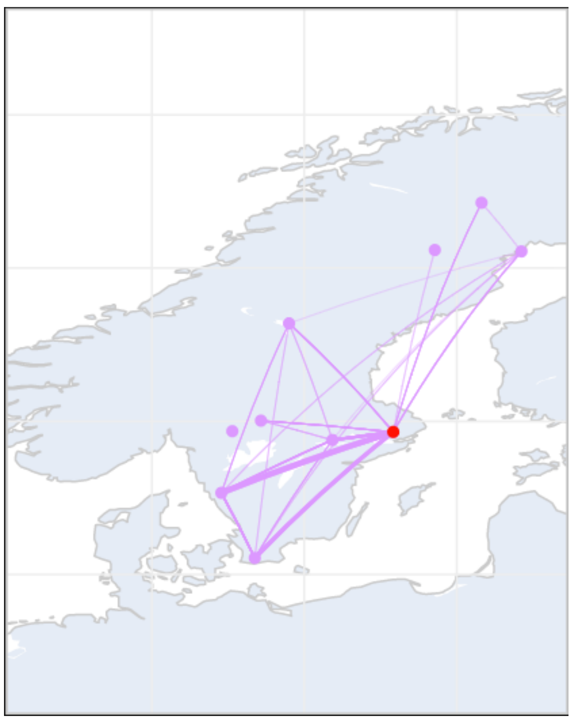
ASSIGNMENT PART 1

AE4423 – Airline Planning & Optimisation



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Introduction

You have recently started a new regional airline company in Italy. The hub of your airline is a large airport in Italy. Apart from your main hub, there are 14 other Italian destinations available to operate flights to.

The goal of this assignment is 1) to develop a network and fleet plan for direct flights only and 2) to develop a network and fleet plan including routes.

The appendices attached to this assignment contain all the data required to determine the revenue, cost, etc. for the development of the network and fleet plans.

In particular, the .csv-files *Group_X_Airport_info.csv, Group_X_Annual_growth.csv, Group_X_Demand.csv, Group_X_Distances.csv, Aircraft_info.csv [*]* contain data on the airports from which you have the right to operate and the respective population and GDP data of the regions, the value of expected annual growth, the weekly demand for some Origin-Destination pairs in Italy, the distances between the airports in your network, and the aircraft data respectively. Your hub is the first in the *Airport_info.csv* list.

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

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

Problem 1

A. Demand forecast

In the first part of the assignment, your job is to start up operations of your airline, that will start flying in 2030. Unfortunately, your airline does not possess any demand data but only population data from 2020 and demand for 10 airports in the Italian network. These airports are not the same as your network, so the demand for your network in the year 2030 should be calculated. The demand for each OD-pair can be calculated by using the following gravity model:

$$D_{ij} = k\frac{\left(pop_i pop_j\right)^{b1}\left(GDP_i GDP_j\right)^{b2}}{\left(f \cdot d_{ij}\right)^{b3}}$$

Where:

D_{ij} is the demand between airports i and j

pop_i, pop_j, are respectively the population in the region of airports i and j

GDP_i GDP_j, are respectively the GDP in the region of airports i and j

f is the fuel cost, which is assumed to remain constant between 2020 and 2030 [USD/gallon]

d_{ij} is the distance between airports i and j.

To achieve this goal, you need to:

1. Calibrate the gravity model (find scaling factor k and coefficients $b1$, $b2$ and $b3$) using the 2020 demand values that are given in data file *Group_X_Demand.csv.*
   a. Tip 1: apply logarithms to linearize the gravity model.
   b. Tip 2: use ordinary least squares to obtain the best fit for the resulting linear formula. You can do this using Excel, Python or Matlab toolboxes, or any statistics software.
2. Forecast the population for 2030, based on the data for 2020 and the annual growth per region given in the Excel. The GDP is considered constant in time.
3. Generate the future demand for your network using the calibrate gravity model and the estimated values for the population.

B. Network & fleet development

Equipped with accurate demand data, 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 from *Aircraft_info.csv* (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 Italian network will be used in this assignment, the input data is synthetic, so treat the results accordingly!**
- This problem only deals with **regional** flights and passengers. 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. *block time = 70 hours/week*
- 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.

Problem 2

Regional network development including electric aircraft

Given its environmental goals, the airline is considering the option of operating electric aircraft (Aircraft 4 and 5, in Appendix D or *Aircraft_info.csv*). A charging station would be located at the hub airport. Therefore, to explore the batteries of the electric aircraft and capture demand from low demand markets, the airline is also considering operating triangular routes, in which the aircraft will fly to two airports before returning to the hub airport. For both kerosene and electric aircraft.

In this question you are asked to solve the network and fleet development problem including routes and this new electric aircraft.

To achieve this goal, you need to:

1. Generate the route matrices, including all possible routes to be operated with all aircraft types.
2. Adapt the **route-based mathematical model** discussed in Lecture 4 (in the classroom) to solve the problem. Write it down the formulation on a piece of paper.
3. Setup a new **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.
4. With the same input data from problem 1, 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.
5. Compare the results with the results from Problem 1 and comment on the best strategy for the airline.

Additional Information

- You can lease as many aircraft as you desire if this maximizes profit.
- Aircraft can only be refueled/recharged at the hub airport.
- All routes should start and end at the hub airport and not have more than 3 airports.

- 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.
- To start coding the problem, first create a script that reads/gathers all required input data and performs the additional required pre-processing to obtain yield, costs etc.
- Create a script to generate the possible routes that you have to consider in your network mathematical model.

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 22nd 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.

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)

- Energy costs ($C^k_{E_{ij}}$) for electric aircraft. This is dependent on the battery capacity of the aircraft, the distance flown and the range of the aircraft. It can be expressed as follows:

$$C^k_{E_{ij}} = e \cdot G^k \frac{d_{ij}}{R^k}$$

  where:
    - $C^k_{E_{ij}}$ is the energy costs to recharge the batteries for a flight between airports i and j, operated by aircraft type k
    - e is the price of energy, assumed to be 0.07 €/kWh
    - G^k is the energy in a fully recharged aircraft type k
    - R^k is the range of aircraft type k.

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

$$C^k_{ij} = C^k_X + C^k_{T_{ij}} + \left(C^k_{F_{ij}} + C^k_{E_{ij}}\right)$$

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, but not the energy costs).

C. Airport data *Already implemented for the distance 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 tuboprop	Aircraft 2: Regional jet	Aircraft 3: Single aisle twin engine jet	Aircraft 4: Electric twinprop aircraft	Aircraft 5: Electric regional aircraft
Aircraft characteristics					
Speed [km/h]	550	820	850	350	480
Seats	45	70	150	20	48
Average TAT [mins]	25	35	45	20	25
Additional charging time[1] [mins]	--	--	--	20	45
Maximum range [km]	1,500	3,300	6,300	400	1,000
Runway required [m]	1,400	1,600	1,800	750	950
Cost					
Weekly lease cost [€]	15,000	34,000	80,000	12,000	22,000
Fixed operating cost C_X [€]	300	600	1250	90	120
Time cost parameter C_T [€/hr.]	750	775	1400	750	750
Fuel cost parameter C_F[gallon/km]	1.0	2.0	3.75	--	--
Batteries energy G^k[kWh]	--	--	--	2130	8216

[1]This time has to be added to the 'Average TAT' to obtain the necessary TAT of the aircraft. The 50% increase in TAT at the hub is not applicable for electric aircraft.

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	# %	# %	# %