Assignment 1

AE4423 – Airline Planning & Optimisation 2025/2026

Deadline: **17h, 21st December 2025**

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

For each problem, describe the mathematical model, your assumptions, results, and KPIs for each of the assignments in detail in a comprehensive report. Use figures and tables to present your results and KPIs and support your conclusions.

The report shall not contain any computer **code**. Add your Python code in BrightSpace as a zip file. Make sure that it is clear and well commented.

Submit your report and model script file(s) through BrightSpace at the latest on December 21st, 17h. The report should have no more than **15 pages A4**. Note that the report shall not contain any computer code. Don't forget to include the group number, names, and student IDs in the report and script file(s). 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 past the deadline.

Minimum 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 5.5 in that case.

Grading of the report is:

- 30% - Mathematical modeling. Correct declaration of objectives and constraints.
- 50% - Programming logic. Correct logic of the simulation. The simulation answers the question.
- 20% - Reporting. Clear report with proper conclusions. Proper use of use figures and tables to present the results.

Contents

Introduction

You have recently started a new airline company in Europe, with a hub-and-spoke model. Apart from your main hub, there are 19 other European destinations available to operate flights to. The goal of the first assignment is to develop a network and frequency plan for your airline to grow out to be a successful airline in the coming years. The second assignment will create a plan for passenger mix flow for planned itineraries.

The appendices attached to this assignment contain all the data regarding the revenue, cost, airport, and aircraft data. Furthermore, the file *AE4423Data1.zip* contains data on the available airports, the demand for each Origin-Destination pair, and population and GDP data for the different cities and countries, to be used for questions 1A and 1B. Zip file *AE4423Datat2.zip* contains information on flights, itineraries, and recapture possibilities for question 2.

For all questions, deliver the mathematical models, and explanations in a written report. The Python/Gurobi files are to be sent together with the report in a zip file.

Question 1A - Demand Forecast

Your job is to start up operations for your airline. In your first year, your home country only has Air Services Agreement (ASAs) with other European countries. The ASAs within Europe allow up to the 9th Freedom of the Air. Unfortunately, the demand data that your airline possesses originates in 2021 (in file *DemandGroupX.xlsx*) and is thus outdated. Also, the most recent GDP (per capita) and Population data is from 2024 (in file *pop.xlsx*). It is up to you to **forecast the demand for 2026**.

This can be done by using the following gravity model:

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

where:

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

2. pop_i, pop_j, GDP_i, GDP_j are, respectively, the population and GDP for airports i and j.
   (Use the population and GDP values in file pop.xlsx for 2021 and 2024.)

3. f is the fuel cost, which is assumed to remain constant between 2024 and 2026.
   (Check Appendix B.)

4. d_{ij} is the distance between airports i and j in km.
   (Use the latitude and longitudes values in file DemandGroupX.xlsx to calculate these distances. Check Appendix C for more information.)

To achieve this goal, you need to:

1. Calibrate the gravity model (find the scaling factor k and the coefficients $b1$, $b2$, and $b3$) using the 2021 GDP and population data from the file *pop.xlsx*.

   (a) Tip 1: apply **logarithms** to linearize the model.
   (b) Tip 2: use **ordinary least squares** to obtain the best fit for the resulting linear formula.

   Print a **graph** of the real demand data for 2021 compared with the estimated demand values (that you get with the linear optimisation for 2021) to confirm your results.

2. Forecast the population and GDP for 2026, based on the data for 2021 and 2024. Consider a **constant annual growth**.

3. Generate the future demand for 2026.

Question 1B - Network & Fleet Development

Equipped with demand data, it is up to you to generate the weekly **flight frequency plan** for your new airline. As the airline is new, they have to acquire new aircraft. You have the options of the four aircraft shown in *AircraftData.xlsx* for your fleet. Thus, you must 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. First, write down the formulation.

2. Setup a **computer model** using Python and GUROBI.

3. With the data available in the files supplied with the assignment and the Appendices, 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:

- All flights start or end at the **hub**.

- Carefully check the corresponding **yield** and **load factors** in *Appendix A*.

- You may **lease** as much aircraft as you desire if this maximizes profit.

- Assume the **operating costs** in *Appendix B*.

- 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.

- Pay close attention to the **range** and **runway requirements** of each aircraft type in *AircraftData.xlsx*.

- 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, 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 *AircraftData.xlsx*.

- Consider the **maximum number of slots available** for landing per airport. This information is available in file *DemandGroupX.xlsx*.

Question 2 - Passenger Mix Flow

Assume that your airline has now a daily flight schedule and you want to study the best **passenger mix flow** in your network, in order to maximize your revenue. The objective of the airline is to identify the best mix of passengers from each itinerary to carry on each flight leg. This problem is to be optimized only for the single day of operations presented in the data sheets. The airline is considering spill costs and recapture opportunities. Capacity constraints per flight leg and limited unconstrained demand per itinerary need to be verified.

Consider the values given in the file *GroupX.xlsx* for question 2. You will find three sheets:

Sheet 1: Refers to the airline's daily flight schedule. The flight number, flight capacity, and the departure times for each flight in the schedule are given.

Sheet 2: Presents a set of passenger itineraries, indicating the origin and destination, the demand, and the fare for each itinerary. In addition, the flight or the pair of flights used in each itinerary is provided.

Sheet 3: Presents the passenger itinerary recapture information, presenting the recapture rates for passengers among different itineraries. Consider a recapture rate equal to zero for itinerary pairs not presented in this sheet.

To achieve this goal, you need to:

1. Adapt the leg-based mathematical model discussed in *Lecture 4* to solve the problem. First, write down the formulation.

2. Setup a computer model using Python and GUROBI.

3. Solve the passenger mix problem to the end. Indicate the optimal airline cost, the total number of passengers spilled, the optimal decision variables associated with the first 5 passengers itineraries and the optimal dual variables for the first 5 flights of the schedule. Provide also information regarding the number of columns in the RMP before and after running the column generation algorithm, the number of iterations required to converge, and the total optimization runtime.

4. Solve also the Keypath problem, and compare the final solution and computational time.

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:

- For intra-European passengers, **yield** depends on distance:

$$Y_{EUR_{i,j}} = 5.9 \dot{d}_{ij}^{-0.76} + 0.043$$

  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.

In order to develop a profitable network, fleet and frequency plan, the average load factor needs to be estimated. Assume a **load factor** of 75%.

B - Costs

For this assignment, two types of cost need to be taken into account:

- 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*.

- **Operating costs** consist of three 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.
    * d_{ij} is the distance in km between origin i and destination j.
    * V_k is the airspeed of aircraft type k.
  - **Fuel costs** C_F^k are dependent on the distance flown, and can be expressed as follows:

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

  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.
    * f is the fuel cost, equal to 1.42 EUR/gallon.
    * d_{ij} is the distance in km between origin i and destination j.

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

$$C_{ij}^k = C_X^k + C_{T_{ij}}^k + C_{F_{ij}}^k$$

For flights departing or arriving at your **hub** airport all 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 provided includes the position of several airports expressed in latitude (φ) and longitude (λ). The **distance** between two airports i and j can be determined using the following equations:

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

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

where:

- $\triangle\sigma_{ij}$ the arc length between airports i and j.

- φ_i, φ_j, λ_i and λ_j are, respectively, the latitude and longitude for airports i and j.

- R_E the radius of the Earth in km, which can be assumed to be 6371 km.

Note that you may also choose to use online tools to determine the great circle distance between two locations on the Earth.