Project 2: ODTMS

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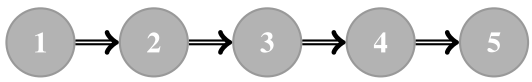
This project consists of 4 parts: 2 ”exam-style” exercises on timetabling (Part 0) and column generation (Part 3) respectively, and 2 reading, modelling, implementation and analysis parts (Part 1 & 2). While Parts 0 and 3 may be answered shortly and to the point, Parts 1 & 2 should be made into a short report (around 3 pages of text). In expectation, you would be able to do parts 0 and 3 in ca 0.5-1h each, while you spend the remaining time on Parts 1 & 2

Part 0 Non-cyclical timetabling (as from the Timetabling lecture)

You are the Infrastructure Manager of the following one-way single corridor railway network with five stations $S = \{1,2,3,4,5\}$.



You have collected the requests of different Train Operators for a total of four trains $T = \{A,B,C,D\}$. The first station f_j, the last station l_j, and the ordered set S_j of stations visited by train $j \in T$ are:

$$f_A = 1 \quad l_A = 5 \quad S_A = \{1,2,3,4,5\}$$
$$f_B = 1 \quad l_B = 5 \quad S_B = \{1,2,3,4,5\}$$
$$f_C = 1 \quad l_C = 3 \quad S_C = \{1,2,3\}$$
$$f_D = 3 \quad l_D = 5 \quad S_D = \{3,4,5\}$$

Table 1 reports, for each train $j \in T$, the ideal timetable along with the minimum dwell time at each station (a dash indicates that the train does not stop at that station).

Table 1: Ideal Timetables

Ideal Timetables

	Train A			Train B			Train C			Train D		
Station	**Arr.**	**Dep.**	**Min. Dwell**	**Arr.**	**Dep.**	**Min. Dwell**	**Arr.**	**Dep.**	**Min. Dwell**	**Arr.**	**Dep.**	**Min. Dwell**
1		8:02	-		8:00	-		8:02	-			-
2	8:14	8:16	2	8:08	8:08	-	8:12	8:14	2			-
3	8:26	8:29	3	8:14	8:18	4	8:20		-		8:18	-
4	8:41	8:43	2	8:26	8:26	-			-	8:28	8:30	2
5	8:48		-	8:30		-			-	8:35		-

For each train and each pair of consecutive visited stations, the ideal running times correspond to the running times of the ideal timetables. For the sake of simplicity, such running times are reported in Table 2.

Table 2: Ideal Running Times

	Train A	**Train B**	**Train C**	**Train D**
$1\dots2$	12	8	10	-
$2\dots3$	10	6	6	-
$3\dots4$	12	8	-	10
$4\dots5$	5	4	-	5

In order to solve this instance of the Train Timetabling Problem, you are provided with the arrival and departure headway times

$$\text{Arrival Headway Times} \qquad h_i^a = 3 \quad i \in S$$

$$\text{Departure Headway Times} \qquad h_i^d = 3 \quad i \in S$$

and with the profit pr_j of the ideal timetable, the penalty for each minute of shift π_j^{sh}, and the penalty for each minute of stretch π_j^{st} of each train $j \in T$ as described in Table 3.

Table 3: Ideal Profits and Shift/Stretch Penalties

	Train A	**Train B**	**Train C**	**Train D**
Ideal profit pr_j	100	500	5	5
Shift penalty π_j^{sh}	50	200	1	1
Stretch penalty π_j^{st}	30	200	2	2

Moreover, you are told that Train B, that passes through stations 2 and 4 without stopping (the minimum dwell time is 0), cannot stop at those two stations: so it can be stretched only at station 3.

Non-cyclical timetabling: Exercise

1. Provide a manual solution of the problem displayed in a space-time diagram

2. Define the following components of the space-time graph for Train B:

- the sets of arrival nodes R_i for each station $i \in S$;
- the set of departure nodes D_i for each station $i \in S$;
- the arc set A_j for train $j = 1$, also indicating the profit of each arc of the set A_j.

Part 1 On-Demand Transit Network Design

It is the ambition of the Capital Region to update their mid-northern bus network while planning it in connection to a bike sharing system. In this first analysis you will be conducting, the assumption is that all users are able to bike.

The objective is to select those buslinks to open that will minimize the total user inconvenience, within a budget for operating costs.
Users will consider one of two options to travel from their origin to their destination:

- A direct bike path, connecting origin to destination
- Biking to one of the three closest hubs to their origin (including their origin stop at a cost of 0), taking the bus, and next biking from their final bus-hub to their destination. Their destination has to be one of the three closest hubs to the final busstop (including the busstop itself). In case the final busstop is at the location of the destination, the bike costs will be zero.

Users will prefer the shortest path. We will assume there are sufficient bikes, and sufficient capacities in the bus available. Busses can be introduced on links in a specific direction (allowing one-directional opening of a buslink), and we only assume the weak-connectivity constraint as in Auad-Perez and van Hentenryck. We will ignore any transfer penalties. The objective is to serve all demand at minimal user inconvenience, within a budget for the bus operating costs. User inconvenience is defined by the distance divided by the speed. Busses are assumed to present a travel speed twice that of a bike. Bus costs are proportional to the length of the links. Busses and Bikes can travel according to the Euclidean distance between two points. Busses can only drive between connected hubs (see Figure 1).

The candidate network is depicted in figure 1. The red circles indicate all possible bushubs, that can also serve as origin and destination nodes of users. The edges of the graph indicate the possible bus-connections between nodes. These connections may be established in either, and both, directions.

On DTU Learn, you can find the file "DataProject2.xlsx" with the following data:

- The list of stations with ID, name, and location (x,y coordinate)
- Bus speed and bike speed
- Graph: a 1 indicates the two nodes are connected.
- OD matrix: volume of passengers that would like to travel from a origin (row) to a destination (column). Note that, for our purpose, we can represent every OD as one user/customer group.

A Ridesharing and fleet sizing for On-Demand Multimodal Transit Systems

Read the following paper to the extent that you can answer the below questions: Ramon Auad-Perez, Pascal Van Hentenryck, *Ridesharing and fleet sizing for On-Demand Multimodal Transit Systems*, Transportation Research Part C: Emerging Technologies, Volume 138, 2022, https://doi.org/10.1016/j.trc.2022.103594.

Questions about the paper:

- What is the problem studied in the paper?
- What do the authors list as their main contributions?
- Are the contributions practical/managerial, or advancing theory?
- Do the contributions have value outside of the application area?

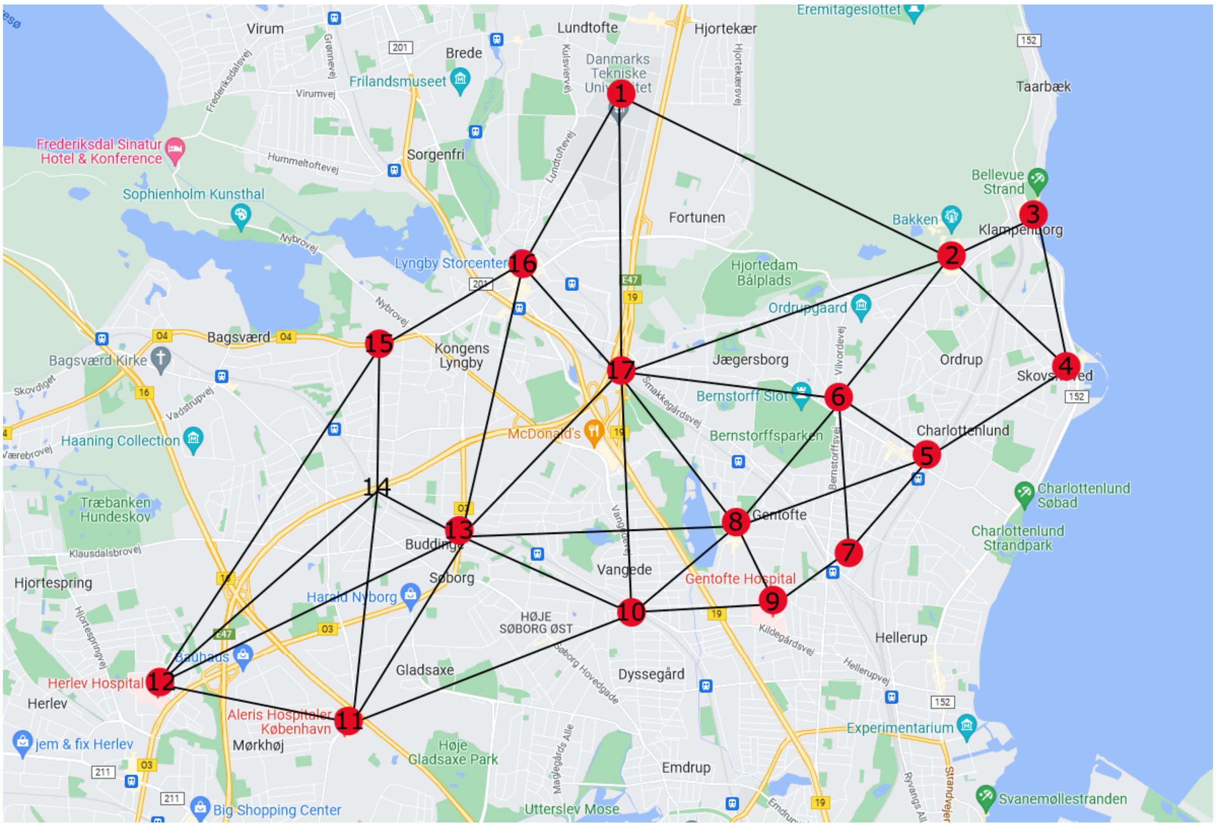


Figure 1: Network of candidate bus-hubs and their possible connections

- Do you think their case study is representative for the Danish setting (or your home countrie's setting)? Can their model be used in practice?
- Do you think their case study results mostly represent an operator or a rider (user, passenger) perspective?
- List the differences between this paper and the project (DTU) problem.
- From a sustainability perspective, in what way does the research contribute to increasing sustainability, and what could be added to increase the potential focus on sustainability?

B On Demand Multimodal Transit System design around DTU

- Formulate the mathematical model for the DTU ODTMS, you can use Auad-Perez and van Hentenryck, 2022, as inspiration
- Implement an Optimization Model for the DTU problem in Julia, using the available data on DTU Learn
- Solve the model, perform a sensitivity analysis on the operating budget (e.g. solving it for different operating budgets).
- Comment on your findings. What would be the best busnetwork design, in your opinion? Motivate your answer.

Hint: 1) additional material has been uploaded where you can easily find examples of other MIP models implemented in julia. This also includes a file that calculates the Euclidean distance between two points. Hint: 2) Where Auad-Perez and Van Hentenryck model every user seperately, you can use one decision variable per OD. The weight is relevant in the objective function.

Part 2 Bike Rebalancing & Rolling Horizon

To Be Announced in the third week of the project.

Part 3 Column Generation Exercise

Answers may be short and to the point.

In this question, consider the Vehicle Routing Problem as described in the lecture.

A General

1. Desrcibe which two main mathematical programming models are at the core of the column generation procedure. Provide the formulation, and indicate the relevant input and output they provide to eachother.
2. Do both problems need to be solved to optimality in each iterayion? Why (not)?
3. In expectation the length of the column generation procedure can be reduced by adding multiple columns in each iteration. This can be done by adding a constraint to the appropriate problem. State to which of the two problems desrcibed in the first task this should be added. Formulate an example of a constraint that can be added to one of the problems in task 1.1 that allows finding multiple columns.

B Subset row cuts

Current optimal MP solution θ for 15 generated routes visiting the 8 customers of a VRP problem with an objective of 29:

Routes:

	r1	r2	r3	r4	r5	r6	r7	r8	r9	r10	r11	r12	r13	r14	r15	
c1	0	0	0	1	1	1	1		0	0	0	0	0	1	0	0
c2	0	0	1	1	1	0	0		0	0	0	0	1	0	1	0
c3	1	0	0	0	1	0	0		0	0	1	0	0	0	1	1
c4	0	0	1	1	0	0	0		0	0	1	1	1	0	1	0
c5	1	0	0	0	0	1	0		0	1	1	0	1	1	0	1
c6	0	1	0	0	0	0	0		1	1	0	0	0	0	0	1
c7	1	0	0	0	0	0	1		1	0	0	0	0	1	0	0
c8	0	1	0	0	0	0	0		1	1	0	0	0	0	0	0
θ	0	0	0	0	$\frac{2}{3}$	$\frac{1}{3}$	0	1	0	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	0	0	0	

1. Can a subset row cut be added for the above solution? If yes, state which one. If not, explain why not.
2. When adding a currently violated subset row cut to the column generation, could you in the next iteration find the same optimal solution for the linear relaxation of the set partitioning formulation of the VRPTW? What about a different solution with the same objective value of 29?