AE4423 Assignment 2

Central Connect Airways: New Cargo division
Group 26

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Contents

Nomenclature

Symbols

Symbol	Description
a_{ij}	Range constraint compliance matrix.
AC^k	Number of aircraft of type k in the fleet.
b_{ij}	Runway constraint compliance matrix.
C_T, C_T, C_F	Fixed, time dependant and fuel operational costs.
d_i	Distance traveled in flight i.
f	The current flight that is considered.
f_{fuel}	The fuel cost in [MU/gallon].
F	The set of flights that are performed.
I	Index set for departure airports 1, 2, ..., |I|
J	Index set for arrival airports 1, 2, ..., |J|
k	Index set for aircraft types 0, 1, 2
L^k	Lease cost of aicraft type k.
w_i, w_f	Amount of cargo that is present in a flight.
V^k	Speed or velocity of aicraft of type k.
t	timestep of six minutes within 120 hour timeframe.
z_{ij}	Number of flights for each aircraft type travelling from airport i to airport j.

Acronyms

Symbol	Description
A/C	Aircraft.
CATK	Operating cost per available tonne kilometer.
ETA	Estimated time of arrival.
ETD	Estimated time of departure.
IATA	International Air Transport Association.
KPI	Key performance indicator.
LF	Load factor of aircraft.
LTO	Landing and take-off time, i.e. Turn around time.

1
Introduction

Central Connect wants to expand its business to cargo transportation. The company has already found out the demand between various European cities, and has decided only to operate hub-to-spoke services. Furthermore, the company already has a small fleet of second-hand aircraft available for cargo operations, and wants to find out the most profitable schedules to operate[2].

Therefore, the goal of this report is to develop the most profitable schedules and make sure none of these operate at a net loss. Since iterating in a classical approach over all possible routes requires too much calculation power, the problem is solved by dynamic programming using a greedy model, as introduced in lectures[4].

Together with this introduction, the report is structured into 3 chapters. The second chapter, chapter 2 explains which assumptions have been made, the mathematical model used and how the dynamic programming has been applied. Chapter 3 gives the resulting schedule and analysis of the key performance indicators (KPIs), followed by a discussion of the results.

2
Numerical Model

In this chapter, the methodology for modelling the aircraft routing problem is described. First, the assumption made while making the model are described in Section 2.1. Then, the mathematical formulation of the problem is portrayed, including its constraints. Next, the dynamic aspect of this model is elaborated upon in Section 2.3. Finally, a pseudo code representing the python script for running the model is also found in this section.

2.1. Assumptions

The model in this report is based on a real-world routing problem. However, several simplifications are made to constrain the scope of the model. The assumption are listed and discussed below. Apart from modelling simplifications, deliberate constraints are placed on the problem. These are discussed in the next section together with the mathematical model.

- **Demand is static.** Unlike in the real world, the demand used to model this routing problem is considered static within the 4-hour bins. In reality, this would be an ever-changing entity. Therefore, in reality this would have to be optimized for a smaller time window, or this demand change has to be mitigated in another way.

- **No competition.** In accordance with the previous assumption, competing airlines are excluded from the model. As such, the demand only changes from the static demand table by our airline's own doing. In reality, competing airlines could reduce our demand matrix also. This would likely reduce potential profits. To account for this in reality, the demand could be estimated in smaller bins, or perhaps updated continuously. Moreover, it is not uncommon to account for this while predicting future demands, as it is a more or less seasonal feature.

- **No cargo classes.** It is assumed that all cargo can be taken by all aircraft types. Moreover, the capacity of all aircraft types is not divided into classes. In reality, an aircraft might, for example, have a limit on how much fragile, or explosive cargo it can take. This could again be addressed by using a more detailed demand input matrix.

- **Single scenario for a static future.** The model is optimized on a single 120-hour data frame. This however is an example of overfitting, as the current 120 hour optimal flight schedule is likely different from the next. To account for this, the model would need to be optimized every 120-hours, using new input. Even better would be to update the schedule continuously in a smart way.

- **No unforeseen costs.** Costs other than operation costs are not considered in this modelling assignment. In reality there would be more costs like, for example, scheduled, unscheduled maintenance and insurance costs.

- **No multi-hub network.** The model is constraint to a single hub and 19 closely surrounding airports. In reality, there could be more hubs and likely more airports. These airports could also be spread more, including long haul flights.

- **No spoke to spoke routes.** An important simplification is that all cargo passes through the hub airport. In other words, there are no flights between two airports which are not the hub airport. In reality, a more complex schedule could be applied where such flights are also an option.

- **Flight time is constant.** The flight times between airports are taken as a single static value, equivalent in both directions. In reality this value can be time varying, as well as be subject to irregular change. For example if the gates are not open yet, and the aircraft has to loiter for a while before landing.

- **No cost on ground.** Costs are assumed to be zero once an aircraft has landed. This means it is assumed airports will not charge any costs for having aircraft parked, nor handling or landing fees, and employees are not paid, nor hotel costs have to be paid, during overnights. Airport costs can easily be added to the cost matrix once they are known, without need to alter the model. Crew costs are normally solved separately[3], since crew can change aircraft, hence it is nearly impossible to solve the crew pairing simultaneously.

2.2. Mathematical Model

The objective is to maximize the profit at the hub airport Paris at time zero, i.e. the final time step in the model. The profit is computed by summing the yield of all flights in the schedule and reducing this by the operation costs of the scheduled flights, as shown in Equation 2.1. Where $Yield_R = 0.26$€ per RTK, Revenue-Ton-Kilometer.

$$\text{Max Profit} = \sum_{i \in R} \left[\text{Yield}_R \times d_i \times w_i - \sum_{k \in K} \left(CATK^k \times d_i \right) \right] \tag{2.1}$$

From here, the model is constraint in several ways. First of all, the cargo taken on board of aircraft has to be smaller than the demand that is available, as well as the capacity of the aircraft. This holds for all aircraft in the fleet, and all flight in the schedule. This is shown by Equation 2.2 and 2.3, respectively.

$$w_f^k \leq q_f \quad , \forall f \in F, k \in K \tag{2.2}$$

$$w_f^k \leq CP_f \quad , \forall f \in F, k \in K \tag{2.3}$$

Next, all aircraft in the fleet begin at the hub airport and should end there in the end again. In other words, all airports have an equal amount of in-going and out-going flights. This is indicated by Equation 2.4.

$$\sum_{j \in N} z_{ij}^k = \sum_{j \in N} z_{ji}^k, \forall i \in N, k \in \boldsymbol{K} \tag{2.4}$$

Next, all aircraft are constraint to only perform a single flight at all times, shown in Equation 2.5.

$$\sum_{f \in F} f^k \leq 1, \forall k \in K, t \in T \tag{2.5}$$

Lastly, the model is constraint to only allow flights if the distance of the flight is lower than the range of the aircraft that has to perform the flight. Moreover, the runway of the arrival and destination airports has to be longer than the required runway length for the aircraft. In both cases, a cost penalty is used to ensure the model accounts for this. Namely, if either one is not true, a big penalty is added, making the option very unfavorable. These are shown in Equation 2.6 and 2.7, respectively.

$$z_{ij}^k \leq a_{ij}^k \quad \rightarrow a_{ij}^k = \begin{cases} 10000 & \text{if } d_{ij} \leq R^k \\ 0 & \text{otherwise} \end{cases} \quad \forall i, j \in N, \forall k \in K \tag{2.6}$$

$$z_{ij}^k \leq b_{ij}^k \quad \rightarrow b_{ij}^k = \begin{cases} 10000 & \text{if } RW_{ij} \leq RW_{req}^k \\ 0 & \text{otherwise} \end{cases} \quad \forall i, j \in N, \forall k \in K \tag{2.7}$$

Operating costs

The operating cost by which the objective function is reduced is calculated in three parts. To start, the landing costs, parking fees and fixed fuel costs are captured by C_X^k, which are shown in Table 2.1. Next, the cost that are dependant on time, like cabin and crew wages, are estimated by Equation 2.9. Lastly, the costs that are dependant on distance, e.g. fuel costs, are captured by Equation 2.9. These three costs are then summed up and form the total operating costs, as shown in Equation 2.10. Apart from this, the lease costs of the aircraft are also subtracted separately from the objective function [2].

$$C_{T_{ij}}^k = c_T^k \frac{d_{ij}}{V^k} \tag{2.8}$$

$$C_{F_{ij}}^k = \frac{c_F^k \cdot f_{fuel}}{1.5} d_{ij} \tag{2.9}$$

$$C_{ij}^k = C_X^k + C_{T_{ij}}^k + C_{F_{ij}}^k = CATK^k \times d_{ij} \times s^k \tag{2.10}$$

Aircraft Types & Fleet

Finally, the parameter K represents the subset of aircraft in the fleet. This fleet is in the end chosen by the optimizer, which has the ability to choose from the four aircraft types indicated in Table 2.1. Moreover, it is allowed to choose multiple aircraft of the same type, of course bounded by the previously mentioned constraints.

Table 2.1: Aircraft type characteristics [2]

Aircraft type	Aircraft 1: Small freighter	Aircraft 2: Mid-size old freighter	Aircraft 3: Large freighter
Aircraft characteristics			
Speed [km/h]	800	850	920
Cargo Capacity [Tonnes kg]	23	35	120
Average TAT [mins]	90	120	150
Maximum range [km]	1,500	3,300	6,300
Runway required [m]	1,400	1,600	1,800
Cost			
Lease cost [€]	2,143	4,857	11,429
Fixed operating cost C_x [€]	750	1,500	3,425
Time cost parameter C_T [€/hr.]	1,875	1,938	3,500
Fuel cost parameter C_f	2.5	5.0	9.5
Fleet			
Amount in fleet	2	2	1

Data: Pre-process data into cost, demand and yield matrices
while *Potentially profitable fleet is available* **do**
  for *available aircraft type* ***in*** *fleet* **do**
    for *timestep* ***in*** *time period* **do**
      Compute potential profit for flights from all airports;
    end
    Select optimal flight route;
    return *optimal profit for current aircraft type.*
  end
  Select aircraft and its optimal flight route;
  Reduce the demand matrix;
end
Result: Return flight schedule for all selected aircraft

Algorithm 1: Pseudo Code Dynamic Approach to Routing Problem

2.3. Dynamic Programming & Pseudo Code

In order to find an optimal flight schedule for the available demand, a dynamic programming approach is taken. In other words, a script recursively seeks for profitable flights to add to the flight schedule. In the same sense, it recursively seeks what type of aircraft and in which amount is, if at all, most profitable to utilize.

In more detail, Figure 2.1 shows a representation of the process of seeking the optimal flight schedule for a single aircraft. First, the orange arrow is followed, starting from the last node, or time-step. Then the potential profit is computed for every step in the past. Note that every flight is connected to the hub in a hub-spoke network. Subsequently, in the direction of the purple arrow, the optimal route is chosen which in turn maximizes profit. Note that in the complete model, this is done using 1200 time steps and 20 airports. This process is executed for every aircraft type, the best of the three is chosen, if available, and then the process is repeated as shown in the pseudo-code represented in Algorithm 1.

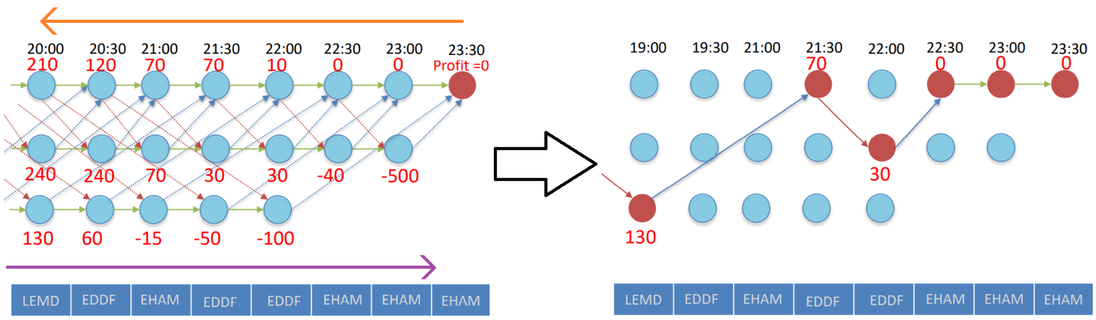

Figure 2.1: Dynamic programming approach [4]

3
Results

After the dynamic programming model from chapter 2 is developed, a flight schedule and a route network for the cargo division of Central Connect Airways can be determined. In this chapter, the resulting flight schedule and routing network are presented with relevant KPIs.

3.1. Flight Schedule

Now that the objective function and all the constraints have been defined, the network and fleet model can be modelled and solved numerically. Using the dynamic programming approach, an optimal solution was found to be a total operating profit of €50296.22 for every 5 days (120 hours) of operation. A detailed build-up of the underlying revenue and expenses are presented in section 3.3. In Table 3.1 up to Table 3.3, the flight schedules for the first three aircraft are shown. First of all, it is observed that the first aircraft contributes an ample amount of 84% to the total profit. This is caused mainly by the high LF and the amount of flights. Secondly, the amount of flights of the large freighter differs significantly with that of the mid-sized freighter. Which can be explained by the high demand between CDG-MAD and CDG-AMS already captured by the large freighter, for a lower cost per kilometer.

Table 3.1: Flight schedule A/C#1

Freighter 1: Type 3 Large Freighter						
Day	**ETD**	**ETA**	**Route**	**Cargo [kg]**	**LF**	**Profit [€]**
1	23:30	01:12	CDG-MAD	120000	1	14714.53
2	03:42	05:24	MAD-CDG	72774.15	0.61	1643.66
2	07:54	08:54	CDG-AMS	120000	1	2454.09
2	20:54	21:54	AMS-CDG	120000	1	2454.09
3	00:24	01:24	CDG-AMS	120000	1	2454.09
3	03:54	04:54	AMS-CDG	120000	1	2454.09
4	03:54	05:36	CDG-MAD	120000	1	14714.53
5	07:54	09:36	MAD-CDG	71528.52	0.6	1298.9
Aircraft Operating Profit [€]						**42187.97**

Table 3.2: Flight schedule A/C#2

Freighter 2: Type 2 Mid-Size Old Freighter						
Day	**ETD**	**ETA**	**Route**	**Cargo [kg]**	**LF**	**Profit [€]**
2	23:54	03:18	CDG-HER	35000	1	2517.81
4	07:54	11:18	HER-CDG	35000	1	2517.81
4	23:54	02:42	CDG-HEL	35000	1	1486.4
5	07:54	10:42	HEL-CDG	32490.17	0.93	249.44
Aircraft Operating Profit [€]						**6771.46**

Table 3.3: Flight schedule A/C#3

Freighter 3: Type 2 Mid-Size Old Freighter						
Day	**ETD**	**ETA**	**Route**	**Cargo [kg]**	**LF**	**Profit [€]**
4	07:54	10:12	CDG-PMO	35000	1	634.58
5	07:54	10:12	PMO-CDG	35000	1	634.58
Aircraft Operating Profit [€]						**1269.17**

Table 3.4: Flight schedule A/C#4

Freighter 4: Type 1 Small Freighter						
Day	**ETD**	**ETA**	**Route**	**Cargo [kg]**	**LF**	**Profit [€]**
2	23:54	02:06	CDG-WAW	23000	1	16.91
5	07:54	10:06	WAW-CDG	23000	1	16.91
Aircraft Operating Profit [€]						**33.81**

Table 3.5: Flight schedule A/C#5

Freighter 5: Type 1 Small Freighter						
Day	**ETD**	**ETA**	**Route**	**Cargo [kg]**	**LF**	**Profit [€]**
2	23:54	02:06	CDG-WAW	23000	1	16.91
5	07:54	10:06	WAW-CDG	23000	1	16.91
Aircraft Operating Profit [€]						**33.81**

In Table 3.4 and Table 3.5, the flight schedules for the fourth and last aircraft in the fleet are shown. Both these aircraft are of type 1, which is the small freighter. Although both aircraft have maximum LF the profit is very small, contributing less than 1% to the total profit. This is mainly because there are relatively high costs involved considering the maximum range of these aircraft. The predominant reason of these high costs are due to the the 30 minutes extra time it takes after take-off and before landing, the maximum range further limits this.

3.2. Route Network

Following from the flight schedules in the previous section, the route network is presented visually in Figure 3.1. As observed in the flight schedules of Table 3.4-Table 3.5, the route is CDG-WAW-CDG is operated by two aircraft. Therefore, on the route map two different coloured lines are shown for the respective aircraft. All the airports are named by their corresponding IATA code, Table 3.6 can be referred to look up the city name to the corresponding IATA code. The airports which are shown without any lines connecting, belong to the airports which were explored but will not have any flights operated to.

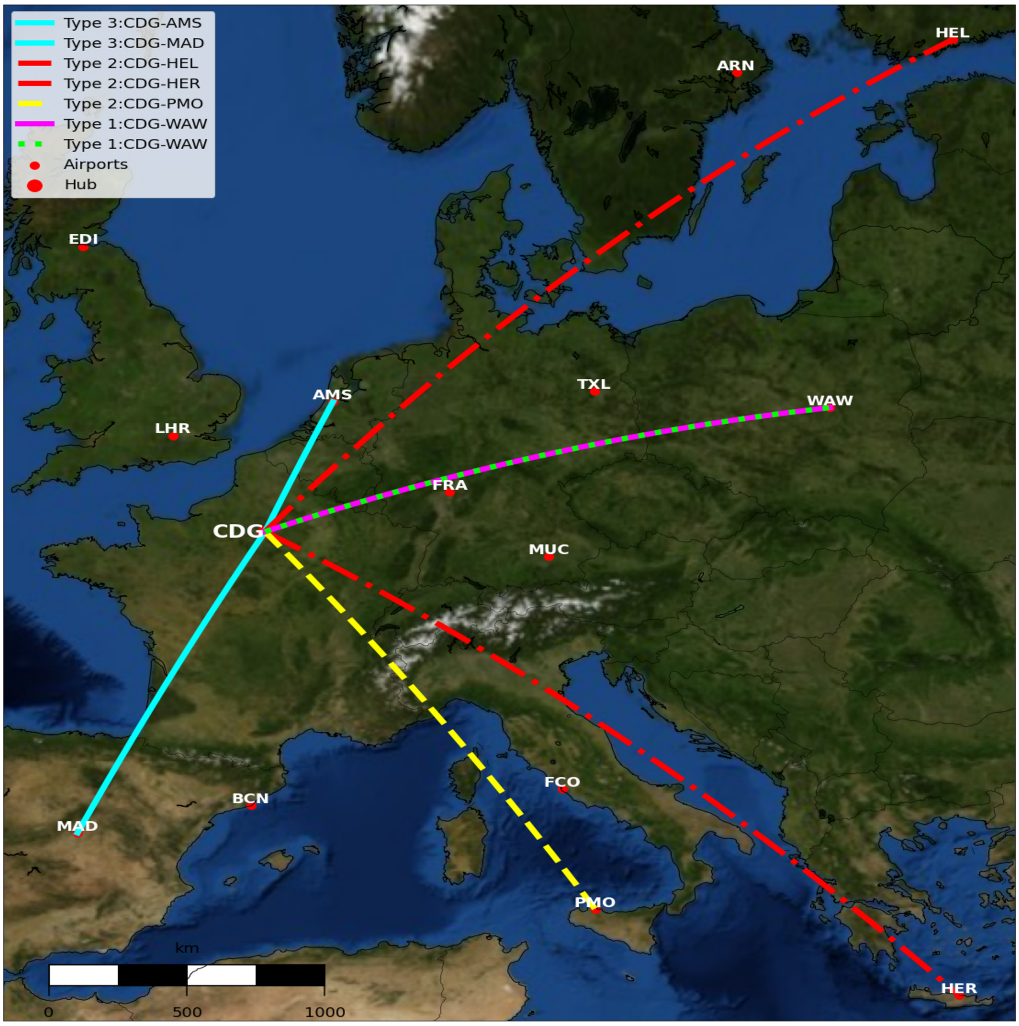

Figure 3.1: Central Connect Airways: Cargo division network

Table 3.6: IATA codes of the network with the corresponding city names

IATA code	LHR	CDG	AMS	FRA	MAD	BCN	MUC	FCO
City	London	Paris	Amsterdam	Frankfurt	Madrid	Barcelona	Munich	Rome
IATA code	ARN	TXL	HEL	WAW	EDI	HER	PMO	
City	Stockholm	Berlin	Helsinki	Warsaw	Edinburgh	Heraklion	Palermo	

3.3. Key Performance Indicators

In this section, the key financial and operation figures are presented. The determination of the KPIs is based on the document of Airline KPIs[1]. To commence operations in the coming quarter, Q2 of 2021, it is assumed that demand and all ratios remain constant. Furthermore, a quarter is assumed to consist of 13 weeks where every week of operations consists of the same 5 days of operation. As already shown in section 3.1, the total operating profits are presented again. However, to get a full understanding of future operations the figures are linearly extrapolated for the performance during one quarter of operations.

Table 3.7: KPIs: financial and operational

(Amounts in EUR)	**A/C #1**	**A/C #2**	**A/C #3**	**A/C #4**	**A/C #5**	**Full Fleet**	**Q2 2021**
Total operating revenue	156,068.94	76,757.37	27,069.59	16,056.22	16,056.22	**292,008.34**	**3,796,108**
Total operating expenses	113880.97	69985.92	25800.42	16022.40	16022.40	**241,712.12**	**3,142,258**
Total operating profit	42,187.97	6,771.46	1,269.17	33.81	33.81	**50,296.22**	**653,851**
Cargo figures and ratios (ratios in EUR)							
Yield	0.26	0.26	0.26	0.26	0.26	**0.26**	**0.26**
Unit Revenue	0.23	0.26	0.26	0.26	0.26	**0.25**	**0.25**
Unit Cost	0.18	0.23	0.25	0.26	0.26	**0.24**	**0.24**
Traffic (in revenue ton kilometers, RTK)	600,265	295.220	104,114	61,755	61,755	**1,123,109**	**14,600,417**
Capacity (in available ton kilometers, ATK)	702,136	299,978	104,114	61.755	61,755	**1,229,738**	**15,986,590**
Average leg load factor (ALLF)	90%	98%	100%	100%	100%	**98%**	**98%**
Break-even load factor (BELF)	68%	90%	95%	99.9%	99.9%	**83%**	**83%**
Weight of Cargo Carried (in tons)	864	137	70	46	46	**1164**	**15,129**

Reviewing the key figures of Table 3.7, the Cargo division will have a solidified financial position to commence operations and also enough margin for possible revenue losses. This is enforced by a BELF of 83% in comparison with the ALLF of 98%. Upon introduction of the Cargo division of Central Connect Airways in Q2 of 2021, a total profit of €653,851 is made by operating a second-hand fleet of 5 freighters. Furthermore, 15 million kilograms of cargo is transported.

Room for improvement can be found when reviewing the high unit cost of A/C numbers 2 until 5. Here, an investment in the renewal of at least one of the small freighters should pay off in the end due to lower costs per flown kilometer, as discussed in section 3.1. In this way, BELF would also become more realistic compared to the 100% it is currently. Additionally, considering a broader market, i.e. more airports and better composed fleet, will likely lead to a more efficient solution.

3.4. Discussion

In this section, the results are analysed critically. Also, the assumptions made during the dynamic programming from section 2.1 and this chapter, are linked to the results to see what the contribution of them is.

In this exploratory report, assumptions were made to asses operational potential for a Cargo division of Central Connect Airways. To further test this, the model would have to be extended to investigate a extended real-life operation among which maintenance and non-operational factors. Besides this, a new assessment of the assumptions and constraints that are important in such a scenario should be done.

Secondly, by far the biggest increase of potential profit can be made by the strategic selection of fleet composition. As already recommended in section 3.3, investing in options to introduce a renewal to the fleet will increase profit. Mainly, this is because the costs of the current small freighters are very high. A new plane will not only be more economical, but can also contribute to a broader mix of capacity in the fleet which in itself contributes to less spillage.

In addition to the previous point regarding the small freighters, the BELF of these aircraft are close to 100%. This can be caused due to unfavourable market demand that is explored combined with the mentioned costs. Therefore, it might be possible to decrease the BELF with a different and more favourable market demand composition.

Third, the development of the flight schedules made by the dynamic programming approach should be extended. Currently, selection of the most profitable flight schedule for every aircraft is based on the first selection only. Therefore, other profitable routes might not be explored due to this approach, which could lead to a local optimum instead of a global optimal solution.

To conclude, this report has explored the potential of a Cargo division of Central Connect Airways to commence operations. A positive performance is expected. Moreover, using the insights gathered from the outcomes, investments are suggested to increase performance and facilitate growth.

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