Master Mobility and Supply Chain Engineering
Integrated practicum 1
Prof. P. Vansteenwegen

IP1b - Assignment: robust timetabling - Analysis

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Introduction

As it is often observed that when a train experiences delay, the passengers who are using that train as a connection to some other train in the network, tend to miss their transfer. With complete control over the line planning and the frequencies of the trains, this assignment tries to minimize a total cost function and generating an optimized timetable.

1 Provided data and problem statement

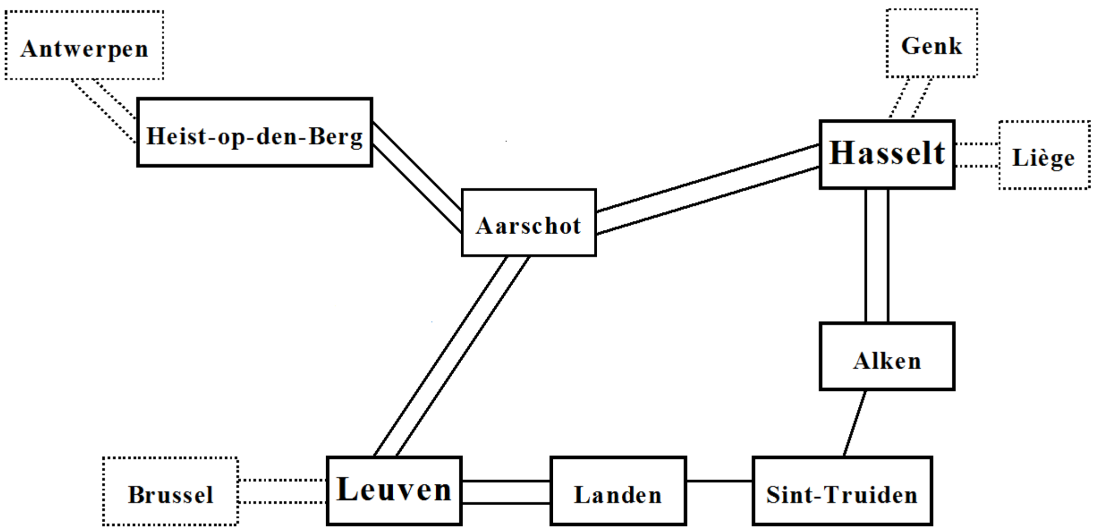

Figure 1: The blank rail network[Vansteenwegen and Van Oudheusden, 2006].

As this paper is a follow-up of report [A. Challana and Vilain, 2021], it is assumed that the terms and objectives that were achieved in the previous paper are well known and don't need to be explained again. This paper is an attempt to optimize the timetable of the same railway network with control on line planning and frequencies of the trains. It was done with the help of the data from the OD matrix.

1.1 Description of problem

The analysis of [A. Challana and Vilain, 2021] directed that the biggest contributor to the total cost was the cost due to missed transfers. If a passenger misses their connection, they must wait for the next connection, which is mostly after 60 minutes and sometimes after 30 minutes, depending on the frequency of the connection. The new line plan was developed to minimize the total number of transfers in the network. Starting with a blank network (Figure 1), lines were to be developed and their frequencies had to be chosen in order to optimize the network. This means creating the lines and stops which results in the lowest total cost possible. As the main objective was the same as the previous paper, so was the main method to solve this. Transfer and buffer times were again used to optimize the timetable and network from the point of view of the passenger, reducing missed transfers, delays and other different kinds of costs.

1.2 OD-matrix

The matrix was a new source of information that could be used during the optimization and analysis of the network. It consists of a 10x10 matrix consisting of the origins and destinations. Each cell describes how many passengers depart from their origin and arrive at their destination during the peak hour that was analyzed. The matrix is almost completely symmetrical (which simplifies some measurements). In effect, this data shouldn't be modified and helped, at first, to develop the new line planning of the trains and their frequencies. The values of the matrix are necessary for calculating the distributions over the new train lines, as they are different from the original numbers used in the Matlab file. The new arriving passengers per destination, through passengers per station and transfer passengers between two trains can then be calculated.

2 Creating a line plan

To analyze the network (Figure 1), a pie chart (Figure 2) was created for the OD pairs sorted according to volumes of traffic to prioritize the lines accordingly. This data was obtained from the provided OD matrix. A full list can be found in the appendix (6).

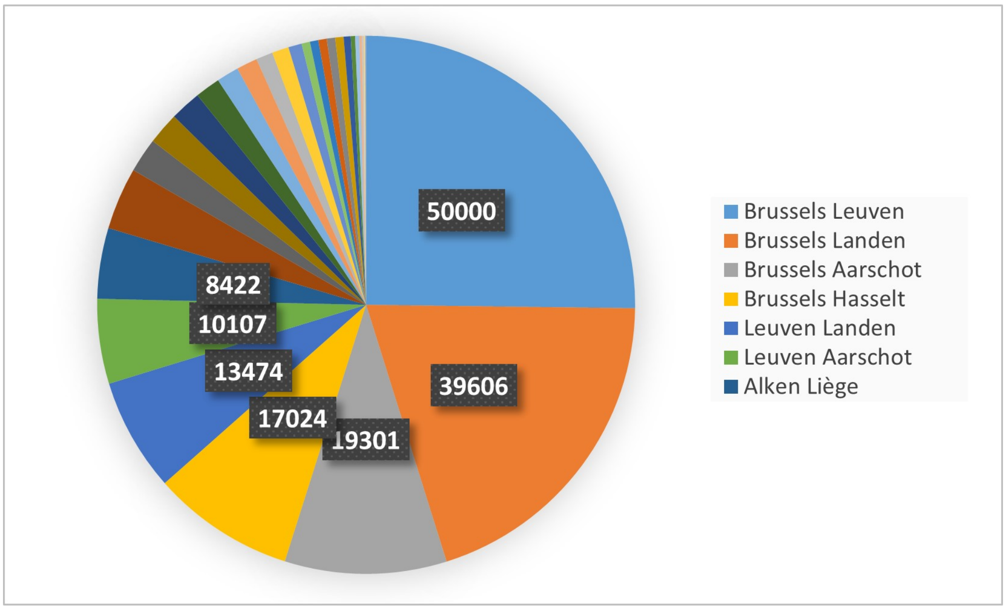

Figure 2: Pie chart of the journeys with the largest volumes of passengers in the network.

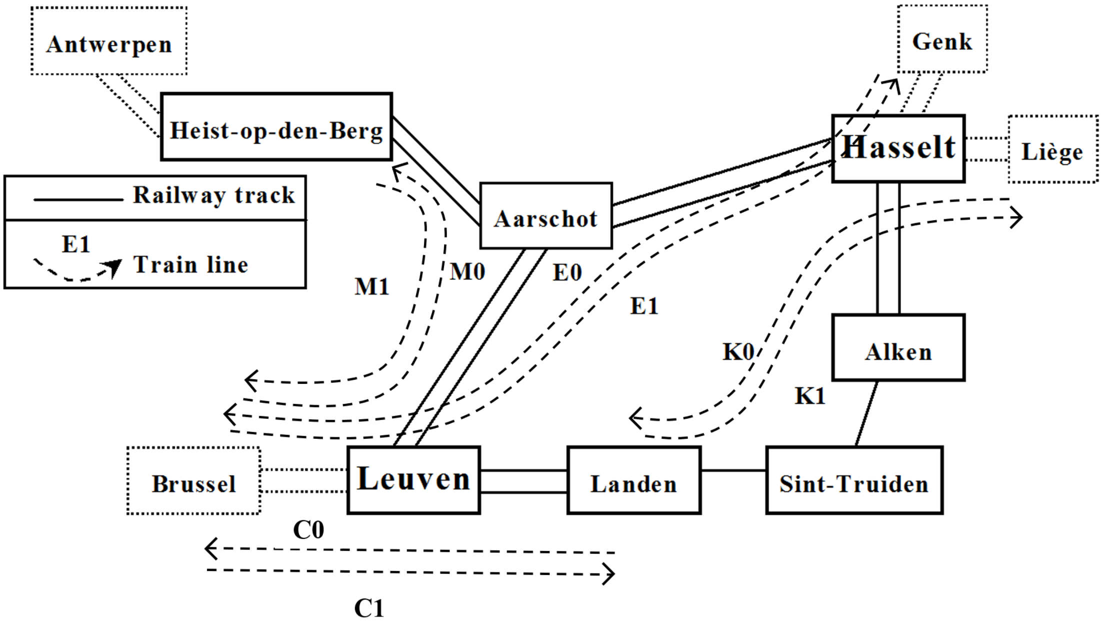

Figure 3: The rail network with the new line plan.

From the pie chart, it was found that there were 39,606 passengers (almost 20% of the total volume) travelling from Brussels to Landen and vice versa and all these passengers had to make a transfer at Leuven as there was no direct train between these stations. At the same time there were only 835 (less than 0.5% of the total volume) passengers travelling from HODB to Hasselt, but there was a dedicated C line (5) so that the passengers travelling from HODB to Hasselt did not have to take a transfer at Aarschot. The journey from Brussels to Landen clearly needed a direct line more than the journey from Hasselt to HODB, hence the C line was changed from the stations HODB and Hasselt to Leuven and Landen. Also, since the C line was moving between Brussels and Landen we did not need the K line to go all the way to Brussels because the C-line was doing that for the network. Therefore the K-line was cut short till Landen. Similarly, to avoid transfers in the journey from Hasselt to Brussels and HODB to Brussels, E and M lines were extended to Brussels respectively. Omitting and/or editing in plans of any other lines was causing an increase in transfers and sometimes making passengers make two transfers between a journey of two stations. So no other line and/or frequency changes were made. The new line plan is shown in Figure 3.

The total transfers in the network with this new line plan were reduced from 24,164 to 18,882 when compared to the original line plan.

3 LINDO Script

There was a LINDO file to start with and that gave an indication of how the planning with LINDO code works, but this code gave little contribution to the projects, as a personalized line planning is coherent with a personalized code. After creating a line planning that seemed to fit with the data from the OD-matrix, a new LINDO script was created. The objective of this LINDO script was exactly the same as in the IP1a i.e. to minimize the three components of the total cost i.e. the TTCOST, the STCOST and the DEVIAT. The minimum transfer time was kept to the original three minutes, the running times between the stations remained the same and the single track specification remained about the same, but all the other variables and constraints had to be redefined and recalculated:

- transfers and transfer times,
- departure and arrival times of the stations on each new line,
- stopping times,
- coefficients of objective function,
- comparison between ideal buffer time and buffer time,
- ideal buffer times.

3.1 Ideal buffer time (IBT)

Ideal buffer times are the buffer times that, if provided, minimize the total cost for that particular transfer. In the LINDO script, the deviations of the actual buffer times from the ideal buffer times, whether negative or positive, were penalized.

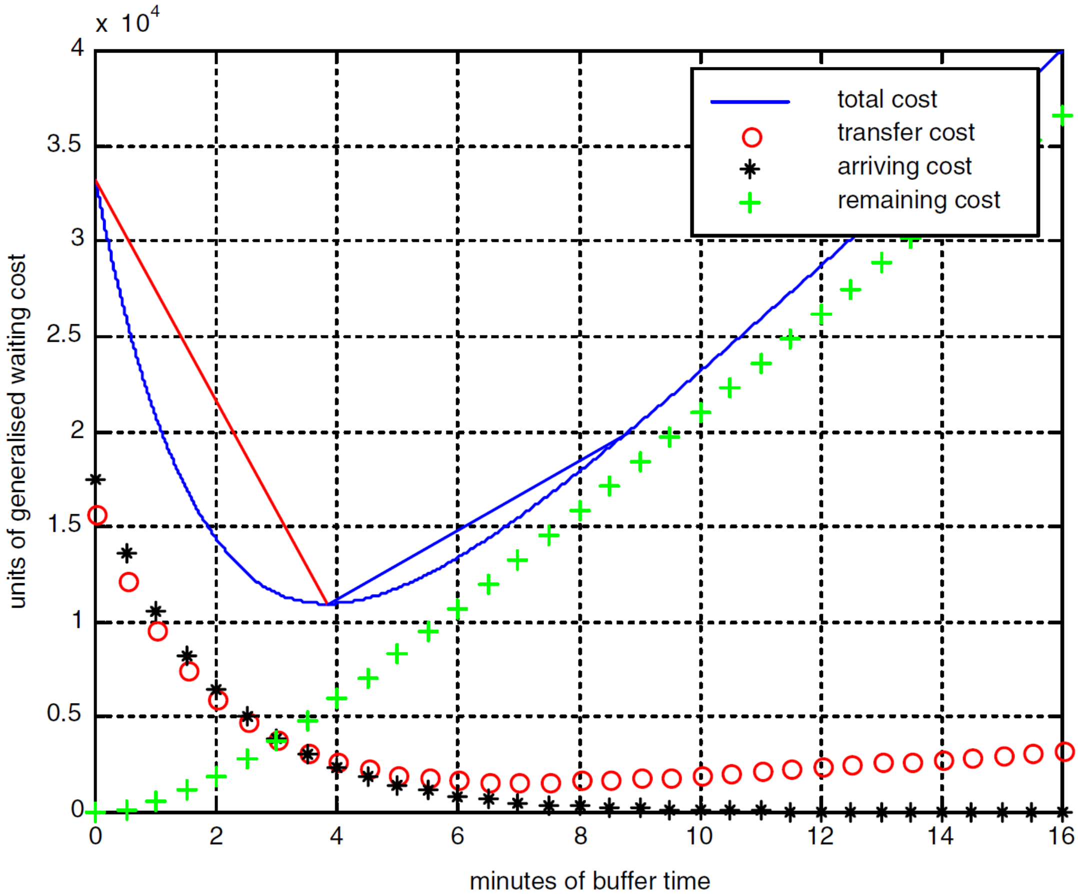

Figure 4: Generalized waiting cost as a function of the buffer time at a certain connection[Vansteenwegen and Van Oudheusden, 2006].

As it can be inferred from this figure is that the total cost from the passengers' perspective has three components: the transfer cost, arriving cost and the remaining cost or through cost. Summation of these three components give us a total cost function which was obtained from [Vansteenwegen and Van Oudheusden, 2006]:

$$C(B) = 2.2P_t p e^{-\frac{1}{\lambda}B} + (2.0P_t + 1.5P_r) * [B + \lambda(e^{-\frac{1}{\lambda}B} - 1)] + 2.5P_a \lambda e^{-\frac{1}{\lambda}B}. \qquad (1)$$

where,

- P_t = number of passengers making transfer at the transfer station.
- P_a = number of passengers ending their journey at the transfer station.
- P_r = number of passengers going to next stations on the connecting train through the transfer station.
- λ = expected delay (in minutes).
- p = frequency of the connection.

To calculate λ, an assumption was made that the expected delay is the property of the train that depends on the running period of the train. Therefore the λ values specific to the trains in the new line plan were calculated by interpolating them on the basis of running times from the rail network with the original line plans.
If the provided buffer time is too small, the transferring passengers are more likely to miss their transfers and the transfer cost will increase. While the through passengers will have to wait less sitting in the train and the remaining cost component will decrease.
On the other hand, if the provided buffer is too large, the transferring passengers will have more time to make their transfer, which will reduce the transfer cost. However, the through passenger's waiting time while sitting in the train will increase and so will the remaining cost.
The arriving cost component will nonetheless keep on decreasing with the increasing buffer time as increasing the buffer time will keep pushing the scheduled arrival times away from the actual arrival times. This will mean that the train will be less likely to arrive late.
The ideal buffer time is the trade-off between these three components of cost that minimizes the total cost. It was calculated by plotting the total cost function and then finding the buffer time for the minimum value of the cost for each transfer. The ideal buffer time was rounded off to the closest integer.

3.2 COST coefficients

There were three components of the LINDO objective function (total cost), STCOST, TTCOST and DEVIAT. All these cost components were divided by 10,000 for scaling purposes.

3.2.1 TTCOST

As described in [A. Challana and Vilain, 2021], the minimum time required to make a transfer was three minutes. So, if any transfer was assigned more than three minutes, that extra time provided was penalized in the TTCOST component as the transferring passengers would have to wait for their connection. The weight/coefficient of the penalty on that transfer obviously depended on the volume of passengers making that transfer. Hence the coefficient of the variables of the TTCOST component, the volume of the transfer was multiplied by two, which is the weight for people waiting for their connection. The formula used for this is TTCOST= $\frac{2*V_{transfer}}{10000}$.

3.2.2 STCOST

Similarly, for the stopping of a train at every stop, the through passengers had to wait while sitting in the train. To minimize these stoppage waiting times, these stops were penalized in the STCOST component. The weight/coefficient of these penalties also depended on the volume of through passengers on that train at the station. For the coefficients, volume of through passengers were multiplied by 1.5, which is the weight for people waiting while sitting in the train. The formula used for this is STCOST= $\frac{1.5*V_{stop}}{10000}$.

3.2.3 DEVIAT

With the DEVIAT component of the cost, the deviations of the provided buffer times from the ideal buffer times were minimized by putting penalty on the deviations. Weight to these deviations were assigned by considering how much the total cost increased per minute deviation of the provided buffer time from the ideal buffer time. Since the cost function was a nonlinear function, it was linearly approximated around the ideal buffer time (IBT) in the range of [IBT – 5, IBT + 5]. This way, two different coefficients were obtained on either side of the IBT for negative and positive deviations in the buffer time of a transfer.

4 Matlab Script and results

As with the LINDO script, the Matlab script also has to be redefined and calculated according to the new line plan. At first, the new arriving passengers per destination, through passengers per station and transfer passengers between two trains can be calculated with the data from the OD matrix. Further, the stopping times and stopping cost, departure times and arrival times had to be adjusted. Again, various plots were programmed to see where transfer time and/or buffer time had to be increased.
In the Matlab script of [A. Challana and Vilain, 2021] delay was only possible between the second to last and last station of a train line. Now the expected delay is spread across the whole track using the travelling time, because the data of the whole track wasn't provided. We assume here that the delay is uniformly divided over the whole track.

Table 1: Final results of the Matlab script.

Parameter	Result of IP1a	Results of IP1b
percentage_missed	5.1996	4.5034
percentage_long	5.1996	4.5034
stopping_cost	10470	0
total_cost_arriving_late	1.1027e+05	1.3975e+05
total_cost_through_passengers	9.5881e+04	6.7882
total_cost_of_transfers	5.4229e+05	2.8010e+05
total_cost	**7.5891e+05**	**5.971e+05**

5 Final timetable

The only thing that was left to do, was adding transfer and buffer times in order to decrease the total cost. This was done with the same method used [A. Challana and Vilain, 2021].

By adding the changes to the LINDO and Matlab script, new timetables were made, as shown in tables 2 to 5. The output of the Matlab script is shown in table 1. There is seen we had a major improvement on the original results looking at the total cost. In comparison with the results of [A. Challana and Vilain, 2021], also a better result has been achieved, mainly due to the fact the line planning was thoroughly developed based on a OD matrix.

Table 2: Optimized timetable of the M line with arrival and departure time for each station.

M track						
M10	Leuven		Aarschot		Heist-ODB	
	A	D	A	D	A	D
		07:51	08:02	08:06	08:18	
M11	Heist-ODB		Aarschot		Leuven	
	A	D	A	D	A	D
		07:31	07:47	07:48	08:06	08:07

Table 3: Optimized timetable of the C line with arrival and departure time for each station.

C track				
C10	Leuven		Landen	
	A	D	A	D
		07:23	07:57	
C11	Landen		Leuven	
	A	D	A	D
		07:08	07:36	07:37

Table 4: Optimized timetable of the E line with arrival and departure time for each station.

E track						
E10	Leuven		Aarschot		Hasselt	
	A	D	A	D	A	D
		07:37	07:49	07:50	08:22	08:32
E11	Hasselt		Aarschot		Leuven	
	A	D	A	D	A	D
		07:32	07:59	08:00	08:14	08:15

Table 5: Optimized timetable of the K line with arrival and departure time for each station.

K track								
K10	Hasselt		Alken		St.-Truiden		Landen	
	A	D	A	D	A	D	A	D
		07:35	07:41	07:42	07:50	07:51	08:00	
K11	Landen		St.-Truiden		Alken		Hasselt	
	A	D	A	D	A	D	A	D
		08:00	08:09	08:10	08:18	08:19	08:29	08:30

Conclusion

In [A. Challana and Vilain, 2021], it was observed that in a rail network, a passenger can experience various costs such as arriving late cost, waiting while sitting in the train cost, waiting for the transfer cost or missed transfer cost. All these cost components summed up to make the total cost. However, the most significant component of all was due to the transfers in the network. If there are more transfers, there are more missed connections, more long connections and more transfer cost. Hence, this assignment was an attempt to create a line plan with the minimum number of transfers. With the new line planning, a new set of transfers and the corresponding volumes for these transfers came along. A new LINDO script was written to keep the line planning and transfers in order. The timetable was further optimized with the process explained in [A. Challana and Vilain, 2021]. As expected, the total cost from the new line plan was by more than 20% less when compared to the cost from the original line plan.

References

[A. Challana and Vilain, 2021] A. Challana, E. V. and Vilain, S. (2021). Ip1a - assignment: robust timetabling - analysis.

[Vansteenwegen and Van Oudheusden, 2006] Vansteenwegen, P. and Van Oudheusden, D. (2006). Developing railway timetables which guarantee a better service. *European Journal of Operational Research*, 173(1):337–350.

[Wardman et al., 2004] Wardman, M., Shires, J., Lythgoe, W., and Tyler, J. (2004). Consumer benefits and demand impacts of regular train timetables. *International Journal of Transport Management*, 2(1):39–49.

Appendix

A Ranked OD pairs

Table 6: OD pairs ranked according to most traffic.

Brussels	Leuven	50000
Brussels	Landen	39606
Brussels	Aarschot	19301
Brussels	Hasselt	17024
Leuven	Landen	13474
Leuven	Aarschot	10107
Alken	Liège	8422
Hasselt	Sint-Truiden	7422
Alken	Landen	4109
Brussels	Sint-Truiden	3817
Alken	Genk	3704
Hasselt	Genk	3000
Aarschot	Hasselt	2656
Brussel	Heist	2501
Leuven	Hasselt	2000
Aarschot	Heist	2000
Aarschot	Liège	1600
Hasselt	Alken	1000
Hasselt	Liège	1000
Alken	Sint-Truiden	1000
Landen	Sint-Truiden	1000
Leuven	Sint-Truiden	1000
Hasselt	Heist	835
Genk	Sint-Truiden	523
Leuven	Heist	501
Aarschot	Landen	288
Heist	Landen	245
Heist	Liège	145
Aarschot	Alken	120

B Original line plan

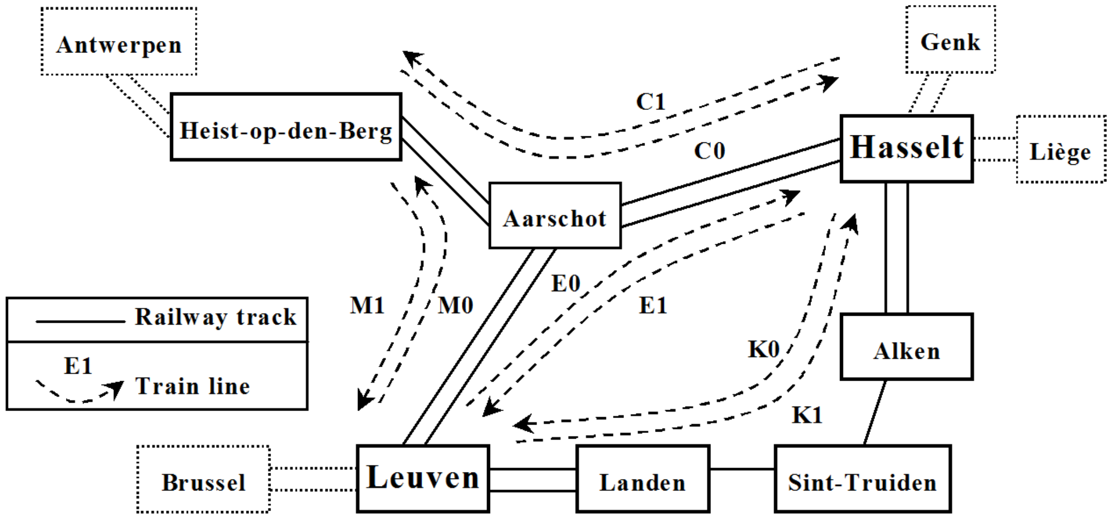

Figure 5: The rail network with the original line plan[Vansteenwegen and Van Oudheusden, 2006]