determine the load per vehicle on each link**, using the obtained link load and the operating frequency from the GTFS data. **Plot an empirical (cumulative) distribution function** of the load per vehicle for each link and use this to analytically set the capacity of vehicles used in your network. When determining the capacity, you should consider the trade-off between **operating costs** and **level-of-service**, **on-board crowding** and potential **denied boardings**. You may assume that all the vehicles in the network will have the same capacity. The capacity you set does not have to resemble real-world public transport network capacities.

Step 4: Analyse the network performance

Analyse the saturation level of each link (i.e. volume over capacity) in the network, based on the determined capacity. **Plot the network on a map**, indicating the saturation level of each link. Are there links that stand out in the system (both highly and little used links) and are at risk of being (over)saturated?

Additionally, report and analyse the passenger-related performance of the network. Report the **average**, **minimal** and **maximal travel time**, as well as the **average waiting time** and **number of transfers** of passengers in your network?

Step 5: Perform a robustness analysis

Transport networks regularly experience disruptions, which result in a drop in performance and mean that travellers will need to detour or their trip can no longer be realized. In this step, you will analyse a targeted attack on the network, test its capability of withstanding disruptions at its key nodes.

In each iteration, the most central node in the network (the one with the highest betweenness centrality), and all its associated links, should be removed from the network. The P-space should then be reconstructed, as transit lines passing through a node are also broken because of such a disruption.

Repeat Steps 2 and 4 for a total of five times (iterations) and note down the changes you observe. Do not change the capacity you choose initially to set in Step 3.

With multiple targeted attacks, the network may become disconnected (two or more sub-networks, that are not connected). In that situation, you should disregard the smaller sub-network and only continue your analysis with the largest connected sub-network.

Note down how this reduction in network size (due to node and potentially sub-network removal) impacts the overall travel demand throughout the five steps of the robustness analysis.

Step 6: Discussion and report

Submit a concise report (8-12 pages) addressing carefully the following guidelines and having the local policy makers in mind as your intended readers. The report should consist of the following elements:

- **Introduction:**
  Describe the context and objectives of your advisory assignment, and introduce the network.
- **Method:**
  Briefly describe the sequence of steps you undertook in performing your analysis.
  A. Elaborate on the assumptions you have made. State **how you chose the population** for your network catchment area (*Step 1*). Explain also how you determined the remaining parameters of the utility function (*Step 2*).
- **Results and discussion:**
  B. Discuss how you determined the optimal capacity of vehicles operating in your network (*Step 3*).
  C. What are the main travel patterns in your network? What seem to be the main bottlenecks? Which links appear to be the most crucial in the network and are operating at/over capacity? Support your analysis by visualizing the OD matrix and showing an assignment map plot showing passenger volumes. (*Step 4*)
  D. Analyse the results of the robustness analysis. How did your network perform? Would you consider it a robust network when dealing with targeted disruptions? Support your analysis with the obtained key performance indicators. Relate these results of the robustness analysis to the structure of the network (*Step 5*).
  E. **Group member 1:**
  Consider the analyses you carried out (network performance under normal conditions and a targeted attack). Based on the result, make some proposals to the operator / transit authority on how the performance of their network could be improved with some **operational (short-term) changes**. What could be implemented, which problems would it alleviate, what would be the downsides and what trade-offs would need to be made. You may make some back-of-the-envelope calculations and refer to some best practice examples from other networks.
  F. **Group member 2:**
  Consider the analyses you carried out (network performance under normal conditions and a targeted attack). Based on the result, make some proposals to the operator / transit authority on how the performance of their network could be improved with some **strategic (long-term) changes**. What could be implemented, which problems would it alleviate, what would be the downsides and what trade-offs would need to be made. You may make some back-of-the-envelope calculations and refer to some best practice examples from other networks.

When submitting your report, attach your origin-destination matrix (as a *.csv* file) and the code you have used for implementing the passenger assignment in python.

Grading:

The grade of this assignment is based on the quality of the **content (Parts A-F)** and the **report** itself. The **report grade** is based on how the information and results are presented, structured, are they clearly readable, the use of scientific language etc. Two parts of the report (**E and F**) should be done by the two students **individually** (each student completes one of the two parts). Additionally, for the group choosing one of the 7 “Large networks”, a 5% bonus is added to account for the extra work and complexity associated with analysing those networks. The final grade of each student is done as follows:

	Student 1	Student 2
Part A	10%	10%
Part B	10%	10%
Part C	20%	20%
Part D	20%	20%
Part E	20%	-
Part F	-	20%
Report grade	20%	20%
Large network bonus	5%	5%

Appendix A – List of public transport systems to choose from

In some cases the city may contain information on several modes. In the table below, the mode of interest is indicated. Additionally, 7 larger and more complex networks are also indicated.

Group number	City / Region	Mode of interest	Large network
1	Amsterdam	metro	
2	Athens	metro	
3	Atlanta	metro	
4	Berlin	metro	X
5	Brussels	metro	
6	Budapest	metro	
7	Buenos Aires	metro	
8	Chicago	metro	
9	Copenhagen	metro	
10	Hyderabad	metro	
11	Lille	metro	
12	Lisbon	metro	
13	London	metro	X
14	Lyon	metro	
15	Madrid	metro	X
16	Marseille	metro	
17	Milan	metro	
18	Montreal	metro	
19	Naples	metro	
20	New York	metro	X
21	Nuremberg	metro	
22	Oslo	metro	
23	Paris	metro	X
24	Philadelphia	metro	
25	Prague	metro	
26	Rotterdam	metro	
27	Santiago	metro	
28	Stockholm	metro	
29	Toronto	metro	
30	Valencia	metro	

31	Vancouver	metro	
32	Vienna	metro	
33	Washington	metro	
34	Berlin	S-bahn	
35	Bern	S-bahn	
36	Brussels	RER	
37	Copenhagen	S-tog	
38	Hannover	S-bahn	
39	Sydney	suburban trains	
40	Basel	tram	
41	Bremen	tram	
42	Freiburg	tram	
43	Gdansk	tram	
44	Helsinki	tram	X
45	Krakow	tram	
46	Mannheim	tram	
47	Montpellier	tram	
48	Oslo	tram	
49	Prague	tram	X
50	Strasbourg	tram	
51	Toronto	tram	
52	Zagreb	tram	
53	Zurich	tram	
54	Salzburg	trolleybus	