TATA CONSULTANCY SERVICES

Building on belief

Optimising Fleet Allocation

TCS Quantum Computing Challenge

07 September 2023

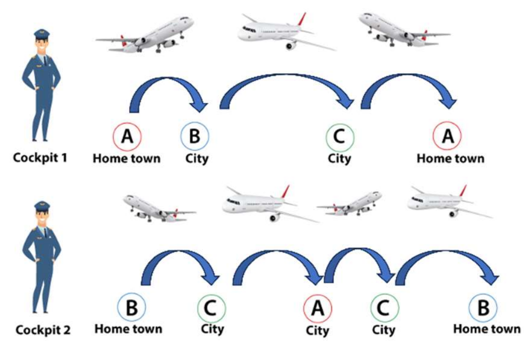
Problem Statement Overview

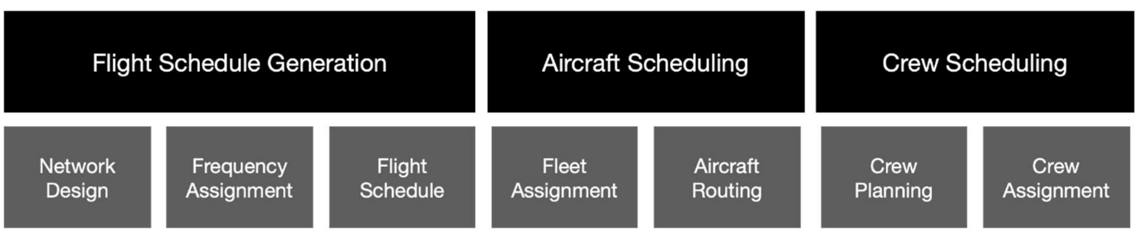
Overview of airline scheduling

The airline scheduling problem is an "unsolved problem". To put it simply, airline scheduling aims to find the most profitable schedule that is reliable and satisfies all operational constraints. The decision space of this problem is immense; airlines can choose any combination of where to fly, when to fly, and what to fly. Expressing profitability is complex and highly non-linear, with many interacting effects. Also, there is a need to respect multiple dimensions of operational constraints. This problem has been and still is too difficult to solve completely.

Overview of the Flight scheduling process

The diagram provides an overview of the overall flight scheduling process.





The following section provides an overview of the steps involved in the flight scheduling process. Airlines must deal with three main categories of scheduling problems:

a) Flight scheduling problem
b) Aircraft scheduling problem (also known as fleet assignment problem)
c) Crew assignment problem

We will only focus on the aircraft scheduling problem in this challenge.

Aircraft scheduling problem

This problem is concerned with the assignment of individual aircraft to a pre-determined network of flights operated by the airline. Given that different assignments result in different amounts of profit or incur different costs, the objective is to maximise total profit taking into consideration factors such as passenger demand, seating capacities, operational costs, maintenance requirements, and governmental regulations.

Three combinatorial optimisation problems are extensively used to model the aircraft scheduling problem:

a) Set partitioning (covering) problem
b) Multi-commodity network flow problem
c) Euler tour problem

The first two are well-known NP-hard problems and the third one is solvable in polynomial time.

Details of the flight scheduling process

The starting point is the flight schedule (summer and winter schedules). This is a list of flights developed by the commercial team based on several factors such as demand, revenue, available service structures (hub and spoke or point-to-point), available equipment, and competition. Multiple cycles of review and optimisation often drive changes that require further examination of the flight schedules.

Fleet assignment problem

The objective is to minimise the total cost of assigning aircraft types to the scheduled flights based on:

a) aircraft capacity
b) aircraft availability
c) operational costs
d) potential revenue

The operational constraints that must be considered for optimised model development are:

1. **Scheduled flights**: Scheduled departures to 'n' cities and scheduled arrivals from 'm' cities to be considered. The flight sequence can have different patterns: Back & Forth (A->B->A), Triangle pattern (A->B->C->A), W pattern (A->B->C->B->A), and any other open patterns.
2. **Aircraft capacity:** The maximum number of passengers that can be flown in each aircraft type. For example, 319 (156 seats), 320 (180 seats), and 321 (235 seats).
3. **Aircraft availability**: Availability of aircraft based on maintenance schedule(s) in the entire network for the flight schedule period.
4. **Operational cost**: Direct cost based on fuel cost, crew cost, and landing fees. Indirect costs are difficult to estimate and arise due to mismatches between fleet capacity and passenger demand; assigning a bigger aircraft results in unsold seats while assigning a smaller aircraft than needed causes passengers to spill over to overcrowd other flights or captured by rival airlines or alternative transportation means. Indirect cost can thus be considered as "forecasted seats" for the purposes of this challenge.
5. **Revenue**: Revenue per seat/passenger.

Fleet assignments are mostly done daily. A weekly schedule is generated by repeating the daily schedule for weekdays and making appropriate changes for the weekend. A better way would be to generate a weekly schedule directly while considering different daily requirements.

Usually, flight segments are given fixed departure and arrival times during the network design stage. This may lead to sub-optimal assignments as these times were generated without considering the differences in speeds of different fleet types. So, it is better to adjust these times at the fleet assignment stage. We must assume that each flight segment is associated with a flexible departure time window, while the exact departure time within the time window is determined during the assignment. However, when departure times are variable within time windows, we need to include a constraint that all flights with the same flight number will depart at the same time each day.

We have provided some mandatory Operational Constraints here but it may vary between airlines.

Abbreviations

FTL = Flight Time Limitations
LOF = Line of Flying (Succession of sectors flown by one aircraft)
STA = Scheduled Time of Arrival
STD = Scheduled Time of Departure

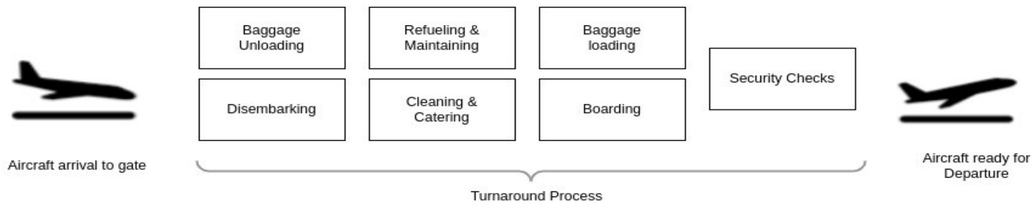
Cabin and flight operational constraint

Commercial night stops must return to base on the first flight, where say 10 min must be added to the turn requirement (if less than 40 min) up to a maximum of 40 min.

Ground operations constraints

1. The minimum turn time required, which assumes that every event happens as planned without complications, is split into two sections.
2. The minimum turn of the airport must be at least the minimum turn specified.
3. Additional time required before specific routes must be at least the additional turn specified.
4. The number of departures at the same STD must not exceed the value specified.
5. The number of departures (STD) in rolling 30 minutes must not exceed the value specified.
6. The number of First Wave departures (STD before 08:30L) at the same STD must not exceed the value specified.
7. The number of First Wave departures (STD before 08:30L) in any rolling 15 minutes must not exceed the value specified.
8. Turn-around time requirements must be met, which involves minimum and maximum turn-around times.

Turn-around time of an aircraft is the time between the arrival time and take-off time of the immediate next new flight of the same aircraft.



Fleet and network operational constraints

1. The ratio of standby aircraft to commercial lines of flying. A final number of standby aircraft required is subject to finalise commercial lines of flying and contractual terms of the airline.
2. The scheduled flights must comply with the airport curfews.

Maintenance planning constraints

Operational planning

All aircraft must achieve 6 hours of night ground time from the last STA to the first STD. 4 hours is acceptable on a limited number of aircraft for a maximum of one consecutive night.

Business Value & Motivation

Why is this problem important for the industry?

The solution to the problem today is a collection of compromises. Today's planning is based on a set of local optimisers and manual interventions. The objective is to have a global optimiser that can consider multiple dimensions of the flight schedule.

Why is this a good problem for exploring a Quantum solution? What metrics are sought to be improved (speed, accuracy, training time, etc.)?

Tail Assignment is the problem of assigning individual aircraft to a set of scheduled flights while ensuring multiple constraints and aiming to minimise an objective function, such as operating costs. Given the enormous possibilities and constraints involved, this problem is very difficult to solve optimally in classical computers within polynomial time.

So, this problem is a good candidate to be explored using Quantum computing as quantum algorithms can solve these kinds of problems faster and more efficiently than classical algorithms.

The quantum solution shall target improvement in metrics such as reduction in operational cost and maximise aircraft utilisation while addressing all constraints.

Current Solution

How is the problem currently being addressed?

The airline's "Schedule Planning Team" decides the flight schedules several months in advance. Airlines use a complex matrix called "Airline Scheduled Planning" to fix flight timings. They use software and feed in the historical data for a flight's departure and arrival, and block time for each specific route on a specific day. The software analyses this data and suggests a schedule for that flight. Other than the software, airlines also consider certain variables to schedule flights such as airport, connecting flights, turnaround time, flight route, competition, type of destination, and unexpected factors such as weather and construction of airports/runways.

What are the results of the current solution?

The metric "on-time performance of flights" reflects the robustness of flight scheduling algorithms. An on-time performance of >80% is considered excellent while an on-time performance of >90% is considered an exception. Airlines operating in congested airports have a hard time maintaining even an 80% performance. A 60-70% on-time performance is considered low while 70-80% is considered OK.

Are the current results satisfactory? What are the limitations of the current solution?

Current results are not satisfactory mainly because of several external and unpredictable factors that impact on-time performance. A more robust solution needs to consider these unpredictable factors. This requires access to a lot of data and advanced algorithms that can consider these factors while scheduling flights.

Problem definition for the Quantum Challenge

Redefined scope of the problem for the purpose of the Challenge

We propose to generate fleet schedules by solving the tail assignment/aircraft assignment problem after taking into consideration all mandatory operational constraints across:

a) Flight operations
b) Maintenance planning

So, the objective of the problem is to maximise aircraft resource utilisation by allocating available aircrafts from the various fleet types to all the flights in the schedule while addressing all the constraints, thereby improving/minimising the operational cost.

Sample mathematical optimisation model of the problem

Parameters

$F =$ Set of flights. Each flight is defined by its origin, destination, departure, and arrival time.

A = Set of available aircraft.

C = Set of base airports.

D = Set of days.

H = Set of fleet types.

w_{ia} : Cost of assigning flight $i \in F$ to aircraft $a \in A$.

$c_{i,j,a}$: Cost of assigning flight j directly after flight i to aircraft $a \in A$.

$p_{a,c} = 1$, if aircraft $a \in A$ is in base $c \in C$, otherwise 0.

$qstart_{c,f} = 1$, if flight $f \in F$ starts from base $c \in C$, else 0.

$qend_{c,f} = 1$, if flight $f \in F$ ends at base $c \in C$, else 0.

$n_{d,h}$: Maximum number of aircraft of fleet type $h \in H$ allowed to fly on day d.

Decision Variables

$x_{i,a} = 1$, if flight i is assigned to aircraft a, else 0. $\forall i \in F$, $\forall a \in A$

$y_{i,j,a} = 1$, if flight i and j both are assigned to aircraft a and are performed consecutively, else 0.

$z_{a,d} = 1$, if aircraft a has been assigned to any flights on day d, otherwise 0.

Objective Function

Minimise the total operating cost and maximise aircraft utilisation.

Constraints

1. Each scheduled flight should be flown by exactly one aircraft.
2. Aircraft continuity constraint: If a flight is arriving at a certain airport assigned to an aircraft, the next flight (if any) assigned to that aircraft must depart from the same airport.
3. For consecutive flights assigned to an aircraft, the turn-around time in the schedule should not be less than the turn-around time of that airport.
4. Demand Fulfilment constraint: Aircraft Type is assigned based on Aircraft capacity and Forecasted seats/demand for the day.
    a. If a suitable Aircraft based on Forecasted seats is not available for the scheduled time, then assign an Aircraft with lower capacity (vice-versa). This is because On-Time-Performance and Aircraft Utilization are more important than demand fulfilment.
5. The last flight should finally return to the same Aircraft base.
6. The number of flights/trips assigned to an Aircraft for a particular day should not exceed the predefined limit.

7. Curfew time constraints: The Flight schedules shall address the following constraints—Airport open and close time, Day of Week, Curfew time of the Airport.
8. Aircraft Maintenance constraint: The flight schedules shall address the following constraints—Unavailability of Aircraft for scheduling due to Aircraft maintenance.

Description of the data/datasets provided

- **Airport**: Departure and Arrival Curfew timings, Day of Operation, Maximum Arrival Buffer Time of the Airport
- **Aircraft**: Aircraft Type, Aircraft Tail, Number of Seats/Capacity, Aircraft Base, Operating cost of the Aircraft, and Maximum allowed trips per day
- **Turn Time**: Minimum Turn time per Airport and Aircraft Type
- **Planned Aircraft Maintenance**: List of Aircraft under Maintenance (unavailability for scheduling)
- **Planned Schedule**: Initial Schedule planned per season based on historical data and demand

Expected Output

The expected output is the optimised schedule based on Fleet Allocation/Tail Assignment addressing all the operational constraints.

For more details, please refer the output data structure file in the provided data set.

Challenge Evaluation Criteria

The entries will be evaluated by a Jury panel consisting of experts from the Industry and Academia. A representative list of criteria that would be considered by the Jury while evaluating the Phase-I and Phase-II submissions is given below. Please note that there are no specific weightages assigned to any of the criteria, and this should not be interpreted as a comprehensive list. The criteria listed below are indicative, and the Jury panel would be free to use their expertise, experience, and judgement to evaluate the entries.

Phase I:

- **Background work done:** Quality of background work done to understand the use case and the state of the art.
- **Innovation Quotient:** The overall innovation quotient in terms of originality and novelty seen in the approach, concept, and the algorithm.
- **Comprehensiveness:** Level of detail, coverage of the tasks towards the targeted goal of the challenge.
- **Promise:** As reflected through the results from any early experimentation done. Promise of the planned approach for Phase II.
- **Technical soundness:** Ability of the team to defend their work during presentation/ interaction with the Jury. Capability of the team to carry forward the work.

Phase II:

- **Innovation Quotient:** The overall innovation quotient in terms of originality and novelty seen in the approach, concept, and the algorithm.
- **Comprehensiveness:** Level of detail, coverage of the tasks towards the targeted goal of the challenge.
- **Technical completeness:** Quality and completeness of the code/solution and its ability to execute and produce results as documented.
- **Comparison with internal benchmarks:** How well the solution compares with any benchmark results that may have been achieved by the organisers.
- **Impact:** Value impact of the solution on current quantum hardware (any benefits shown in terms of improved optimisation, speed, and accuracy vis-à-vis classical approaches).
- **Extensibility:** Ease of adapting/modifying the solution to address variants of the use case (especially additional complexities).
- **Resource requirements & Scalability:** Any resource estimation provided for the solution to indicate the potential future scaling of the solution.
- **Technical soundness:** Ability of the team to defend their work during presentation/ interaction with the Jury. Capability of the team to carry forward the work.
- **Pitch:** Clarity, demonstration, and structure of the overall pitch.

Solution KPI

The participant can come up with one schedule.

Alternately, the participant can come up with multiple schedules with different resource utilisation levels that address all constraints but provide different operational efficiencies for each schedule, demonstrating the flexibility provided (in terms of additional buffer for any runtime disruptions) at a minimal cost. More weightage will be given to such a solution.