Assignment 1

AE4423 – Airline Planning & Optimisation 2024/2025

Deadline: **17h, 20th December 2024**

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 20th, 17h. 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.

Individual Workload: To distinguish between workload in the group, provide an indication of each member's workload in three separate disciplines. This workload distribution should be in a separate file uploaded along with the assignment. Follow the template below.

Student Name & Number	Mathematical Modelling	Programming	Reporting
Name & Number #1	#%	#%	#%
Name & Number #2	#%	#%	#%
Name & Number #3	#%	#%	#%

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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 of your airline. In your starting 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 origins from 2020 (in file *DemandGroupX.xlsx*) and is thus outdated. Also, the most recent GDP and Population data is from 2023 (in file *pop.xlsx*). It is up to you to **forecast the demand for 2025**.

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 2020 and 2023.)
3. f is the fuel cost, which is assumed to remain constant between 2023 and 2025.
   (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 scaling factor k and coefficients $b1$, $b2$, and $b3$) using the 2020 GDP and population data from 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 of 2020 compared with the estimated demand values (that you get with the linear optimization for 2020) to confirm your results.
2. Forecast the population and GDP for 2025, based on the data for 2020 and 2023. Consider a **constant annual growth**.
3. Generate the future demand for 2025.

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 *Appendix D* 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:

- 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 careful attention to the **range** and **runway requirements** of each aircraft type in *Appendix D*.
- 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 *Appendix D*.

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 initial **Restricted Master Problem (RMP)** of this problem and give the optimal objective value, the optimal decision variables associated with the first 5 passengers itineraries and the optimal dual variables for the first 5 flights of the schedule.

4. 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.

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:

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

  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:

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

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 chose to use online tools to determine the great circle distance between two locations on the Earth.

D - Aircraft Data

You have the choice to operate any of the four aircraft defined in the table below.

Aircraft Type	**Aircraft 1** Regional turboprop	**Aircraft 2** Regional jet	**Aircraft 3** Single aisle, twin engine jet	**Aircraft 4** Twin aisle, twin engine jet
Aircraft Characteristics				
Speed [km/h]	550	820	850	870
Seats	45	70	150	320
Average TAT [mins]	25	35	45	60
Maximum range [km]	1,500	3,300	6,300	12,000
Runway required [m]	1,400	1,600	1,800	2,600
Cost				
Weekly lease cost [€]	15,000	34,000	80,000	190,000
Fixed operating cost C_X [€]	300	600	1250	2000
Time cost parameter C_T [€/hr]	750	775	1400	2800
Fuel cost parameter C_F	1.0	2.0	3.75	9.0