Parameters

1 April 2025

This review explores the parameters of a bi-level optimization model to optimize pricing and fleet sizing in a multi-modal network. We will discuss how various parameters are determined in the literature, highlight the methods used to estimate them, and explain how we will use them in our model.

The parameters that we need to calibrate the bi-level optimization model are listed as follows:

1. Capacity per lane (vehicle/hours)
2. Travel time value (car, bike, public transportation, combined mode) (€/hour)
3. BPR parameters
4. Running cost (bike, public transportation) (€/km)
5. Purchase cost (bike, public transportation) (€/hours)
6. Speed (bike, public transportation) (km/hours)
7. Social cost of CO_2 (€/ton)
8. Health benefit (€/km)
9. Vehicle component of emission (car, bike, public transportation) (gCO_2/pkm)
10. Fuel component of emission (car, bike, public transportation) (gCO_2/pkm)
11. Infrastructure component of emission (car, bike, public transportation) (gCO_2/pkm)

The network that is selected to be used to test the algorithm and the model is Mandl's network. This is a theoretical transportation network which was presented by Mandl (1980). This network is often used as a benchmark in transportation studies. The network consists of 15 nodes (representing origin and destination or stations) and 21 links. Mandl's network is a synthetic network - meaning it is not based on a real city. Therefore to calibrate the model we chose Switzerland as the reference. Thus, we use its features and related information as the parameters.

1 Parameters description and adaptation

In this section, we provide a brief overview of the references for the parameters that are mentioned in the previous section.

- **Capacity:** The capacity for cars per lane will be used for calculating the BPR travel time for cars. The capacity that is considered here is 600 vehicles per hour per lane. This is based on the author's choice according to the size of the network and the number of demands between each origin and destination.

- **Travel time value:** Travel time value is defined as the amount of money at which a change in travel time can be compensated. Travel time is regarded as a disutility and reducing travel time increases utility and vice versa [1] . Schmid et al. (2021) calculated the travel time value for all modes of transportation based on the data that was collected in 2015 and 2016 in the Canton of Zurich [2]. The travel time values are as follows:

  1. Travel time value of car = 30.6 CHF/hr
  2. Travel time value of pubic transportation = 14.8 CHF/hr
  3. Travel time value of bike = 18.2 CHF/hr These values are based on a dataset from 2015.

- **Running cost:** The running cost (the maintenance cost) for each mode of transportation is part of the operators' expenses. Audikana et al. (2017) presented that the running cost for a bike-sharing system based on the information from a bike-sharing company in Zurich (PublicBike) is 1200$/a per bike [3]. What we need is the running cost per km. To this end, we need information on the km/a per bike. Reck et al. (2021) presented that an average trip distance for bikes in a bike-sharing system is approximately 1200 meters [4]. Data from PublicBike's website [5] suggest that each bike does 2 trips per day on average. Thus, the running cost of bikes per km will be as follows: (1.2 (km) * 2 (trips))*365 = 876 km/a (1200/ 876) = 1.36 $/ km which will be 1.3 CHF/km

  The next value is the running cost of the public transportation system (trains). Bösch et al. (2018) mentioned that the operator costs for trains in Switzerland is 31.40 CHF/km. This is based on the data from 2016[6].

- **Purchase cost:** The value of buying a fleet for the public transportation or bike-sharing system is also part of the operator's expenses. According to Audikana et al. (2017) study from PublicBike, the installation cost for each bike in the bike-sharing system is 2000 $ [3]. However, we want to have this value based on the CHF/hr. This means that we need the average travel time per trip. Based on Reck et al. (2021), the shortest trips are 12 min and the longest trips are 1 min within the bike-sharing system [4]. On average a trip can take 15 min. According to this, we have: (15 * 4) * 365 = 21400 hr/a. Therefore, 2000/21400 = 0.091 $/hr

The other value in a category is the purchase cost for public transportation fleets. Sinner et al. (2018) presented different parts of operators' costs for trains and buses as public transportation [7]. Based on this study, the value of the vehicle cost is 153727 CHF/a. Based on the train schedule in Switzerland, the Swiss trains work for around 19 hours a day, which is 6935 hr/a. Thus, the purchase cost of trains in Switzerland is 15.95 CHF /hr

- **Speed:** The speed for bikes and public transportation is used to calculate the travel time for these modes of transportation. The speed of bikes is considered 15 km/hr [8], and the speed of public transportation (trains) is 37.82 km/hr [6].

- **Social cost of CO_2:** Social cost of the CO_2 is economic damage caused by the emission of one ton of carbon [9]. The GHG emission reductions agreed in the Paris Agreement are based on preventing temperature rises above 1.5-2 degrees Celsius. Exceeding this level is considered to be too risky for future generations. Therefore, it makes sense to formulate climate change costs as avoidance costs [10]. Therefore, the literature revealed that the central value for the short-and-medium-run costs (up to 2030) is € 100/tCO2 equivalent (€2016).

- **Health benefit:** The health benefit is the economic value of health benefit that we get from using cycling as an active mode of transportation. This value was not specifically found for Switzerland, therefore, we used the study of Schröder et al. (2024) [11]. In their study, they evaluated the health benefits of walking and cycling in Munich based on the HEAT approach. They reported the value to be 578.56 €/a for bikes. If we say the same amount is applicable for Switzerland, based on the information that we mentioned earlier there are 876 km/a for each bike. Thus, the health benefit value will be approximately 0.66 €/km. This value was estimated as the internal health benefit by monetizing avoided deaths among individuals using active transportation modes (e.g., cycling), employing the WHO's HEAT [12] tool and the value of a statistical life. Additionally, [13] reported that the ratio of external to internal health benefits is 0.38. Therefore, the external value of health benefit will be 0.38*0.66 = 0.25 €/km.

The following table summarizes the parameters of the model. All the values were changed to euro. Moreover, we used [14] to change all the monetary values to a similar time base (the year 2024) based on the inflation rate in Switzerland.

References

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Parameter	Value	Reference
Capacity and Travel Time		
Capacity per lane (vehicles/hour)	600	Authors' assumption
Travel time value (car) (€/hour)	31.56	[1]
Travel time value (public transport) (€/hour)	15.7	[1]
Travel time value (bike) (€/hour)	18.93	[1]
Travel time value (combined mode) (€/hour)	16.66	Authors' assumption
BPR Parameters		
α_1	4	[15]
α_2	0.15	[15]
Bike Availability Probability		
Probability range	0.7 - 1	Authors' assumption
Running and Vehicle Costs		
Running cost (bike) (€/km)	0.98	[3]
Running cost (public transport) (€/km)	35.49	[7]
Purchase cost (bike) (€/h)	0.098	[2]
Purchase cost (public transport) (€/h)	18.04	[8]
Mode Speeds (km/h)		
Bike speed (v_b)	15	[9]
Public transport speed (v_p)	37.82	[7]
Health and Environmental Factors		
Social cost of CO_2 (€/tonCO_2)	100	[10]
Health benefit (€/km)	0.66	[10]
Emission Costs (gCO_2/pkm)		
Vehicle component (car)	25	[13]
Fuel component (car)	125	[13]
Infrastructure component (car)	15	[13]
Vehicle component (bike)	25	[13]
Fuel component (bike)	0	
Infrastructure component (bike)	15	[13]
Vehicle component (public transport)	5	[13]
Fuel component (public transport)	20	[13]
Infrastructure component (public transport)	15	[13]

Table 1: Transportation Network Parameters