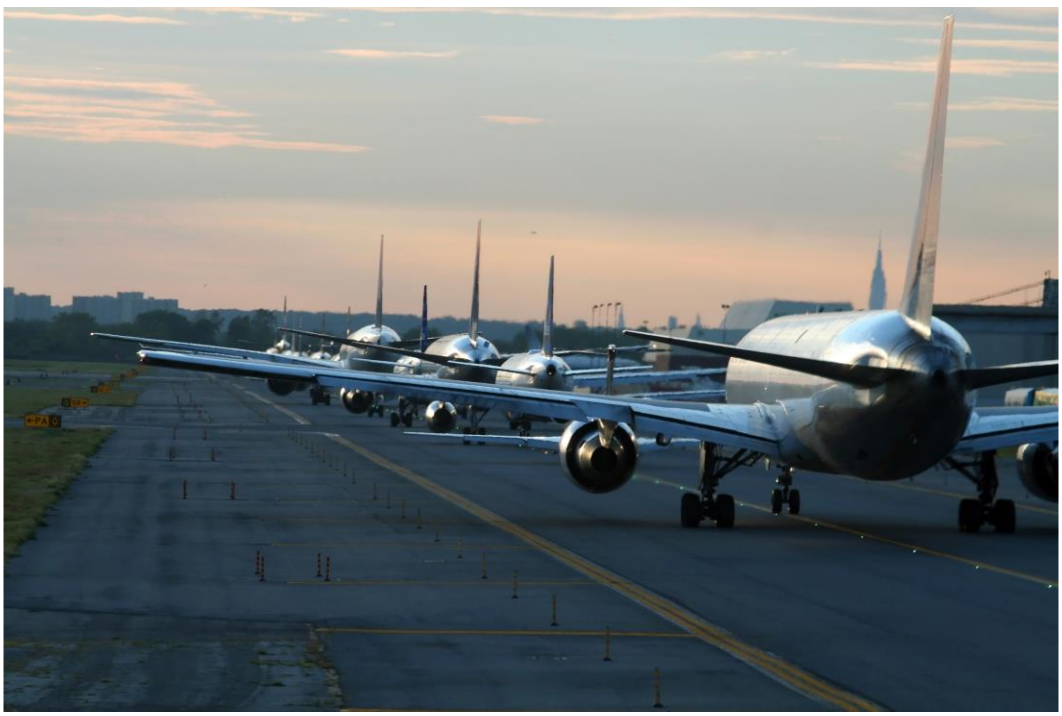
ASSIGNMENT PART 2

AE4423 – Airline Planning & Optimisation



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Introduction

You are a flight analyst for a full-cargo airline, and you are assigned the task of determining the most cost-effective routing strategy of your fleet of full freighters for the next few days. Your goal is to pick up Unit Load Devices (ULDs) and deliver them according to pre-defined release time and due dates, with the option of not transporting some of them (incurring into a monetary penalty) if that is more cost-efficient.

The goal of this assignment is 1) to develop a fully arc-based formulation of the problem and 2) to develop a hybrid arc- and path-based formulation (where ULDs now move along paths that are computed by the model with column generation).

The appendices attached to this assignment contain all the data required to determine the costs etc. for the development of the models.

In particular, the Excel-file *Assignment_Part2_Datasheets.xlsx* contains data on the location of your airports, the set of ULDs (with properties) you need to transport, your fleet composition (with properties), and input data to define the Time-Space Network (TSN).

First read the entire assignment carefully (including the appendices) to extract all information required to adapt the models presented in the lectures!

Problem 3

A. TSN generation

Your commodities (aircraft and ULDs) will move in a TSN in both formulations. The first step of the problem is to properly define the TSN. Given the provided values on time-step, planning horizon, distances between airports, cruise speed, additional Landing and TakeOff (LTO) time, and minimum Turnaround Time (TAT), you will need to define the set of nodes, ground arcs, and flight arcs composing your TSN. To define the flight arcs, check the OD pairs of your instance (in one of the input files), and define flight arcs only for those OD pairs that are specified. Given your fleet's initial and final position requirements, you should also properly define which nodes will serve as source/sink nodes for each fleet type.

Once the TSN is generated, you need to populate it with ULDs. Since ULDs can become available/must be delivered at times that are not necessarily multiple of our time-step, you need to properly define, for each ULD, the right source/sink node with the procedure that was explained in the lecture. In addition, do not forget to add a no-service arc for each ULD to model the possibility of not delivering that ULD.

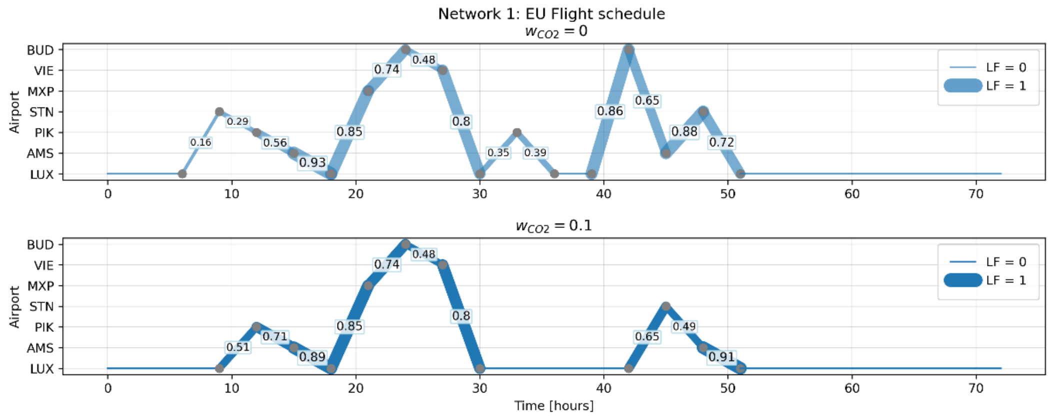
B. Arc-based model

Once your TSN and all the necessary input data are defined, your first task is to define and solve a fleet assignment model that tracks aircraft movements (per fleet type) together with ULDs movements within the TSN

To achieve this goal, you need to:

1. Use the **arc-based mathematical model** discussed in Lecture 7.1 and 7.2 to solve the problem. Go through the formulation again and make sure you fully understand it
2. According to the given model, **set up a computer** model (e.g., in Python or MATLAB using CPLEX or GUROBI, or any other software that you wish to use).
3. With the data available in the Excel file supplied with the assignment and the Appendix, determine the **fleet assignment and routing per fleet type** and the **routing of each ULD** in the optimal solution. One efficient

way to visualize this output is, for example, to plot the solution directly on your TSN (see an example below).



Additional Information

- **Although a real full-cargo network will be used in this assignment, the input data is synthetic, so treat the results accordingly!**
- Since your time-step and planning horizon are given in hours, make sure you are consistent unit-wise when building your TSN and model in general.
- While the **planning horizon for the fleet assignment problem starts at time 0**, some of your ULDs might have a **negative release time**. This means they are available to be transported before the planning horizon starts, but that aircraft are not available yet. Take this into account when defining the proper source node of such ULDs.
- Your optimal solution might result in not all ULDs being transported. There is a trade-off between the penalty incurred when not transporting an ULD and the extra cost this might entail, so depending on the specific instance this case might occur.
- We **do not have more restrictive TAT limitations on ULDs** (e.g., a ULD must stay in a warehouse 8 hours between consecutive flight legs), which might instead occur in real operations.
- **The internal ULD layout** of each aircraft type is assumed **not to be restrictive** to the capacity of the aircraft. That is, the only capacity constraint is the weight capacity of each aircraft.

– To start coding the problem, first create a script that reads/gathers all required input data and performs the required pre-processing to obtain all necessary inputs.

Problem 4

A. Hybrid arc- and path-based model

In this second problem, while fleet assignment does not change and still follows an arc-based formulation, the goal is to model the ULD routing with a path-based perspective as seen in Lecture 7.3. Hence, we want to solve the same overarching problem, but with a different mathematical formulation

To achieve this goal, you need to:

1. Use the **hybrid arc- and path-based mathematical model** discussed in Lecture 7.3 as your **Restricted Master Problem (RMP)**.
2. Given this RMP, identify which constraint sets provide dual values that are needed for the **pricing problem**. Define the pricing problem for each ULD as a **shortest-path problem**, defined as a function of the dual values. The goal is to find a **feasible** path for the current ULD with a **negative reduced cost**. Make sure to include the formulation of the pricing problem (as explained in Lecture 7.3) in your final report.
3. Define the **Column Generation (CG)** algorithm that starts with an initial RMP, solves the pricing problem for each ULD given the duals of the current RMP, and add the resulting new path (column) if beneficial.
4. With the same input data from Problem 3, solve the same instance using the CG algorithm. **It is up to you to decide which initial set of paths per request to include. One option is to just include the no-service arc for each request (which is a path). You can also use some user-defined heuristics to compute some additional initial paths.** Remember that after all the CG iterations, you need to re-instate integrality constraints to have a final solution that is mathematically (and operationally) meaningful.

5. Compare the solution obtained in Problem 4 with the one obtained in Problem 3 and critically discuss why they are different, in case they are different.

Additional Information

- Remember that constraints must ensure the path you are adding is feasible in the pricing problem.

General information

- **Motivate your choices, comment on results, and be critical towards results!**
- Describe the mathematical model, your assumptions, results and KPIs for each of the assignments in detail in a comprehensive report of **no more than 15 pages A4** (excluding cover but including appendixes; font equivalent to Times New Roman – 12 pt., line spacing 1.15 and standard margins). **Note that the report shall not contain any computer code.**
- Use **figures** and **tables** to present your results and KPIs and support your conclusions.
- Submit your report and model script file(s) through **BrightSpace** (assignment folder in our course webpage) at the **latest on Friday 14 January, 18.00 hrs**. Do not forget to include the group number, names, and student IDs in the report (and script file(s)). Do **NOT** submit input (Excel) files. Files submitted by email will not be considered.
- **If you fail to meet the deadline**, 0.5 points will be deducted from your grade for **each day** after the deadline. No excuses will be accepted! Make sure that you work as a group and save the latest versions of your work in multiple places.
- All files uploaded in BrightSpace should be uploaded as **individual files** (i.e., do not compressed as '.zip', '.tar',…) to be subjected to **Ouriginal check**. **If compressed files are uploaded**, 1.0 points will be deducted from your grade.
- **If you fail to obtain a grade of 5.5 or higher you will fail the assignment.** In that case, you will get a chance to improve your work and pass the assignment. Your final grade cannot become higher than 6.0 in that case.
- You should include a separate overview of the **workload distribution** of each group member. Indicate (in percentages) each member's contribution to the three categories **mathematical modelling (30%)**, **programming (50%)** and **reporting (20%)**. Based on this overview you will receive an individualized grade for the assignment. There is a maximum different of 2 points possible between group members. For an example of the format see Appendix F.
- **An assessment matrix** will be available to clarify the grading process.

Appendices

A. TSN input data

For your TSN, consider an initial time equal to **0 hours** and a final time equal to **96 hours**. Hence, the planning horizon is 4 days. Consider a **time-step of 4 hours** when defining your nodes and arcs. Note that in the requests file, release time and due date are given in minutes. Make sure to be consistent and use either minutes or hours to define each time-stamp (it is your choice which unit to use as long as you are consistent).

B. Formula to compute the marginal cost of a flight arc

Given a flight arc f in your TSN, characterized by an origin airport with index i a destination airport with index j, an overall number of airports equal to n, a hour of departure h and a day of departure d, the associated marginal cost is

$$MC_f = 0.05\ \frac{i+j}{2n-1} + 0.15 \sin^2 \frac{2\pi h}{24} + 0.005d\ [\frac{MU}{km*ton}]$$

Note: MU stands for Monetary Unit. Since data is synthetic, we refer to a generic currency

C. Aircraft data

Table 1: Aircraft data

Aircraft type	Full freighter type 1	Full freighter type 2
Aircraft characteristics		
Speed [km/h]	800	800
Payload [ton]	50	40
TAT [h]	2	2
LTO [h]	0.5	0.5
Operational cost [MU/km]	8	6

Note: since the two aircraft types have the same characteristics in terms of speed, TAT, and LTO, you can define flight arcs for your TSN once since the two aircraft types can move in the same way in the TSN

D. Airport data

The data available in the provided Excel-sheet contains, among others, the position of each of the 20 available airports expressed in latitude (φ) and longitude (λ). The distance between two airports i and j can be determined using the following equations:

$$\Delta\sigma_{ij} = 2arcsin\sqrt{sin^2\left(\frac{\varphi_i - \varphi_j}{2}\right) + cos\varphi_i cos\varphi_j sin^2\left(\frac{\lambda_i - \lambda_j}{2}\right)}$$

$$d_{ij} = R_E \Delta\sigma_{ij}$$

where:

1. $\Delta\sigma_{ij}$ is the arc length between airports i and j.
2. $\varphi_i, \varphi_j, \lambda_i$ and λ_j are, respectively, the latitude and longitude for airports i and j.
3. R_E is the radius of the Earth in km; this can be assumed to be 6378 km.

Note that you can use online tools to determine the great circle distance between two locations on the Earth to confirm the correct implementation in your code.

Finally, you can assume there are no restrictions in the number of airport slots you can use.

E. Individual workload

To distinguish between each student's workload in the group, you are required to provide an indication of each group member's workload in three separate disciplines. Provide the workload distribution in a separate file uploaded along with the assignment and follow the template below (or similar).

Student names	Mathematical modelling (30%)	Programming (50%)	Reporting (20%)
Student name #1	# %	# %	# %
Student name #2	# %	# %	# %
Student name #3	# %	# %	# %