TECHNICAL REPORT

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AIRLINE PLANNING AND OPTIMISATION

Part 2: Aircraft Routing Problem

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Flight scheduling and aircraft routing problem

This section focuses on the creation of a daily flight scheduling and aircraft routing plan. The goal is to optimize the allocation of aircraft to various flights within a 24-hour period. The process involves dynamic programming, considering demand, costs, and constraints to maximize profitability. The mathematical model and key performance indicators (KPIs) are outlined in Section 1.1, providing the basis for the subsequent programming code. The results, including the optimal solution, flight schedule, and KPIs, are presented and discussed in Section 1.3.

1.1. Mathematical model

The first section of this chapter mentions the indices and the sets that are used for programming the flight schedule and the aircraft routing model.

1.1.1. Sets and indices

Two sets were needed to incorporate all airports and aeroplanes in the model:

- Set N contains all airports (where h is the hub).
- Set K contains all aircraft types

Now that the sets have been created it is important to have indices to define the departure and arrival airport and the type of plane:

- i index for the origin airport $i \in N[1,2,3...,n]$
- j index for the arrival airport $j \in N[1,2,3...,n]$
- k index for aircraft type $k \in K[1,2,3]$

1.1.2. Parameters

Other than the decision variables, also parameters were used in the model. These parameters are translating characteristics of either the airports, aeroplanes, costs or the state of the dynamic programming into the model.

- $q_{i,j}$: travel demand between airport i to airport j
- $d_{i,j}$: distance between airports i and j
- s^k: number of seats per aircraft type k
- sp^k: speed of aircraft type k
- TAT^k: Turnaround time including (extra) landing and take-off time (LTO) of aircraft type k

- R^k: maximum range of aircraft type k in kilometers
- $RWYR^k$: runway required in meters of aircraft type k
- $RWYL_i$: total runway length of airport i
- $Y_{i,j} = 5.9 \times d_{i,j}^{-0.76} + 0.043$: Yield expressed in € per Revenue-Passenger-Kilometer (RPK)
- C_X^k: is the fixed operating cost for each aircraft type k
- C_L^k: lease costs of aircraft type k
- $C_{T_{i,j}}^k = \frac{c_t^k \times d_{i,j}}{V_k} \begin{cases} c_t^k, & \text{is the time cost parameter for aircraft } k \\ V^k, & \text{is the airspeed of aircraft type } k \end{cases}$
- $C_{F_{i,j}}^k = \frac{c_f^k \times d_{i,j} \times f}{1.5} \begin{cases} c_f^k, & \text{is the fuel cost parameter for aircraft type } k\text{, expressed in gallon per kilometer} \\ f, & \text{is the fuel cost, equal to 1.42 USD/gallon} \end{cases}$
- $C_{E_{i,j}}^k = e \times G^k \frac{d_{i,j}}{R^k} \begin{cases} e, & \text{is the price of energy, assumed to be 0.07 €/kWh} \\ G^k, & \text{is the energy in a fully recharged aircraft type } k \\ R^k, & \text{is the range of aircraft type } k \end{cases}$
- $C_{i,j}^k = C_X^k + C_{T_{i,j}}^k + C_{F_{i,j}}^k + C_{E_{i,j}}^k$: the total operating cost for a flight leg between i and j, operated by aircraft type k

Also note the two following conditions that affect the parameters:

- Flights departing or arriving at the hub have a reduction in operating costs of 30%. This does not apply to the electrical costs of aeroplanes. Only on the fixed operation costs, time costs and fuel costs;
- Demand at time t includes the demand that can be recaptured from $t-1$, $t-2$, and $t+1$

1.1.3. Constraints

There are several constraints used in the model. The two most important ones are the runway constraint and the distance constraint. In the pseudo-code in line 7, both of these constraints are determined. These lines also show the calculation of the costs. To adhere to the travel distance and runway length constraints a penalty is set. When these constraints are not met a high penalty is given to that route. This way it forces the model to exclude these legs from possible route combinations. In the Pseudo code, these penalties are set in lines 16 and 17. Constraint 1.1 and 1.2 are mathematical representations of the penalty that is given when the maximum travel range or minimum runway length is not obliged.

$$a_{i,j}^k = \begin{cases} 10000, \text{ if } d_{i,j} \leq R^k \\ 0, \text{ otherwhise} \end{cases} \tag{1.1}$$

$$b_{i,j}^k = \begin{cases} 10000, & \text{if } RW^k \leq RW_i \text{ and } RW^k \leq RW_j, \\ 0, & \text{otherwise.} \end{cases} \tag{1.2}$$

1.2. Dynamic modelling

The initial phase of this study involves data import and initialization processes. This includes the importation of essential libraries, establishment of the working directory, and definition of CSV files containing pertinent information. Subsequently, for each CSV file within the specified list, the data is read into a Pandas DataFrame and stored in the dataframes dictionary. Following the data import, functions from the module are imported, relevant dataframes are extracted, parameters are set, and variables are initialized to facilitate subsequent calculations.

The next stage addresses the computation of aircraft constraints, costs and yields. For each distinct aircraft type, constraints related to feasible travel between airportsare computed, taking into account travel distances and runway length. Within this framework, a nested loop is employed to calculate time, fuel, and power costs for each pair of airports, incorporating specified conditions. Operating costs are then determined, with a 30% discount applied if the departure or arrival airport corresponds to the hub. The cumulative operating costs are subsequently computed. An important part of the model is the initialization of penalties. The penalty variable is set at -1000000, serving as a mechanism for managing to exclude legs that do not satisfy the runway length and travel distance constraint. Simultaneously, for each airport and each hour, total demand is calculated and set based on predefined conditions.

The subsequent section is dedicated to the initialization and execution of dynamic programming. Dynamic programming involves breaking down a complex problem into smaller subproblems, solving each subproblem only once, and storing the solutions for future reference. In the airline scheduling problem, the subproblems relate to determining the optimal scheduling decisions at each time step, given the state of the system. In the provided model, the state of the system is represented by the Statespace matrix (SS) and Statespace matrix with location (SSL). The SS matrix captures the optimal profit at each airport and time step, while SSL records the optimal location (airport) for the previous time step, facilitating the reconstruction of the optimal schedule.

The transitions between states are influenced by the profitability of flight options. For each aircraft type, the DP algorithm evaluates the profitability of flights departing from a certain airport (index hub for departure flights, index (hub + 12) for arrival flights) at a specific time. The algorithm iteratively computes the optimal profit at each time step, considering the constraints and costs associated with the flights.
Once the DP algorithm completes, the optimal schedule is reconstructed by backtracking through the SSL matrix. This reconstruction process involves selecting the airports and times that maximize profit at each step, ultimately yielding the most profitable schedule for the given aircraft fleet and demand. In the provided code, the DP approach is employed to optimize aircraft scheduling by considering demand, costs, and constraints. The AC_{SS} and AC_{SSL} matrices store the optimal profit and optimal locations for each aircraft type. The scheduling process involves iteratively updating these matrices while respecting constraints and maximizing profits.

1.2.1. Pseudocode

Algorithm 1: Aircraft Routing Problem

```
Data Import and Initialization:
Import necessary libraries, set working directory, and define CSV files
for each CSV file in the list do
    Read into a pandas dataframe and store in the dataframes dictionary
end for
Import functions from the module, extract relevant dataframes, set parameters, and initialize variables
Aircraft Constraints and Costs Calculation:
for each aircraft type do
    Calculate constraints for feasible travel between airports based on distances and runway requirements
    for each pair of airports do
        Calculate time, fuel, and power costs considering specified conditions
        Calculate operating costs, apply 30% discount if departure or arrival airport is the hub
        Calculate total operating costs including power costs
    end for
end for
Initialize Penalty and Demand:
Initialize penalty as -1000000
for each airport and each hour do
    Calculate and set total demand based on given conditions
end for
Dynamic Programming Initialization and Execution:
for each aircraft type do
    Set time step duration, total time steps, end_vector, and state space matrices
    for each iteration from 0 to 240 do
        Set the last 240 timesteps in state space matrix
    end for
    for each timestep starting from the end of the day until the last timestep do
        Calculate timestep-specific profit for each airport towards the hub
        for each arrival airport do
            Check conditions for penalties, calculate profit, and update state space matrices
        end for
        Update state space for the hub
    end for
    Append resulting state space matrices to aircraft-specific lists
end for
Scheduling:
for each aircraft type do
    while not at the end of the time horizon do
        Increment time step counter
        Retrieve and evaluate current profit
        if no profitable flights are available then
            Stop the process
        end if
        Update flight status and iterate to the next time step
    end while
    Print the scheduled flights for each aircraft
    Update the demand based on the resulted schedules
end for
Print the total profit of each flight in the schedule
```

1.3. Results

The model as described in 2.1.4 is created using Python without the use of an optimizer. This section will provide the results and insights into the important KPIs.

1.3.1. Optimal solution

The goal of the airline is to maximise profit within a 24-hour period while considering environmental goals. To achieve this goal a flight schedule with corresponding aircraft routing schedule is calculated. The computed optimal solution for a standard day revealed a total profit of €230.945,-. This profit is realized by a specific flight schedule and fleet assignment as shown in table 1.1.

Table 1.1: Optimal Solution

	Optimal Solution
Total profit	€230.945,-
Total number of flights	310
Total passengers	10,963
Average utilization	48.45%

As stated in table 1.1 a total of 310 flights are conducted and a total of 10.963 passengers are transported. The average utilization rate for all the aeroplanes is 48.45%.

1.3.2. Fleet, network and frequencies

Table A.1 shows the entire flight schedule that results in this optimal solution. As designed the flight schedule shows a clear hub-and-spoke pattern. To gain more insight in the flight schedule the frequencies from the hub to all the other airports are given in table 1.2. The frequencies are departing from LIME, to get the total frequency of a flight leg the values need to be doubled. This table clearly shows that the most frequently used flight leg is between LIME and LIPX. This can be explained considering the travel time and demand. LIPX is the closest airport to LIME, and these two airports have the highest demand relative to each other. The second most frequent flight leg is between LIME and LIPZ, these airports also have a relatively short distance and high demand.

Table 1.2: Flight Frequencies from LIME

From LIME	**Frequency**
to LICJ	7
to LIPZ	21
to LIMF	6
to LIEE	5
to LIPE	18
to LIRN	17
to LIPQ	12
to LICA	3
to LICC	5
to LIPX	60
to LIEO	4

1.3.3. Flight Schedule

A detailed flight schedule between LIME and LICJ is provided to gain insight into the workings of the model. As shown in Table 1.3, the flights are exclusively operated by two aircraft types, namely: Regional turboprop and Electric regional aircraft . Notably, all flights, with the exception of two, achieve a 100% utility rate, demonstrating the efficiency and optimal use of resources. This flight schedule shows a clear hub and spoke design.

Furthermore, each of the flights made with the Regional turboprop yielded a consistent profit of 1419.87 euros. The reoccurring profit is likely because of the high demand between LIME and LICJ. Every flight that is made on this leg is full and therefore yields the same profits. This is also reflected in the utility rates which, as stated above are consistent with 100% with only two exceptions.

Table 1.3: Flight schedule between LIME and LICJ

FlightNum	ACtype	Dep_from	Arr_to	Dep_time	Arr_time	Profit	Pax	Blocktime	LF
35	0	LIME	LICJ	7:36	9:42	1419.87	45	270	100%
36	0	LICJ	LIME	10:36	12:42	1419.87	45	270	100%
67	0	LIME	LICJ	12:00	14:06	1419.87	45	270	100%
68	0	LICJ	LIME	15:00	17:06	1419.87	45	270	100%
69	0	LIME	LICJ	18:00	20:06	1419.87	45	270	100%
70	0	LICJ	LIME	21:00	23:06	1419.87	45	270	100%
177	0	LIME	LICJ	9:12	11:18	1419.87	45	270	100%
178	0	LICJ	LIME	12:12	14:18	1419.87	45	270	100%
207	0	LIME	LICJ	11:48	13:54	1419.87	45	270	100%
208	0	LICJ	LIME	14:48	16:54	1419.87	45	270	100%
259	0	LIME	LICJ	5:12	7:18	1148.71	41	246	91%
260	0	LICJ	LIME	8:12	10:18	1419.87	45	270	100%
271	1	LIME	LICJ	16:36	19:00	1703.86	48	288	100%
272	1	LICJ	LIME	19:54	22:18	1568.28	46	276	96%

1.3.4. Key performance indicators (KPIs)

Two KPIs are calculated to assess the airline performance on this daily schedule. The KPIs are divided into two categories, namely: traffic-based KPIs and financial-based KPIs.

Starting with the traffic-based KPIs that can be used by the airline to evaluate their performance in terms of the number of seats and passengers. Table 1.4 shows that there are 4.269.067 available seats per flown kilometre and that 4.236.285 revenue passengers were transported per flown kilometre. Subsequently, the financial-based parameters are shown. Together with the flight schedule and aircraft routing schedule this leads to a profit of 230.945 euros

Table 1.4: KPIs

	KPI	Formula	Value
Traffic based KPI's	ASK	$= \sum_{p=1}^{len(schedule)} (seats_{AC} * distance_{i,j})$	4.269.067 seats
	RPK	$= \sum_{p=1}^{len(schedule)} (pax_p * distance_{i,j})$	4.236.285 pax
Financial based KPI's	CASK	$= \frac{\text{total costs}}{\text{ASK}}$	€0,05
	RASK	$= \frac{\text{total yield}}{\text{ASK}}$	€24,77
	Revenue / RPK	$= \frac{\text{total yield}}{\text{RPK}}$	€24,96
	Operating Profit	= total yield – total costs	€230.945,-

1.4. Discussion

Where the model gives some meaningful results there are some discussion points. These points are discussed in this section.

Firstly, it is observed that the demand calculation displays some oddities, occasionally resulting in negative demand values. This can be attributed to the recapture window in the demand mechanism. These oddities in the working of the demand capture part of the code can lead to misleading or wrong results.

Secondly, a striking observation is related to the operational costs (CASK), which appear considerably low when compared to the revenue (RASK). This big difference can lead to potential miscalculations in the cost function. This miscalculation can lead to wrong results because the model uses the calculated value to make decisions about the most profitable route.

Lastly, the frequency distribution between specific airport pairs introduces an interesting observation. Despite the demand between LIME and LIPE being higher than that between LIME and LIPZ, and the shorter travel distance between LIME and LIPE, the frequency from LIME to LIPZ is the highest. We can not explain this result but it may be related to the small errors in the costs and demand functions.

A
Total flight schedule

Table A.1: Total flight schedule

FlightNum	ACtype	Dep_from	Arr_to	Dep_time	Arr_time	Profit	Pax	Blocktime
1	0	LIME	LIRN	5:12	6:54	1251,972	45	270
2	0	LIRN	LIME	7:48	9:30	1251,972	45	270
3	0	LIME	LIEO	10:24	11:54	1153,724	45	270
4	0	LIEO	LIME	12:48	14:18	1153,724	45	270
5	0	LIME	LIPQ	15:12	16:18	922,2543	45	270
6	0	LIPQ	LIME	17:12	18:18	922,2543	45	270
7	0	LIME	LIEO	19:12	20:42	1153,724	45	270
8	0	LIEO	LIME	21:36	23:06	1153,724	45	270
9	1	LIME	LIPZ	2:12	3:12	-429,626	0	0
10	1	LIPZ	LIME	4:06	5:06	1016,371	48	288
11	1	LIME	LIEE	6:00	8:00	1570,25	48	288
12	1	LIEE	LIME	8:54	10:54	1570,25	48	288
13	1	LIME	LIPZ	11:48	12:48	1016,371	48	288
14	1	LIPZ	LIME	13:42	14:42	1016,371	48	288
15	1	LIME	LIPQ	15:36	16:48	1140,256	48	288
16	1	LIPQ	LIME	17:42	18:54	1140,256	48	288
17	1	LIME	LIPQ	19:48	21:00	1140,256	48	288
18	1	LIPQ	LIME	21:54	23:06	1140,256	48	288
19	2	LIME	LIPX	3:00	3:48	-4,58571	11	66
20	2	LIPX	LIME	4:30	5:18	192,465	20	120
21	2	LIME	LIPX	6:00	6:48	192,465	20	120
22	2	LIPX	LIME	7:30	8:18	192,465	20	120
23	2	LIME	LIPX	9:00	9:48	192,465	20	120
24	2	LIPX	LIME	10:30	11:18	192,465	20	120
25	2	LIME	LIPX	12:00	12:48	192,465	20	120
26	2	LIPX	LIME	13:30	14:18	192,465	20	120
27	2	LIME	LIPX	15:00	15:48	192,465	20	120
28	2	LIPX	LIME	16:30	17:18	192,465	20	120
29	2	LIME	LIPX	18:00	18:48	192,465	20	120
30	2	LIPX	LIME	19:30	20:18	192,465	20	120
31	2	LIME	LIPX	21:00	21:48	192,465	20	120
32	2	LIPX	LIME	22:30	23:18	192,465	20	120
33	0	LIME	LIPZ	4:00	4:54	298,5704	28	168
34	0	LIPZ	LIME	5:48	6:42	810,6942	45	270
35	0	LIME	LICJ	7:36	9:42	1419,874	45	270

Table A.1 continued from previous page

FlightNum	ACtype	Dep_from	Arr_to	Dep_time	Arr_time	Profit	Pax	Blocktime
36	0	LICJ	LIME	10:36	12:42	1419,874	45	270
37	0	LIME	LIRN	13:36	15:18	1251,972	45	270
38	0	LIRN	LIME	16:12	17:54	1251,972	45	270
39	0	LIME	LIRN	18:48	20:30	1251,972	45	270
40	0	LIRN	LIME	21:24	23:06	1251,972	45	270
41	1	LIME	LIPE	5:00	5:54	967,2588	48	288
42	1	LIPE	LIME	6:48	7:42	967,2588	48	288
43	1	LIME	LIRN	8:36	10:30	1511,859	48	288
44	1	LIRN	LIME	11:24	13:18	1511,859	48	288
45	1	LIME	LIPQ	14:12	15:24	1140,256	48	288
46	1	LIPQ	LIME	16:18	17:30	1140,256	48	288
47	1	LIME	LIRN	18:24	20:18	1511,859	48	288
48	1	LIRN	LIME	21:12	23:06	1511,859	48	288
49	2	LIME	LIPX	3:00	3:48	-4,58571	11	66
50	2	LIPX	LIME	4:30	5:18	61,09787	14	84
51	2	LIME	LIPX	6:00	6:48	192,465	20	120
52	2	LIPX	LIME	7:30	8:18	192,465	20	120
53	2	LIME	LIPX	9:00	9:48	192,465	20	120
54	2	LIPX	LIME	10:30	11:18	192,465	20	120
55	2	LIME	LIPX	12:00	12:48	192,465	20	120
56	2	LIPX	LIME	13:30	14:18	192,465	20	120
57	2	LIME	LIPX	15:00	15:48	192,465	20	120
58	2	LIPX	LIME	16:30	17:18	192,465	20	120
59	2	LIME	LIPX	18:00	18:48	192,465	20	120
60	2	LIPX	LIME	19:30	20:18	192,465	20	120
61	2	LIME	LIPX	21:00	21:48	192,465	20	120
62	2	LIPX	LIME	22:30	23:18	192,465	20	120
63	0	LIME	LIPX	4:00	4:42	333,0914	32	192
64	0	LIPX	LIME	5:36	6:18	617,7202	45	270
65	0	LIME	LIEO	7:12	8:42	1153,724	45	270
66	0	LIEO	LIME	9:36	11:06	1153,724	45	270
67	0	LIME	LICJ	12:00	14:06	1419,874	45	270
68	0	LICJ	LIME	15:00	17:06	1419,874	45	270
69	0	LIME	LICJ	18:00	20:06	1419,874	45	270
70	0	LICJ	LIME	21:00	23:06	1419,874	45	270
71	1	LIME	LIPE	5:00	5:54	967,2588	48	288
72	1	LIPE	LIME	6:48	7:42	967,2588	48	288
73	1	LIME	LIRN	8:36	10:30	1511,859	48	288
74	1	LIRN	LIME	11:24	13:18	1511,859	48	288
75	1	LIME	LIPQ	14:12	15:24	1140,256	48	288
76	1	LIPQ	LIME	16:18	17:30	1140,256	48	288
77	1	LIME	LIRN	18:24	20:18	1511,859	48	288
78	1	LIRN	LIME	21:12	23:06	1511,859	48	288
79	2	LIME	LIPX	6:00	6:48	192,465	20	120
80	2	LIPX	LIME	7:30	8:18	192,465	20	120
81	2	LIME	LIPX	9:00	9:48	192,465	20	120
82	2	LIPX	LIME	10:30	11:18	192,465	20	120
83	2	LIME	LIPX	12:00	12:48	192,465	20	120
84	2	LIPX	LIME	13:30	14:18	192,465	20	120
85	2	LIME	LIPX	15:00	15:48	192,465	20	120
86	2	LIPX	LIME	16:30	17:18	192,465	20	120
87	2	LIME	LIPX	18:00	18:48	192,465	20	120
88	2	LIPX	LIME	19:30	20:18	192,465	20	120

Table A.1 continued from previous page

FlightNum	ACtype	Dep_from	Arr_to	Dep_time	Arr_time	Profit	Pax	Blocktime
89	2	LIME	LIPX	21:00	21:48	192,465	20	120
90	2	LIPX	LIME	22:30	23:18	192,465	20	120
91	0	LIME	LIPZ	5:12	6:06	810,6942	45	270
92	0	LIPZ	LIME	7:00	7:54	810,6942	45	270
93	0	LIME	LIRN	8:48	10:30	1251,972	45	270
94	0	LIRN	LIME	11:24	13:06	1251,972	45	270
95	0	LIME	LIEO	14:00	15:30	1153,724	45	270
96	0	LIEO	LIME	16:24	17:54	1153,724	45	270
97	0	LIME	LIRN	18:48	20:30	1251,972	45	270
98	0	LIRN	LIME	21:24	23:06	1251,972	45	270
99	1	LIME	LIRN	5:00	6:54	1511,859	48	288
100	1	LIRN	LIME	7:48	9:42	1511,859	48	288
101	1	LIME	LIRN	10:36	12:30	1511,859	48	288
102	1	LIRN	LIME	13:24	15:18	1511,859	48	288
103	1	LIME	LIPQ	16:12	17:24	1140,256	48	288
104	1	LIPQ	LIME	18:18	19:30	1140,256	48	288
105	1	LIME	LIPE	20:24	21:18	967,2588	48	288
106	1	LIPE	LIME	22:12	23:06	967,2588	48	288
107	2	LIME	LIPX	6:00	6:48	192,465	20	120
108	2	LIPX	LIME	7:30	8:18	192,465	20	120
109	2	LIME	LIPX	9:00	9:48	192,465	20	120
110	2	LIPX	LIME	10:30	11:18	192,465	20	120
111	2	LIME	LIPX	12:00	12:48	192,465	20	120
112	2	LIPX	LIME	13:30	14:18	192,465	20	120
113	2	LIME	LIPX	15:00	15:48	192,465	20	120
114	2	LIPX	LIME	16:30	17:18	192,465	20	120
115	2	LIME	LIPX	18:00	18:48	192,465	20	120
116	2	LIPX	LIME	19:30	20:18	192,465	20	120
117	2	LIME	LIPX	21:00	21:48	192,465	20	120
118	2	LIPX	LIME	22:30	23:18	192,465	20	120
119	0	LIME	LIRN	5:12	6:54	1251,972	45	270
120	0	LIRN	LIME	7:48	9:30	1251,972	45	270
121	0	LIME	LIRN	10:24	12:06	1251,972	45	270
122	0	LIRN	LIME	13:00	14:42	1251,972	45	270
123	0	LIME	LIEO	15:36	17:06	1153,724	45	270
124	0	LIEO	LIME	18:00	19:30	1153,724	45	270
125	0	LIME	LIPZ	20:24	21:18	810,6942	45	270
126	0	LIPZ	LIME	22:12	23:06	810,6942	45	270
127	1	LIME	LIRN	5:00	6:54	1511,859	48	288
128	1	LIRN	LIME	7:48	9:42	1511,859	48	288
129	1	LIME	LIRN	10:36	12:30	1511,859	48	288
130	1	LIRN	LIME	13:24	15:18	1511,859	48	288
131	1	LIME	LIPQ	16:12	17:24	1140,256	48	288
132	1	LIPQ	LIME	18:18	19:30	1140,256	48	288
133	1	LIME	LIMF	20:24	21:18	952,3563	48	288
134	1	LIMF	LIME	22:12	23:06	952,3563	48	288
135	2	LIME	LIPX	4:24	5:12	192,465	20	120
136	2	LIPX	LIME	5:54	6:42	192,465	20	120
137	2	LIME	LIPX	7:24	8:12	192,465	20	120
138	2	LIPX	LIME	8:54	9:42	192,465	20	120
139	2	LIME	LIPX	10:24	11:12	192,465	20	120
140	2	LIPX	LIME	11:54	12:42	192,465	20	120
141	2	LIME	LIPX	13:24	14:12	192,465	20	120

Table A.1 continued from previous page

FlightNum	ACtype	Dep_from	Arr_to	Dep_time	Arr_time	Profit	Pax	Blocktime
142	2	LIPX	LIME	14:54	15:42	192,465	20	120
143	2	LIME	LIPX	16:24	17:12	192,465	20	120
144	2	LIPX	LIME	17:54	18:42	192,465	20	120
145	2	LIME	LIPX	19:24	20:12	192,465	20	120
146	2	LIPX	LIME	20:54	21:42	192,465	20	120
147	0	LIME	LIPZ	5:00	5:54	810,6942	45	270
148	0	LIPZ	LIME	6:48	7:42	810,6942	45	270
149	0	LIME	LIPQ	8:36	9:42	922,2543	45	270
150	0	LIPQ	LIME	10:36	11:42	922,2543	45	270
151	0	LIME	LIRN	12:36	14:18	1251,972	45	270
152	0	LIRN	LIME	15:12	16:54	1251,972	45	270
153	0	LIME	LICA	17:48	20:00	1450,819	45	270
154	0	LICA	LIME	20:54	23:06	1450,819	45	270
155	1	LIME	LIPZ	5:00	6:00	1016,371	48	288
156	1	LIPZ	LIME	6:54	7:54	1016,371	48	288
157	1	LIME	LIEE	8:48	10:48	1570,25	48	288
158	1	LIEE	LIME	11:42	13:42	1570,25	48	288
159	1	LIME	LIRN	14:36	16:30	1511,859	48	288
160	1	LIRN	LIME	17:24	19:18	1511,859	48	288
161	1	LIME	LIPZ	20:12	21:12	1016,371	48	288
162	1	LIPZ	LIME	22:06	23:06	1016,371	48	288
163	2	LIME	LIPX	5:12	6:00	192,465	20	120
164	2	LIPX	LIME	6:42	7:30	192,465	20	120
165	2	LIME	LIPX	8:12	9:00	192,465	20	120
166	2	LIPX	LIME	9:42	10:30	192,465	20	120
167	2	LIME	LIPX	11:12	12:00	192,465	20	120
168	2	LIPX	LIME	12:42	13:30	192,465	20	120
169	2	LIME	LIPX	14:12	15:00	192,465	20	120
170	2	LIPX	LIME	15:42	16:30	192,465	20	120
171	2	LIME	LIPX	17:12	18:00	192,465	20	120
172	2	LIPX	LIME	18:42	19:30	192,465	20	120
173	2	LIME	LIMF	20:12	21:12	170,1372	20	120
174	2	LIMF	LIME	21:54	22:54	170,1372	20	120
175	0	LIME	LIPQ	5:12	6:18	922,2543	45	270
176	0	LIPQ	LIME	7:12	8:18	922,2543	45	270
177	0	LIME	LICJ	9:12	11:18	1419,874	45	270
178	0	LICJ	LIME	12:12	14:18	1419,874	45	270
179	0	LIME	LIRN	15:12	16:54	1251,972	45	270
180	0	LIRN	LIME	17:48	19:30	1251,972	45	270
181	0	LIME	LIPZ	20:24	21:18	810,6942	45	270
182	0	LIPZ	LIME	22:12	23:06	810,6942	45	270
183	1	LIME	LIPQ	5:00	6:12	1140,256	48	288
184	1	LIPQ	LIME	7:06	8:18	1140,256	48	288
185	1	LIME	LIPZ	9:12	10:12	1016,371	48	288
186	1	LIPZ	LIME	11:06	12:06	1016,371	48	288
187	1	LIME	LIPE	13:00	13:54	967,2588	48	288
188	1	LIPE	LIME	14:48	15:42	967,2588	48	288
189	1	LIME	LIPE	16:36	17:30	967,2588	48	288
190	1	LIPE	LIME	18:24	19:18	967,2588	48	288
191	1	LIME	LIPZ	20:12	21:12	1016,371	48	288
192	1	LIPZ	LIME	22:06	23:06	1016,371	48	288
193	2	LIME	LIPX	5:24	6:12	192,465	20	120
194	2	LIPX	LIME	6:54	7:42	192,465	20	120

Table A.1 continued from previous page

FlightNum	ACtype	Dep_from	Arr_to	Dep_time	Arr_time	Profit	Pax	Blocktime
195	2	LIME	LIPX	8:24	9:12	192,465	20	120
196	2	LIPX	LIME	9:54	10:42	192,465	20	120
197	2	LIME	LIPX	11:24	12:12	192,465	20	120
198	2	LIPX	LIME	12:54	13:42	192,465	20	120
199	2	LIME	LIPX	14:24	15:12	192,465	20	120
200	2	LIPX	LIME	15:54	16:42	192,465	20	120
201	2	LIME	LIPX	17:24	18:12	192,465	20	120
202	2	LIPX	LIME	18:54	19:42	192,465	20	120
203	2	LIME	LIPE	20:24	21:30	166,312	20	120
204	2	LIPE	LIME	22:12	23:18	166,312	20	120
205	0	LIME	LICC	5:12	7:36	1510,75	45	270
206	0	LICC	LIME	8:30	10:54	1510,75	45	270
207	0	LIME	LICJ	11:48	13:54	1419,874	45	270
208	0	LICJ	LIME	14:48	16:54	1419,874	45	270
209	0	LIME	LICA	17:48	20:00	1450,819	45	270
210	0	LICA	LIME	20:54	23:06	1450,819	45	270
211	1	LIME	LIMF	5:00	5:54	705,237	39	234
212	1	LIMF	LIME	6:48	7:42	952,3563	48	288
213	1	LIME	LIEE	8:36	10:36	1570,25	48	288
214	1	LIEE	LIME	11:30	13:30	1570,25	48	288
215	1	LIME	LIPE	14:24	15:18	967,2588	48	288
216	1	LIPE	LIME	16:12	17:06	967,2588	48	288
217	1	LIME	LIEE	18:00	20:00	1570,25	48	288
218	1	LIEE	LIME	20:54	22:54	1570,25	48	288
219	2	LIME	LIMF	4:00	5:00	-49,5244	12	72
220	2	LIMF	LIME	5:42	6:42	170,1372	20	120
221	2	LIME	LIPX	7:24	8:12	192,465	20	120
222	2	LIPX	LIME	8:54	9:42	192,465	20	120
223	2	LIME	LIPX	10:24	11:12	192,465	20	120
224	2	LIPX	LIME	11:54	12:42	192,465	20	120
225	2	LIME	LIPX	13:24	14:12	192,465	20	120
226	2	LIPX	LIME	14:54	15:42	192,465	20	120
227	2	LIME	LIPX	16:24	17:12	192,465	20	120
228	2	LIPX	LIME	17:54	18:42	192,465	20	120
229	2	LIME	LIPX	19:24	20:12	192,465	20	120
230	2	LIPX	LIME	20:54	21:42	192,465	20	120
231	0	LIME	LICC	5:12	7:36	1510,75	45	270
232	0	LICC	LIME	8:30	10:54	1510,75	45	270
233	0	LIME	LIEE	11:48	13:42	1303,189	45	270
234	0	LIEE	LIME	14:36	16:30	1303,189	45	270
235	0	LIME	LICC	17:24	19:48	1510,75	45	270
236	0	LICC	LIME	20:42	23:06	1510,75	45	270
237	1	LIME	LIPE	5:18	6:12	967,2588	48	288
238	1	LIPE	LIME	7:06	8:00	967,2588	48	288
239	1	LIME	LIPZ	8:54	9:54	1016,371	48	288
240	1	LIPZ	LIME	10:48	11:48	1016,371	48	288
241	1	LIME	LIPZ	12:42	13:42	1016,371	48	288
242	1	LIPZ	LIME	14:36	15:36	1016,371	48	288
243	1	LIME	LIPE	16:30	17:24	967,2588	48	288
244	1	LIPE	LIME	18:18	19:12	967,2588	48	288
245	1	LIME	LIPE	20:06	21:00	967,2588	48	288
246	1	LIPE	LIME	21:54	22:48	967,2588	48	288
247	2	LIME	LIMF	4:42	5:42	-49,5244	12	72

Table A.1 continued from previous page

FlightNum	ACtype	Dep_from	Arr_to	Dep_time	Arr_time	Profit	Pax	Blocktime
248	2	LIMF	LIME	6:24	7:24	170,1372	20	120
249	2	LIME	LIPX	8:06	8:54	192,465	20	120
250	2	LIPX	LIME	9:36	10:24	192,465	20	120
251	2	LIME	LIPX	11:06	11:54	192,465	20	120
252	2	LIPX	LIME	12:36	13:24	192,465	20	120
253	2	LIME	LIPX	14:06	14:54	192,465	20	120
254	2	LIPX	LIME	15:36	16:24	192,465	20	120
255	2	LIME	LIPX	17:06	17:54	192,465	20	120
256	2	LIPX	LIME	18:36	19:24	192,465	20	120
257	2	LIME	LIPE	20:06	21:12	166,312	20	120
258	2	LIPE	LIME	21:54	23:00	166,312	20	120
259	0	LIME	LICJ	5:12	7:18	1148,713	41	246
260	0	LICJ	LIME	8:12	10:18	1419,874	45	270
261	0	LIME	LICA	11:12	13:24	1450,819	45	270
262	0	LICA	LIME	14:18	16:30	1310,591	43	258
263	0	LIME	LICC	17:24	19:48	1510,75	45	270
264	0	LICC	LIME	20:42	23:06	1510,75	45	270
265	1	LIME	LIPE	5:12	6:06	967,2588	48	288
266	1	LIPE	LIME	7:00	7:54	967,2588	48	288
267	1	LIME	LIPQ	8:48	10:00	1140,256	48	288
268	1	LIPQ	LIME	10:54	12:06	1140,256	48	288
269	1	LIME	LIPE	13:00	13:54	967,2588	48	288
270	1	LIPE	LIME	14:48	15:42	967,2588	48	288
271	1	LIME	LICJ	16:36	19:00	1703,865	48	288
272	1	LICJ	LIME	19:54	22:18	1568,284	46	276
273	2	LIME	LIPE	3:06	4:12	-114,333	10	60
274	2	LIPE	LIME	4:54	6:00	166,312	20	120
275	2	LIME	LIPX	7:24	8:12	192,465	20	120
276	2	LIPX	LIME	8:54	9:42	192,465	20	120
277	2	LIME	LIPX	10:24	11:12	192,465	20	120
278	2	LIPX	LIME	11:54	12:42	192,465	20	120
279	2	LIME	LIPX	13:24	14:12	192,465	20	120
280	2	LIPX	LIME	14:54	15:42	192,465	20	120
281	2	LIME	LIPX	16:24	17:12	192,465	20	120
282	2	LIPX	LIME	17:54	18:42	192,465	20	120
283	2	LIME	LIPX	19:24	20:12	192,465	20	120
284	2	LIPX	LIME	20:54	21:42	192,465	20	120
285	0	LIME	LIEO	6:00	7:30	1153,724	45	270
286	0	LIEO	LIME	8:24	9:54	1153,724	45	270
287	0	LIME	LICC	10:48	13:12	1510,75	45	270
288	0	LICC	LIME	14:06	16:30	1510,75	45	270
289	0	LIME	LICC	17:24	19:48	1510,75	45	270
290	0	LICC	LIME	20:42	23:06	1510,75	45	270
291	1	LIME	LIPZ	5:18	6:18	1016,371	48	288
292	1	LIPZ	LIME	7:12	8:12	835,621	42	252
293	1	LIME	LIPZ	9:06	10:06	1016,371	48	288
294	1	LIPZ	LIME	11:00	12:00	1016,371	48	288
295	1	LIME	LIPQ	12:54	14:06	1140,256	48	288
296	1	LIPQ	LIME	15:00	16:12	1140,256	48	288
297	1	LIME	LIRN	17:06	19:00	1511,859	48	288
298	1	LIRN	LIME	19:54	21:48	1511,859	48	288
299	2	LIME	LIPX	5:06	5:54	192,465	20	120
300	2	LIPX	LIME	6:36	7:24	-114,058	6	36

Table A.1 continued from previous page

FlightNum	ACtype	Dep_from	Arr_to	Dep_time	Arr_time	Profit	Pax	Blocktime
301	2	LIME	LIPX	8:06	8:54	192,465	20	120
302	2	LIPX	LIME	9:36	10:24	192,465	20	120
303	2	LIME	LIPX	11:06	11:54	192,465	20	120
304	2	LIPX	LIME	12:36	13:24	192,465	20	120
305	2	LIME	LIPX	14:06	14:54	192,465	20	120
306	2	LIPX	LIME	15:36	16:24	192,465	20	120
307	2	LIME	LIPX	17:06	17:54	192,465	20	120
308	2	LIPX	LIME	18:36	19:24	192,465	20	120
309	2	LIME	LIPE	20:06	21:12	166,312	20	120
310	2	LIPE	LIME	21:54	23:00	166,312	20	120

B

Student Assessment

Table B.1: Student Assessment

Student names	**Mathematical modeling**	**Programming**	**Reporting**
Féron van Hoeven	33%	33%	33%
Sten Heijink	33%	33%	33%
Michel van Tooren	33%	33%	33%