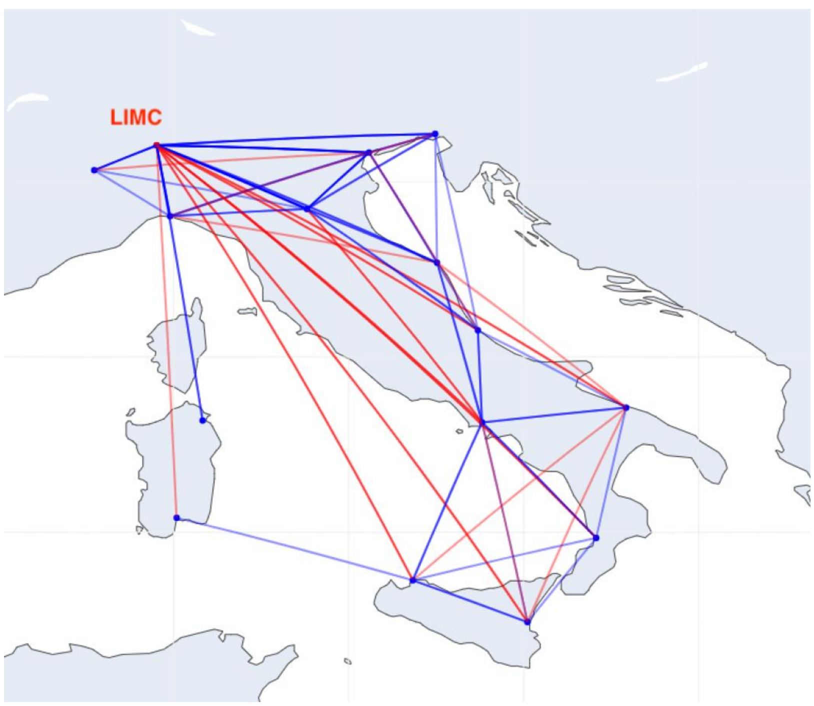
ASSIGNMENT PART 1

AE4423 – Airline Planning & Optimisation



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Introduction

You are working for a new airline company in Europe. The hub of your airline is a large airport in Italy. Apart from your main hub, there are 32 other European and international destinations available to operate flights to.

In this assignment, you will have to address two different case studies referring to 1) the strategic decision framework and 2) to the tactical decision framework. The results of the first part of the assignment are not relevant for the second part.

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

Problem 1

A. Network and fleet development

In the first part of the assignment, your job is to start up operations of your airline, that will start flying in 2030. It is up to you to generate the weekly flight frequency plan for your airline. As the airline is new, you must acquire new aircraft. You have Aircraft 1, 2, and 3 (also shown in Appendix D) as options for your fleet. Thus, you are also asked to determine how many aircraft should be leased to maximize the profit.

To achieve this goal, you need to:

1. Adapt the **leg-based mathematical model** discussed in Lecture 3 to solve the problem. Write it down the formulation on a piece of paper.
2. Setup a **computer model** (e.g., in Python or MATLAB using CPLEX or GUROBI, or any other software that you wish to use) according to the model written on paper.
3. With the data available in the Excel file supplied with the assignment and the Appendix, determine the **network to be operated and the corresponding flight frequency** assuming one standard week of operations. Also determine **how many aircraft of each type** will be leased in the most optimal solution.

Additional Information

- **Although a real network will be used in this assignment, the input data is synthetic, so treat the results accordingly!**
- Carefully check the corresponding **yield** and **load factors** in the appendices.
- You can lease as much aircraft as you desire if this maximizes profit.
- Assume that the aircraft are only available for operations for **10 hours** per day, ensuring sufficient time for maintenance and no operations in periods of the day with very low demand.
- Turn-Around-Times (TAT), including landing and take-off times (LTO), **depend on the aircraft type** and the route operated. To allow for good connections in the hub (first airport in the Airport_info.csv list), it should

be assumed that the TAT for **flights to the hub are 50% longer** than the normal TAT. Typical TATs per aircraft type can be found in Table 1.

- To assist you in the process, the airports data, the distances, and the aircraft data have already been pre-processed.
- In Brightspace, 4 .csv files are provided:
  - *Group_X_Airport_info.csv* contains data on the airports from which you have the right to operate.
  - *Group_X_Demand.csv* contains the weekly demand for Origin-Destination pairs.
  - *Group_X_Distances.csv* contains the the distances between the airports in your network.
  - *Aircraft_info.csv* contains the data from aircraft 1,2,and 3

[*] – X is a place holder for your group number.

Problem 2

In the second part of the assignment your job is to help the airline organize the flight schedule around the hub airport. The objective of the airline is to maximize the fleet allocation contribution (i.e., reduce spillage costs), by assigning aircraft types to scheduled flights in order to better match demand per flight with the number of supplied seats, and to capture the network effects of spillage and recapture. To achieve this goal, you need to use the itinerary-based fleet assignment model (IFAM) discussed during the lectures.

To achieve this goal, you need to use the column generation algorithm discussed during the lectures and follow the steps below:

1. Solve the initial RMP of the problem and give the optimal objective value, the 5 first non-null optimal decision variables associated with the initial passengers itineraries, and the optimal non-null dual variables for the first flights of the schedule.
2. Solve the relaxed IFAM problem. Consider a maximum of 20 iterations (the number of iterations varies per group). Indicate the columns you add to the problem and the optimisation runtime associated with each iteration you run from the column generation algorithm.
3. Consider the IFAM problem with integer decision variables again and solve it with the columns you add. Indicate the final airline cost, the total number of passengers spilled, the first 5 non-null optimal decision variables associated with the initial passengers itineraries and the first 5 non-null variables for the initial flights of the schedule.

Additional Information

- Although a real network will be used in this assignment, the input data is synthetic, so treat the results accordingly!
- In the Excel file provided on Brightspace you find five sheets.
  - The first one refers to your airline's daily flight schedule, which contains, for each flight in the schedule, the flight number, the departure and arrival times, and operating costs for each aircraft type (in €).

- The second sheet presents the set of passenger itineraries, indicating the origin and destination, the demand and the fare (in €) for each itinerary. In addition, the flight or pair of flights used in each itinerary is provided.
- The third sheet presents the passenger itinerary recapture information, presenting the recapture rates for passengers among different itineraries. Consider a recapture rate equal to one for the fictious (spillage) path and desired path. And a recapture rate zero for the other itinerary pairs not presented in this third sheet.
- Finally, the fourth sheet shows the composition of your airline's fleet. It shows, for each aircraft type, how many are available, the number of seats, and the turn-around time in minutes.

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 **Thursday 21th of December, at 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 **Turnitin 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. Revenue

Revenue is generated by transporting passengers. To determine the revenue for Problem 1, yield is expressed in € per Revenue-Passenger-Kilometer (RPK). The following revenue formula is to be used:

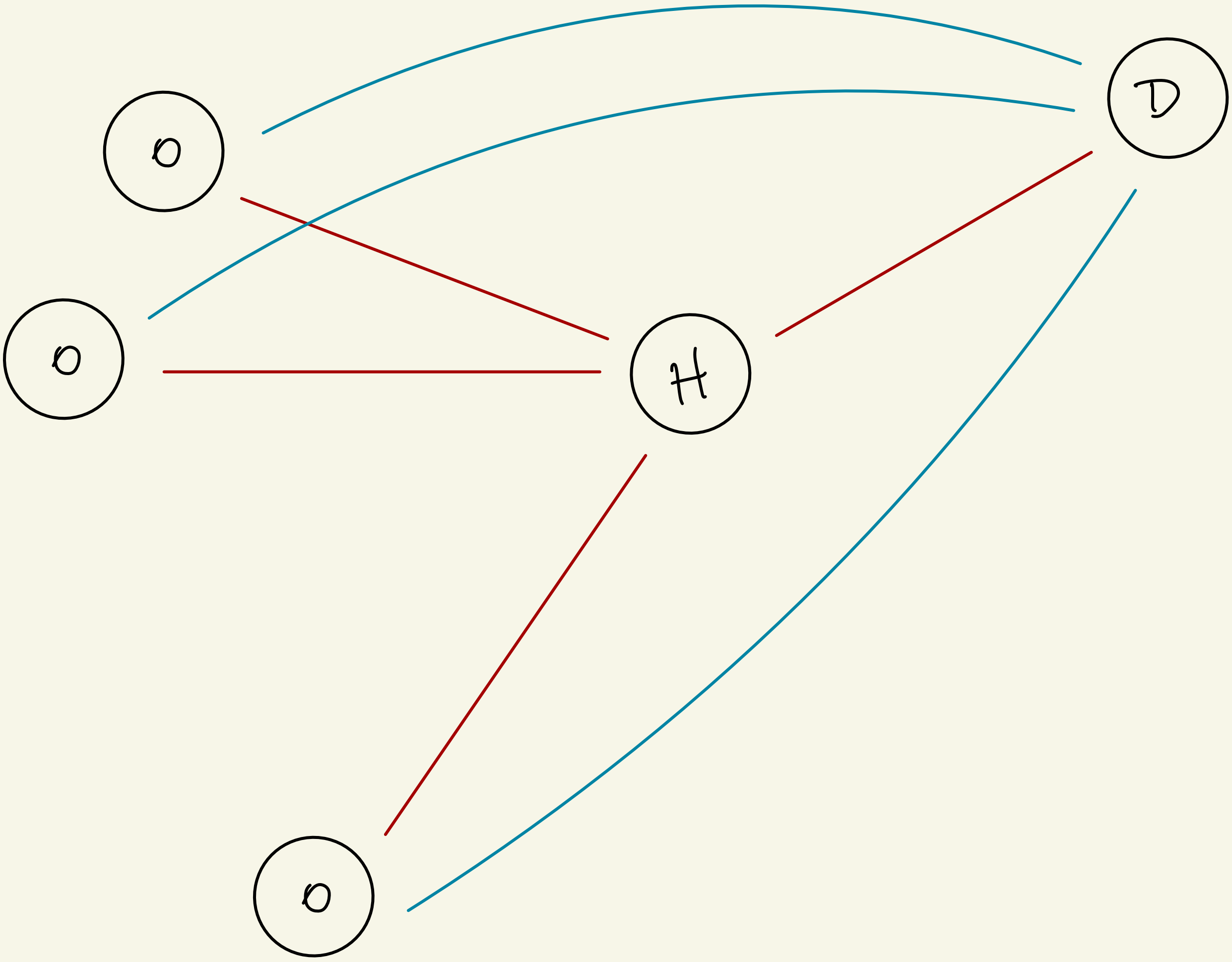
- The yield depends on the distance and can be formulated as follows:

$$Y_{EUR_{i,j}} = 5.9 \cdot d_{ij}^{-0.76} + 0.043$$

where:

- $Y_{EUR_{i,j}}$ is the yield in € between origin i and destination j.
- d_{ij} is the distance in km between origin i and destination j.

Assume that in this case of the revenue generated by passengers connecting at the hub will be 10% lower, to capture a lower willingness from passengers to transfer between flights. Also, consider that in the long term, the average load factor is not higher than 80% of the cabin capacity.



$$Y_{EUR_{i,j}} = 5.9 \cdot d_{ij}^{-0.76} + 0.043$$

B. Costs

Operating your aircraft logically induces costs. For Problem 1 of this assignment, two types of cost need to be considered (all expressed in Euros):

- All aircraft are leased, and therefore a leasing cost needs to be accounted for. The weekly leasing cost is a fixed amount depending on the type of aircraft, and can be found in Appendix D, Table 1.
- Operating costs consist of four components:
  - Fixed operating costs (C_X^k) are costs **per flight leg** and represent costs such as landing rights, parking fees and fixed fuel cost. They depend only on the aircraft type k.
  - Time-based costs (C_T^k) are costs that are defined in € per flight hour and represent time-dependent operating costs such as cabin and flight crew. They depend on the distance of the flight leg and the aircraft type k. Time costs can be defined as follows:

    $$C_{T_{ij}}^k = c_T^k \frac{d_{ij}}{V^k}$$

    where:
    - $C_{T_{ij}}^k$ is the total time cost for a flight leg between airports i and j, operated by aircraft type k.
    - c_T^k is the time cost parameter for aircraft type k.
    - V^k is the airspeed of aircraft type k.
  - Fuel costs ($C_{F_{ij}}^k$) for kerosene powered aircraft, which are dependent on the distance flown and can be expressed as follows:

    $$C_{F_{ij}}^k = \frac{c_F^k \cdot f}{1.5} d_{ij}$$

    where:
    - $C_{F_{ij}}^k$ is the fuel cost for a flight leg between airports i and j, operated by aircraft type k.
    - c_F^k is the fuel cost parameter for aircraft type k, expressed in gallon per kilometer.
    - f is the fuel cost, equal to 1.42 USD/gallon in 2020. (Conversion to € already accounted for in the formula)

The total operating cost for a flight leg between airports i and j, operated by aircraft type k can then be expressed as:

$$C_{ij}^{k} = C_{X}^{k} + C_{T_{ij}}^{k} + \left(C_{F_{ij}}^{k}\right)$$

The required parameters to determine the operating costs can be found in Table 1.

It should be noted that for flights departing or arriving at your hub airport the operating costs can be assumed to be 30% lower due to economies of scale (this includes fixed operating costs, time-based costs, and fuel costs)

C. Airport data

The data available in the provided *.csv*-sheet contains, among others, the position of each of the 15 available airports expressed in latitude (φ) and longitude (λ). The distance between two airports i and j was 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 6371 km.

Note that you can use online tools to check the great circle distance between two locations on the Earth to confirm the data provided in *Group_X_Distances.csv*.

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

D. Aircraft data

You have the choice to operate any of the four aircraft defined in Table 1.

Table 1: Aircraft data

Aircraft type	Aircraft 1: Regional jet	Aircraft 2: Single aisle twin engine jet	Aircraft 43 Twin aisle, twin engine jet
Aircraft characteristics			
Speed [km/h]	820	850	870
Seats	70	165	320
Average TAT [mins]	35	45	60
Maximum range [km]	3,300	6,300	12,000
Runway required [m]	1,600	1,800	2,600
Cost			
Weekly lease cost [€]	34,000	70,000	180,000
Fixed operating cost C_X [€]	600	1250	2000
Time cost parameter C_T [€/hr.]	775	1400	2800
Fuel cost parameter C_F[gallon/km]	2.0	3.75	7.0

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	# %	# %	# %