Inter IIT Tech Meet 12.0, IIT Madras

# Quantum – Computing Challenge

# Understanding the Problem Statement

01.

Analyse flights impacted due to schedule changes, aircraft type changes etc.

02.

PNR level re-accommodation.

03.

Allotment of Cabin and subsequently a class for each passenger within PNR.

04.

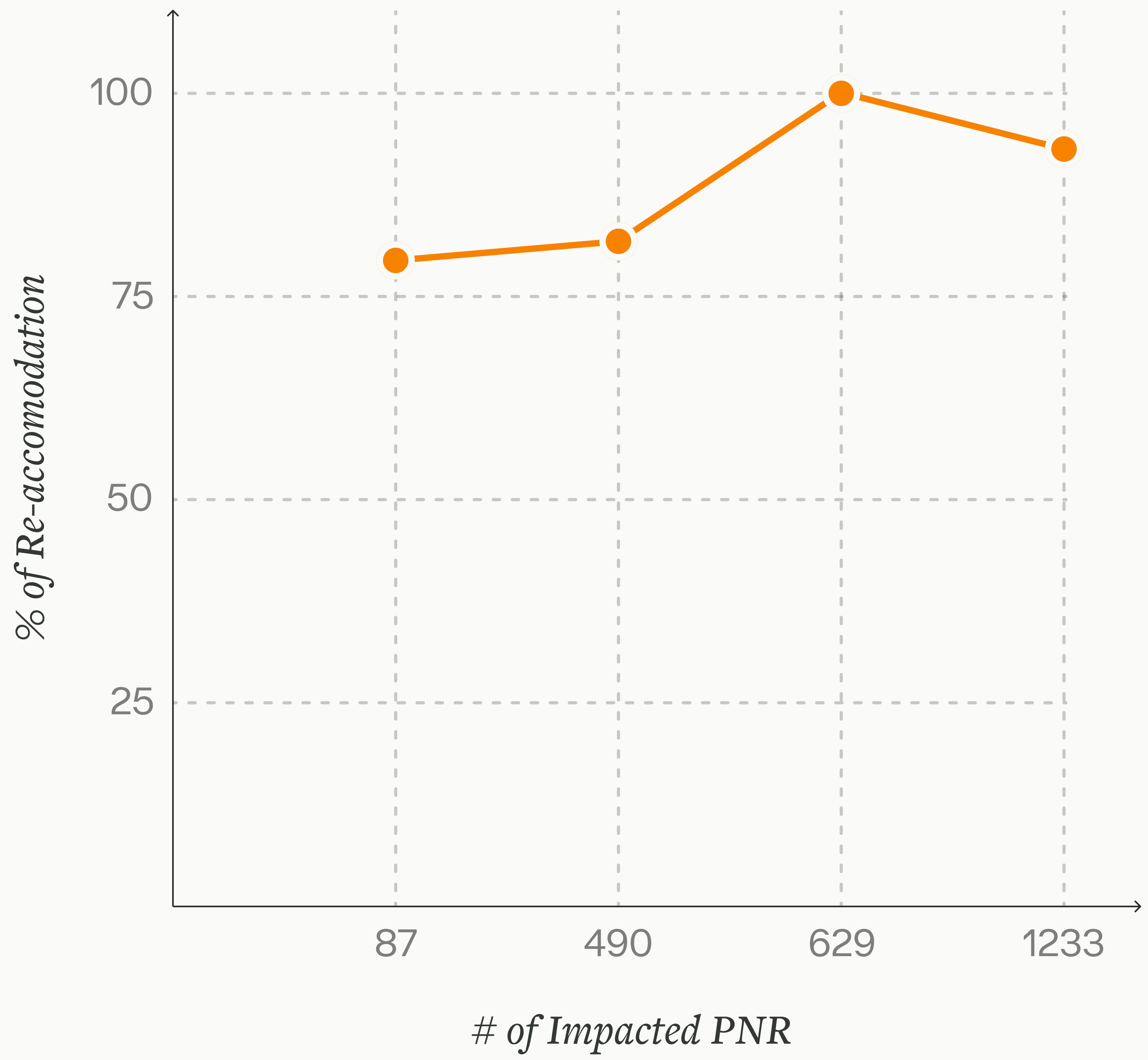
Alternate flight solutions with configurable number of hops.

05.

Exhaustiveness and effectiveness of our quantum solution with flexible business rules.

Setting the Stage

# Introducing Our Primary Solution



## Setting the Stage

# Introducing Our Primary Solution

## Solution File - 1

Select a PNR:

BDGM27

Email: mockpnr@gmail.com

### Original Flights

**Inventory ID:** INV-ZZ-7954823

**Cabin:** FC

**PAX Classes:** F, F

**Departure Time:** 2024-04-10 02:25:00

**Arrival Time:** 2024-04-10 21:44:00

**Departure Airport:** MAA

**Arrival Airport:** TRV

### Proposed Flights

**Inventory ID:** INV-ZZ-9584146

**Cabin:** BC

**PAX Classes:** J, J

**Departure Time:** 2024-04-10 19:54:00

**Arrival Time:** 2024-04-11 02:05:00

**Departure Airport:** MAA

**Arrival Airport:** TRV

| Solution 1 | Solution 2 | Solution 3 |
|---|---|---|
| Total impacted PNRs are : 1233 | Total impacted PNRs are : 1233 | Total impacted PNRs are : 1233 |
| Reaccommodated PNRs : 1117 | Reaccommodated PNRs : 1117 | Reaccommodated PNRs : 1117 |
| Total impacted PAX are : 4427 | Total impacted PAX are : 4427 | Total impacted PAX are : 4427 |
| Reaccommodated PAX : 3744 | Reaccommodated PAX : 3744 | Reaccommodated PAX : 3745 |
| PNRs Upgraded : 667 | PNRs Upgraded : 653 | PNRs Upgraded : 622 |
| PNRs Downgraded : 233 | PNRs Downgraded : 235 | PNRs Downgraded : 245 |
| PNRs with city pairs same : 1108 | PNRs with city pairs same : 1108 | PNRs with city pairs same : 1108 |
| PNRs with city pairs different : 9 | PNRs with city pairs different : 9 | PNRs with city pairs different : 9 |
| Mean Arrival Delay(in Hours) : 31.847 | Mean Arrival Delay(in Hours) : 31.823 | Mean Arrival Delay(in Hours) : 31.878 |
| One-One(%) : 97.224709042077 | One-One(%) : | One-One(%) : |

Understanding the Problem Statement

# Input Structure

PNRs

Flight Schedules

Disrupted Flights

Business Rule Profile

Penalty Scores

Understanding the Problem Statement

# Output Structure

| | | | | |
|---|---|---|---|---|
| Accommodated PNRs (same city pair) | Accommodated PNRs (different city pair) | Unaccommodated PNR List | Email option to get PAX preferences | Multiple Feasible accommodation solutions |

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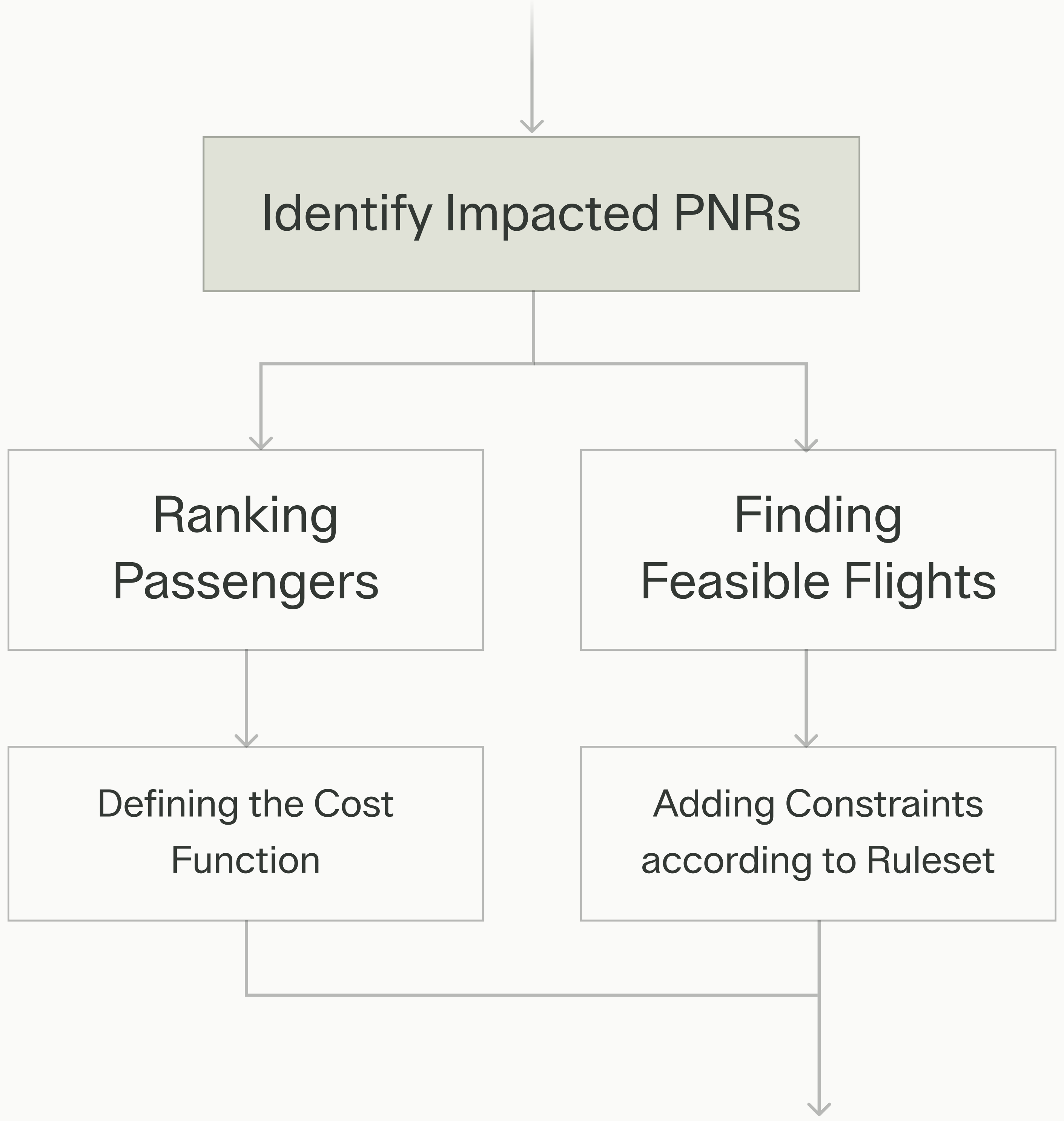
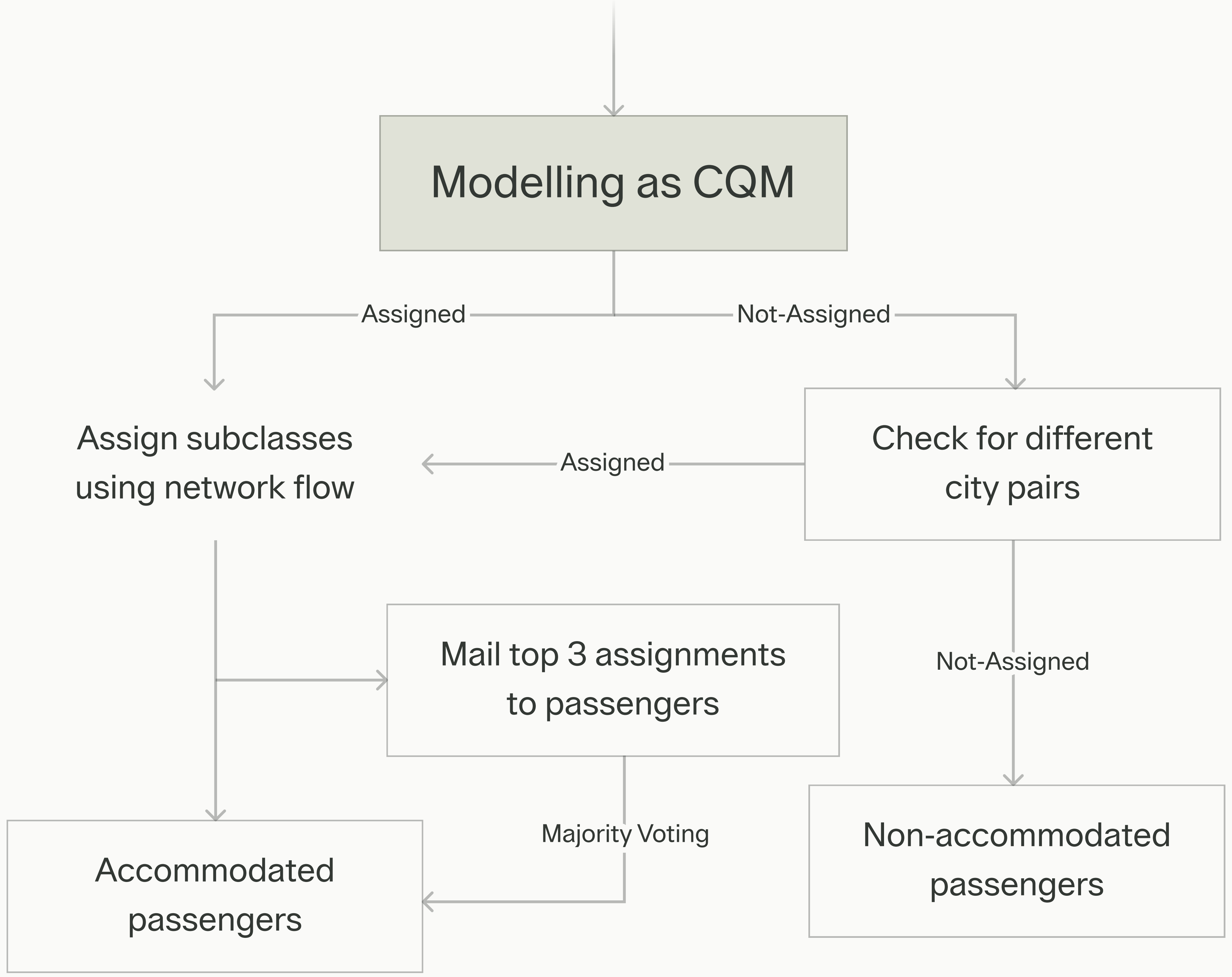
# Our Pipeline

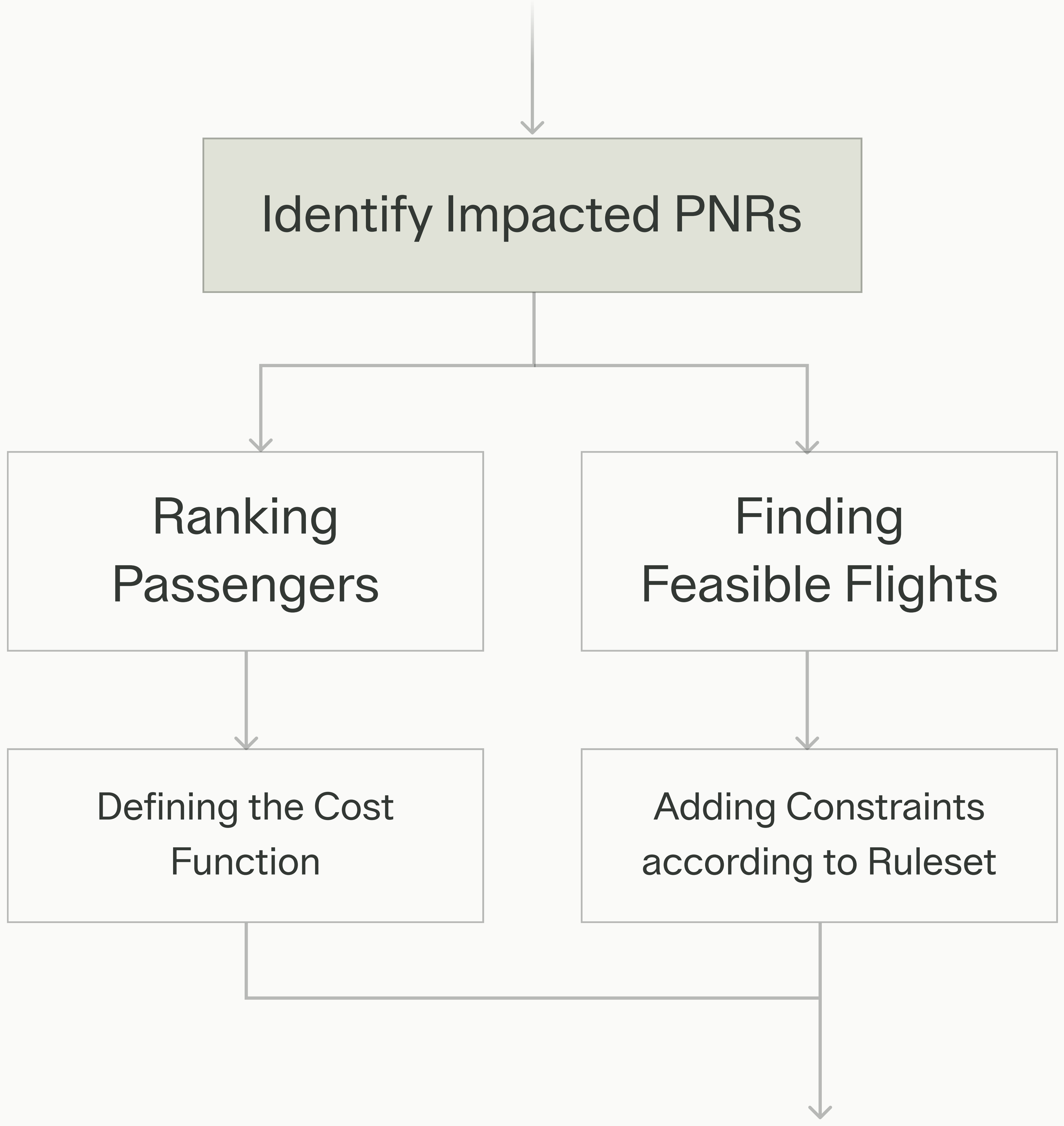



*PreProcessing*




*Quantum Modelling*

# PreProcessing




01\.
**Identifying Impacted PNRs**

02\.
Finding Feasible Flights

03\.
Adding Constraints

04\.
Cost Function and PNR ranking

# Identification of Impacted PNRs

01.

## Identifying Impacted PNRs

Impacted PNRs are filtered out of the input dataset by identifying flights which have been cancelled and extracting the PNRs that were originally travelling on those flights.

02.

## PNR Splitting

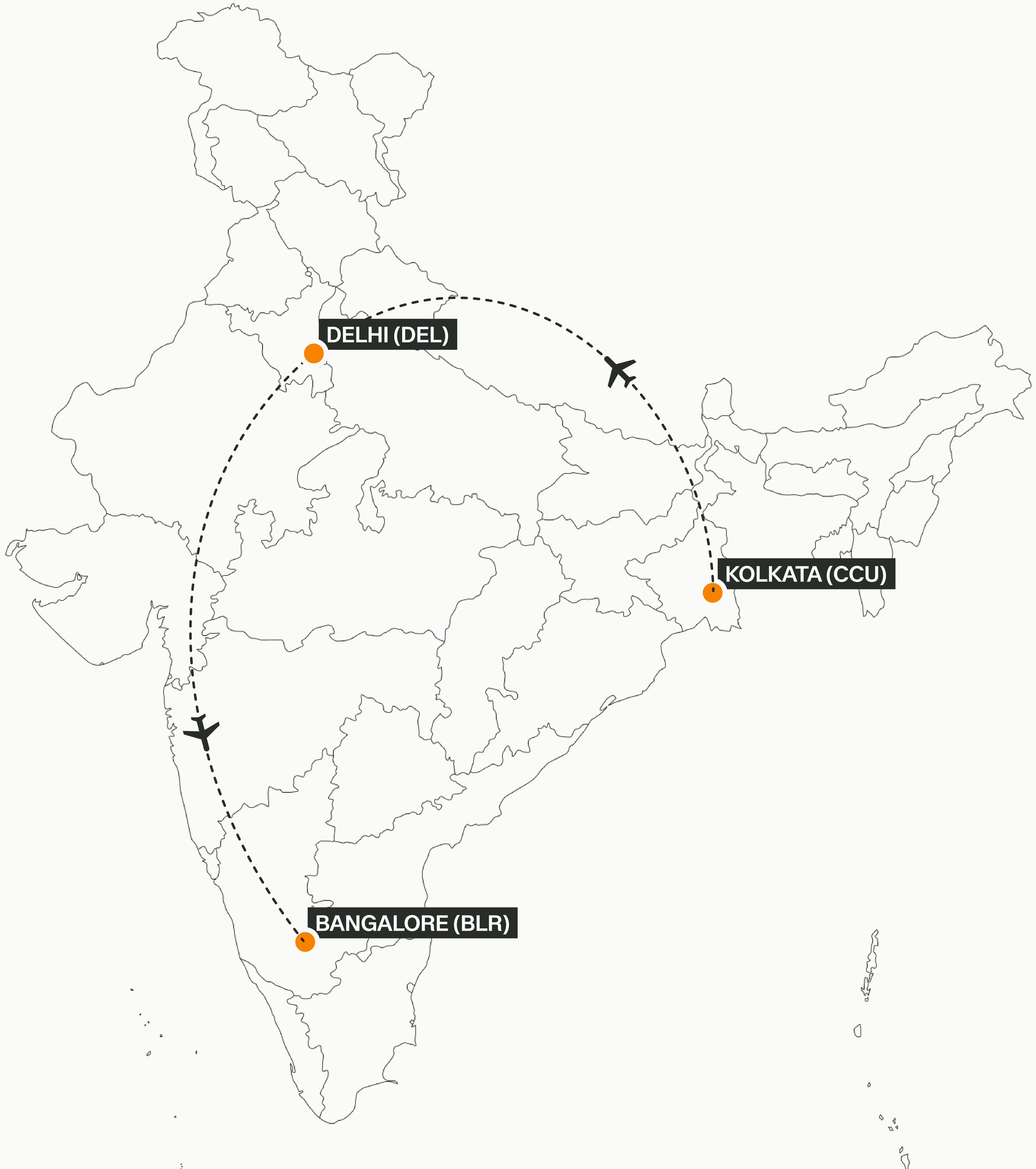
Our Algorithm uses a novel PNR Splitting approach to handle round trip and Multi-City Bookings by splitting the PNR into different parts so that each leg of the journey is treated separately.

# Cancellation in Multi-City Bookings

**PNR 1**

01. CCU - DEL
02. DEL - BLR

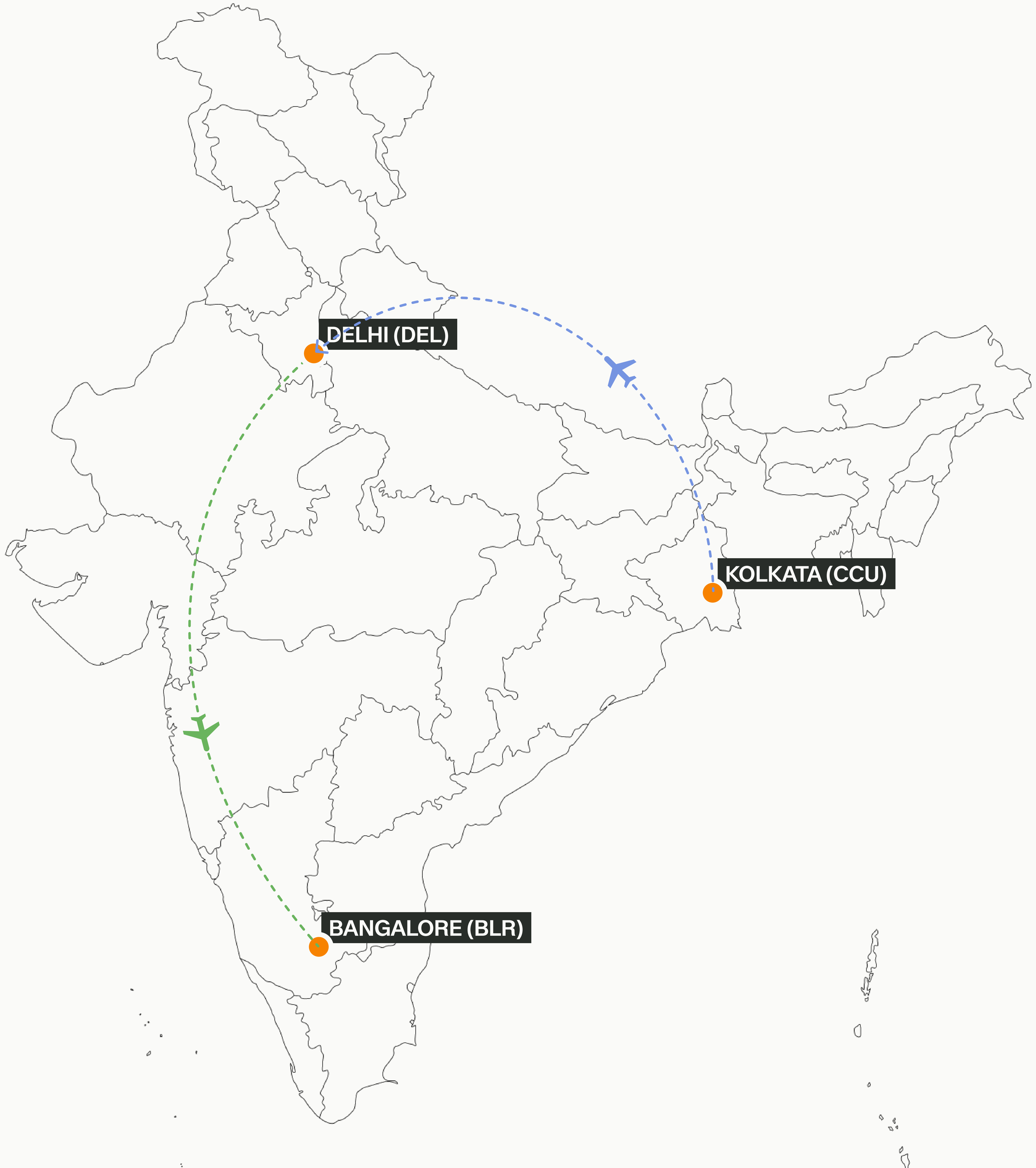
When the time difference between the 2 flights exceeds the maximum connection time, they are considered as a multi city booking instead of a connecting flight.



# Cancellation in Multi-City Bookings

**PNR 1 #1**
01. CCU - DEL

**PNR 1 #2**
01. DEL - BLR



# Cancellation in Round Trip Booking

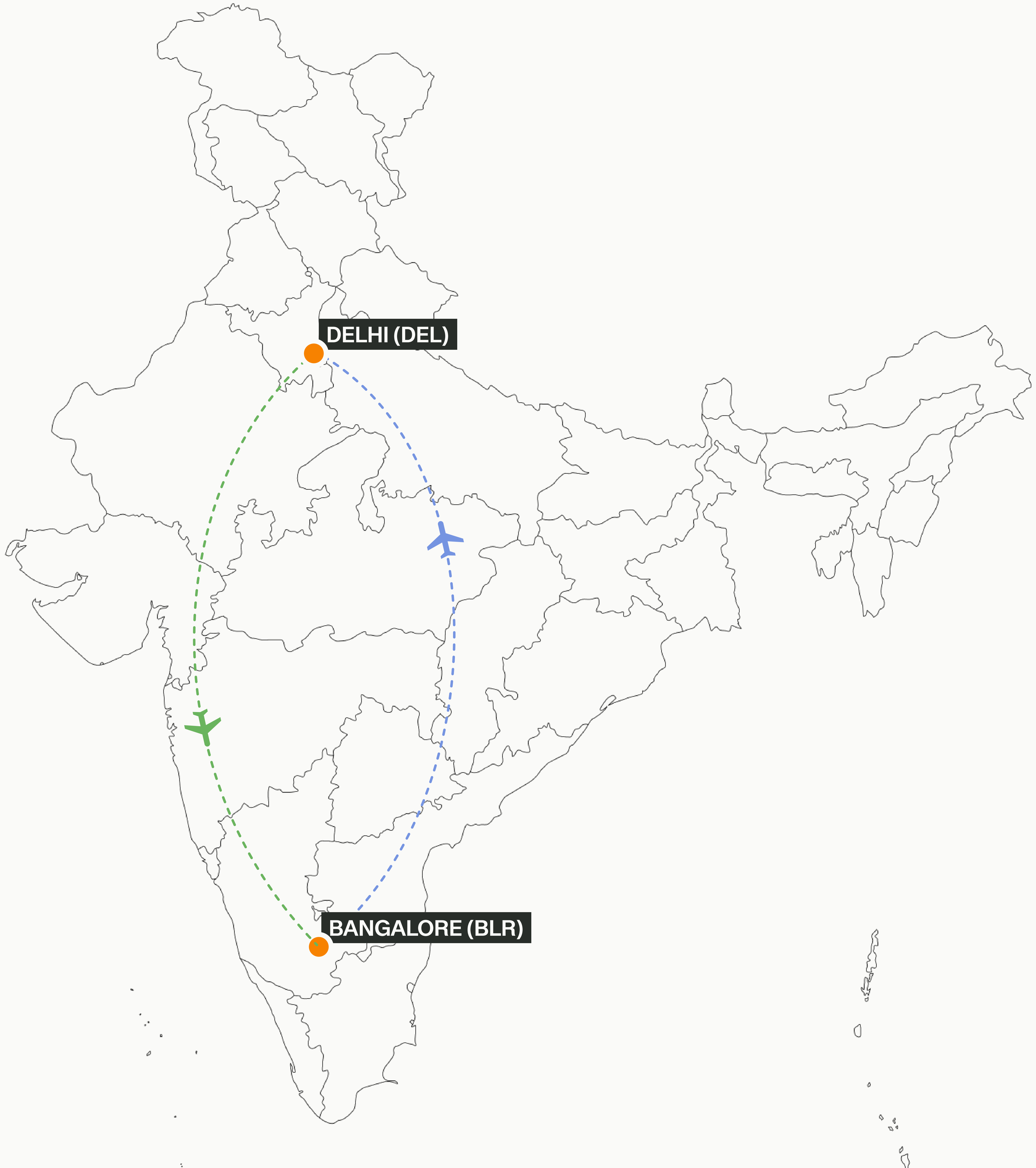

**PNR 1**

01. DEL - BLR
02. BLR - DLR

# Cancellation in Round Trip Booking

**PNR 1 #1**
01. DEL - BLR

**PNR 1 #2**
02. BLR - DEL



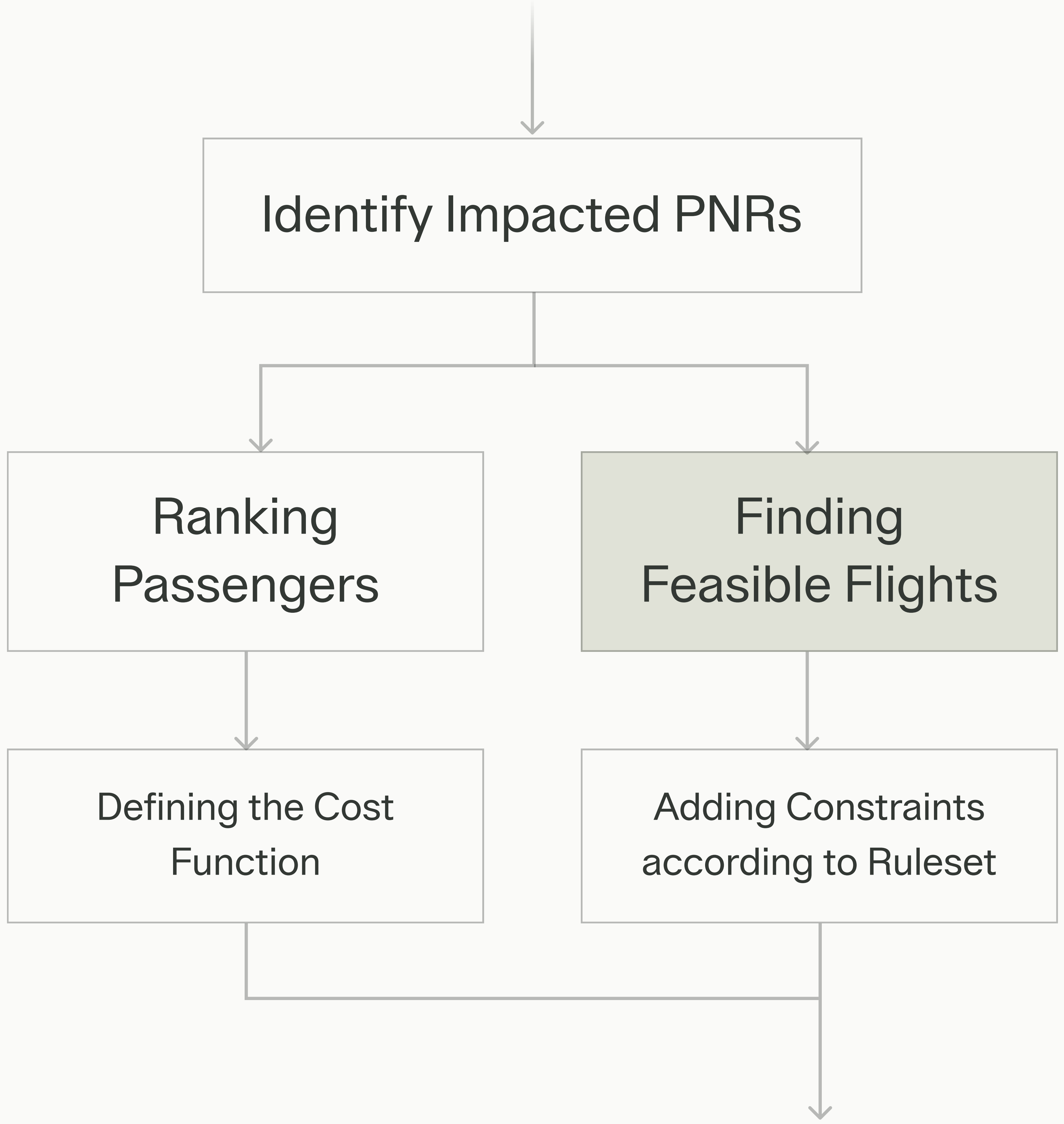
# PreProcessing

01\. Identifying Impacted PNRs

02\. Finding Feasible Flights

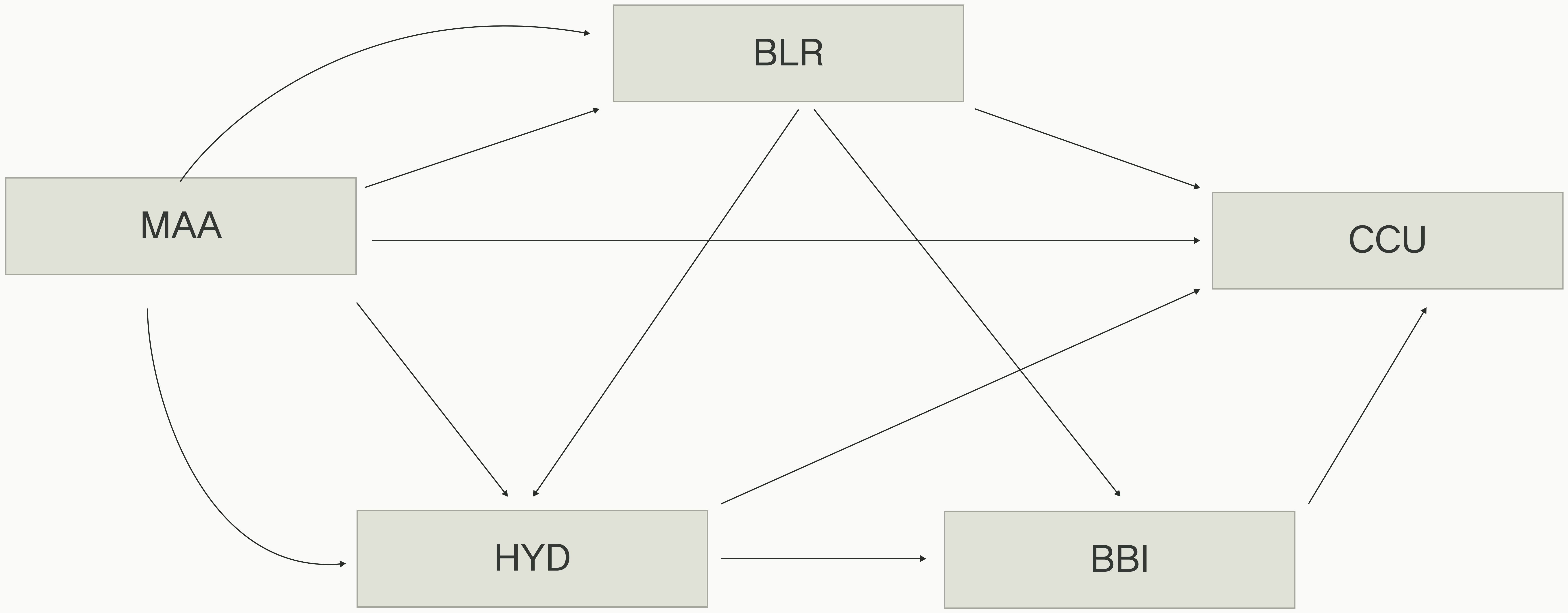
03\. Adding Constraints

04\. Cost Function and PNR ranking



# Finding Feasible Flights

**Scenario:**
PNR 1's impacted flight is from MAA to CCU.




*Multi-DiGraph of On-Time Flights*

# PreProcessing

01.

Identifying Impacted PNRs

02.

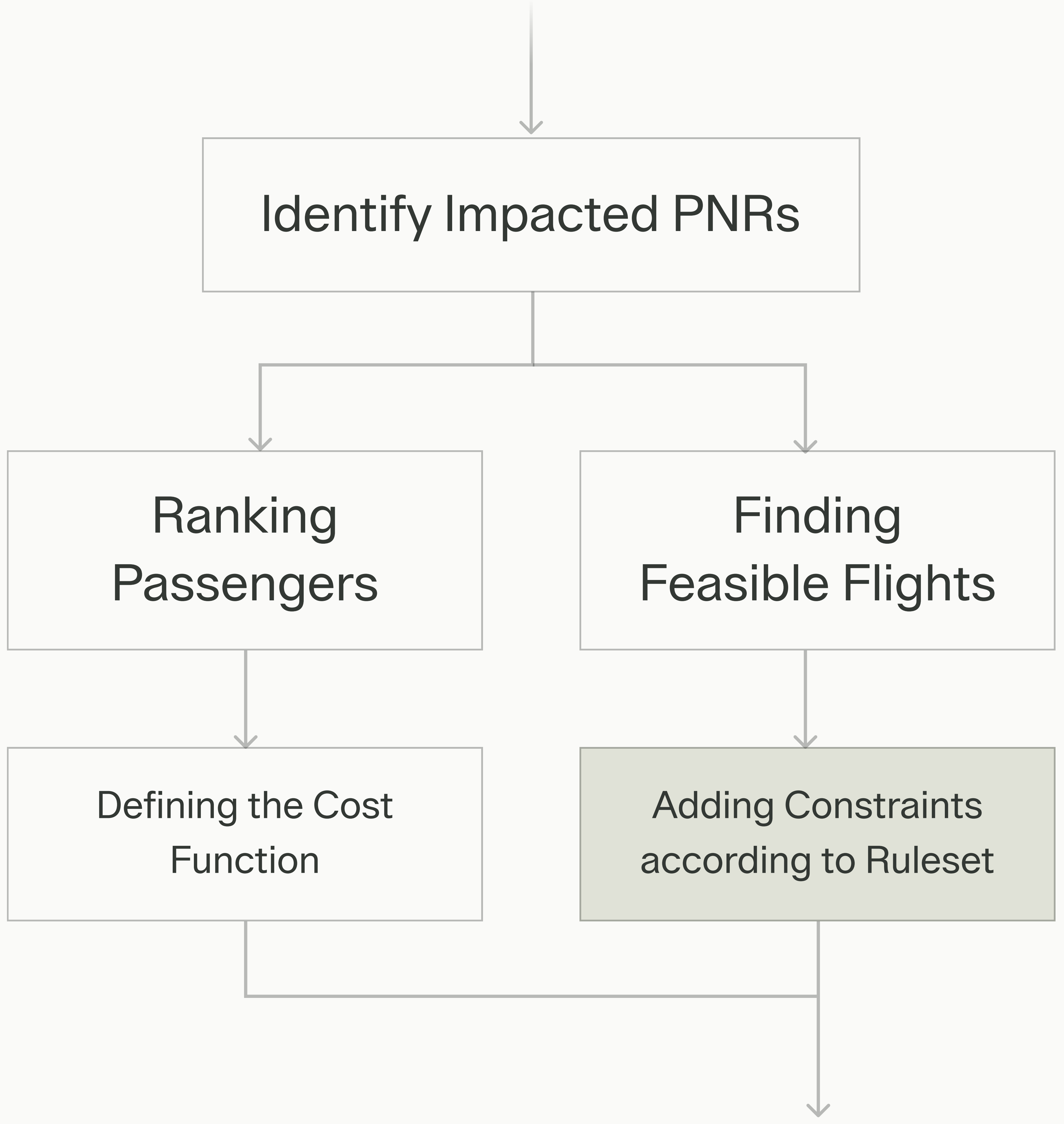
Finding Feasible Flights

03.

Adding Constraints

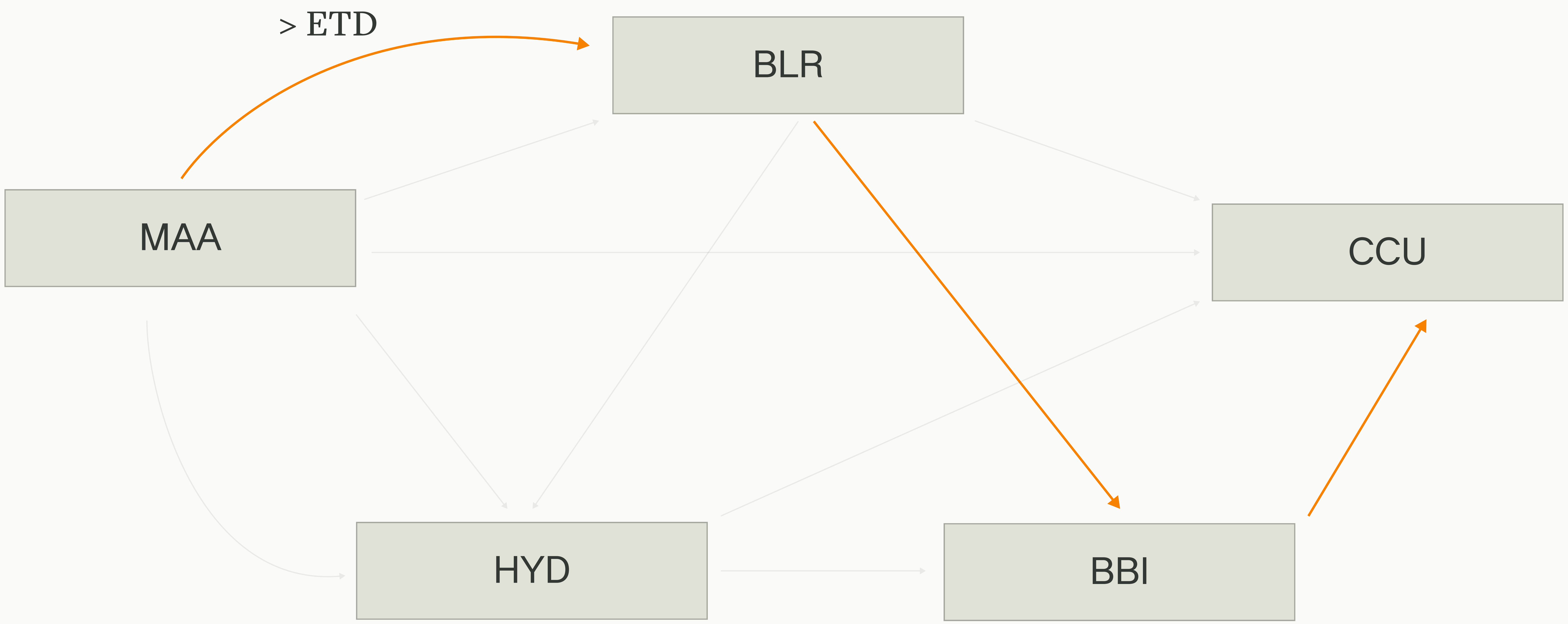
04.

Cost Function and PNR ranking



# Prune and Search

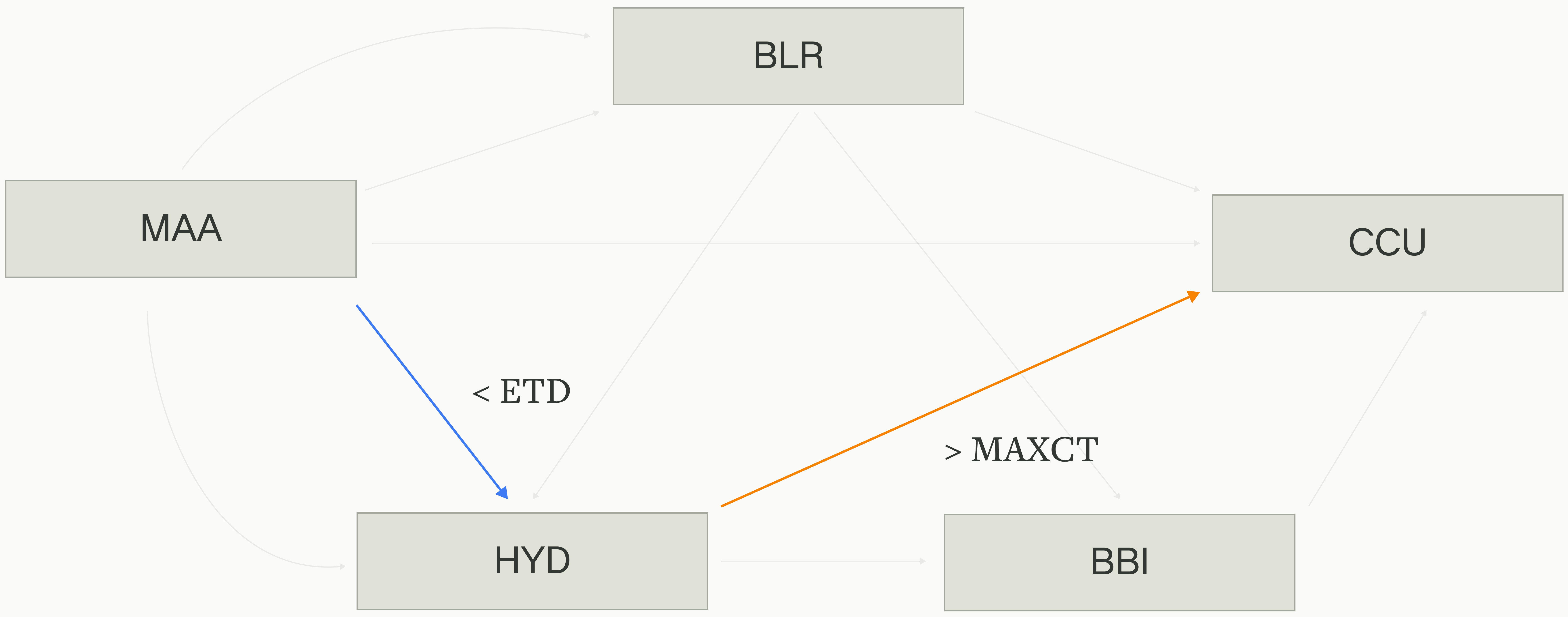
**Constraint Check 1:**
We don't visit an edge further if **Dep Delay** >**Max Dep. Delay**




*Multi-DiGraph of On-Time Flights*

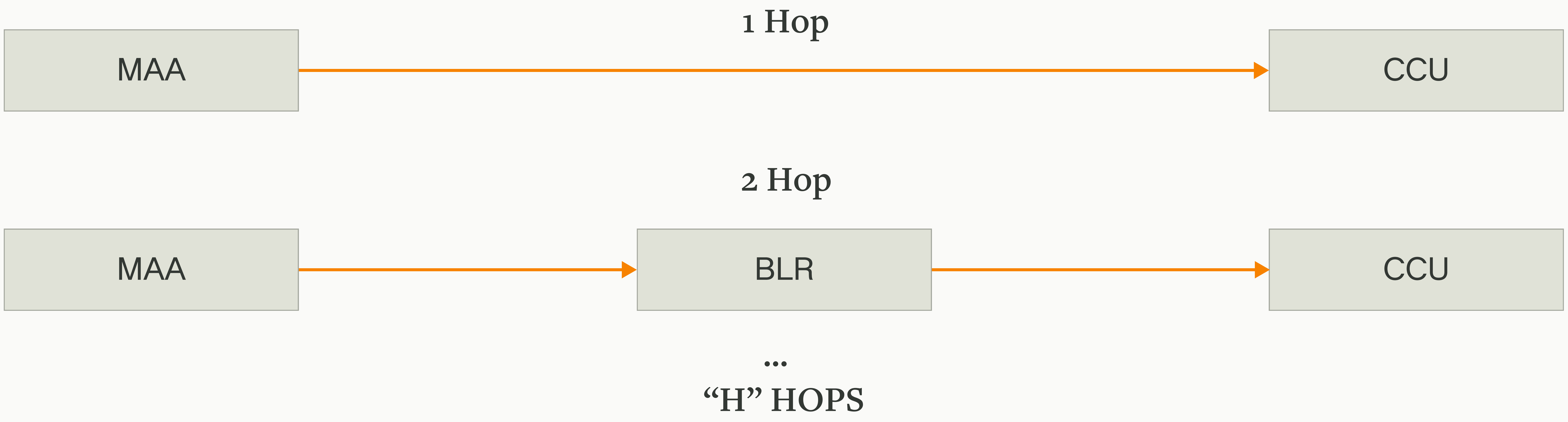
# Prune and Search

**Constraint Check 2:**
We visit an edge only if
**MINCT <= Connection Time <= MAXCT**




*Multi-DiGraph of On-Time Flights*

# Feasible Flights




01.

Outputs all possible paths like one-one, multi-one , multi-multi and one-multi.

02.

Exponential Decrease in Inference Time using Dynamic Programming

03.

Flexible Number of Hops which can be configured by the airline

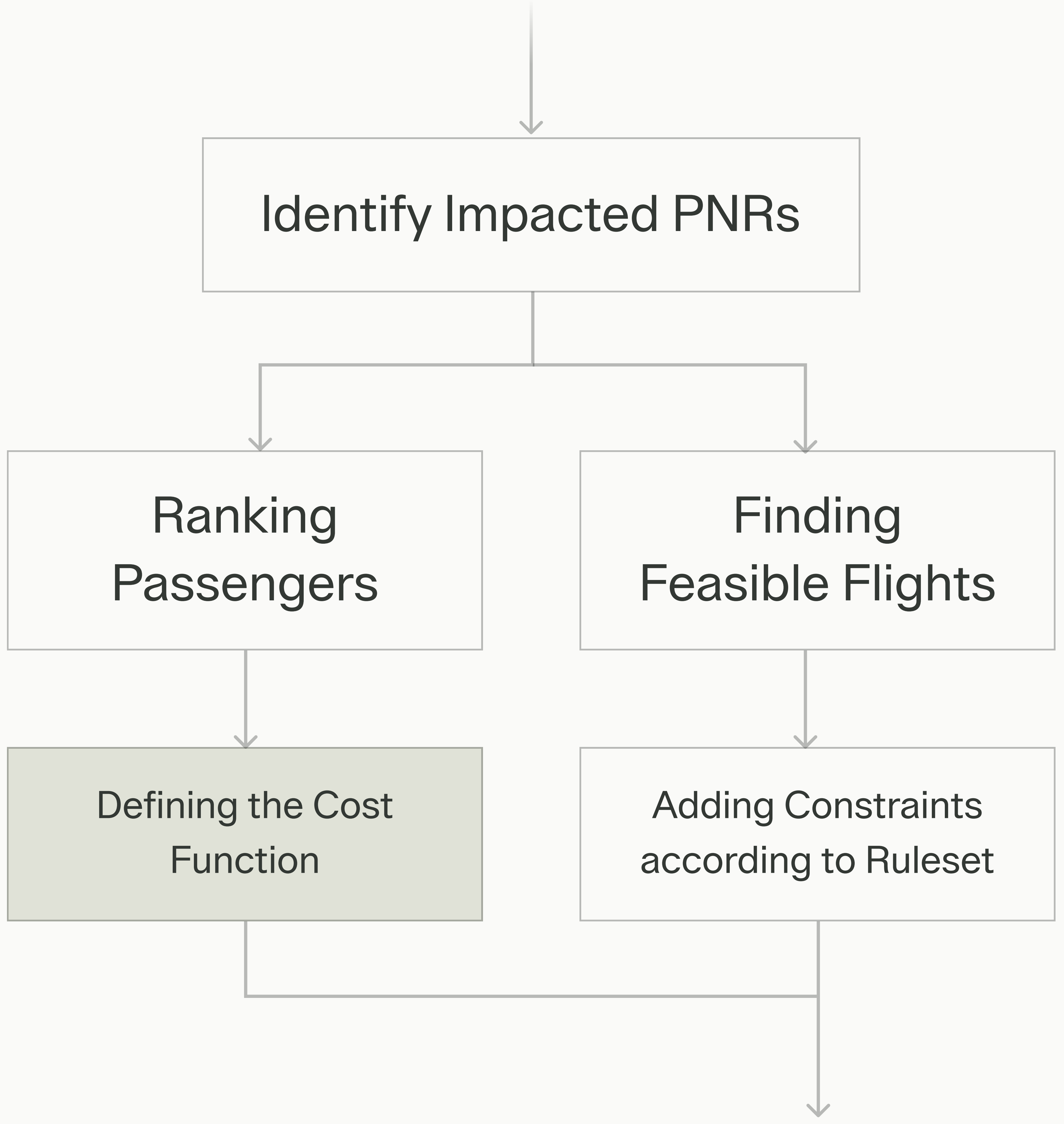
# PreProcessing

01\.
## Identifying Impacted PNRs

02\.
## Finding Feasible Flights

03\.
## Adding Constraints

04\.
## Cost Function and PNR ranking



# Cost Function

$$C_{ijk} = a * log(s_1) + b * log(s_2) + c * log(s_3)$$

$s_1$ = Flight Quality Score

$s_2$ = PNR Ranking Score

$s_3$ = Cabin Ranking Score

a, b, c are the **input weight** given by the airlines.

# Cost Function

$$C_{ijk} = a * log(s_1) + b * log(s_2) + c * log(s_3)$$

$s_1$ = Flight Quality Score

$s_1 = \sigma$ (Delay Score × Connection Score),

Delay Score = Arrival Delay Score + Departure Delay Score

Connection Score = CC - length of proposed itinerary + length of original itinerary

$\sigma$ is the sigmoid function $\sigma(x) = \dfrac{1}{1 + exp(-x)}$

# Cost Function

$$C_{ijk} = a * log(s_1) + b * log(s_2) + c * log(s_3)$$

$s_2$ = PNR Ranking Score

$s_2 = \sigma$ (SSR Score + Loyalty Score + PAX Score),

$\sigma$ is the sigmoid function $\sigma(x) = \dfrac{1}{1 + exp(-x)}$

# Cost Function

$$C_{ijk} = a * log(s_1) + b * log(s_2) + c * log(s_3)$$

$s_3$ = Cabin Quality Score

Weighted average of cabin for entire itinerary

Weights based on industry standards

Downgrades are penalised more than upgrades are rewarded

a, b, c are the **input weight** given by the airlines.

Cost Function

# Why Logarithms?

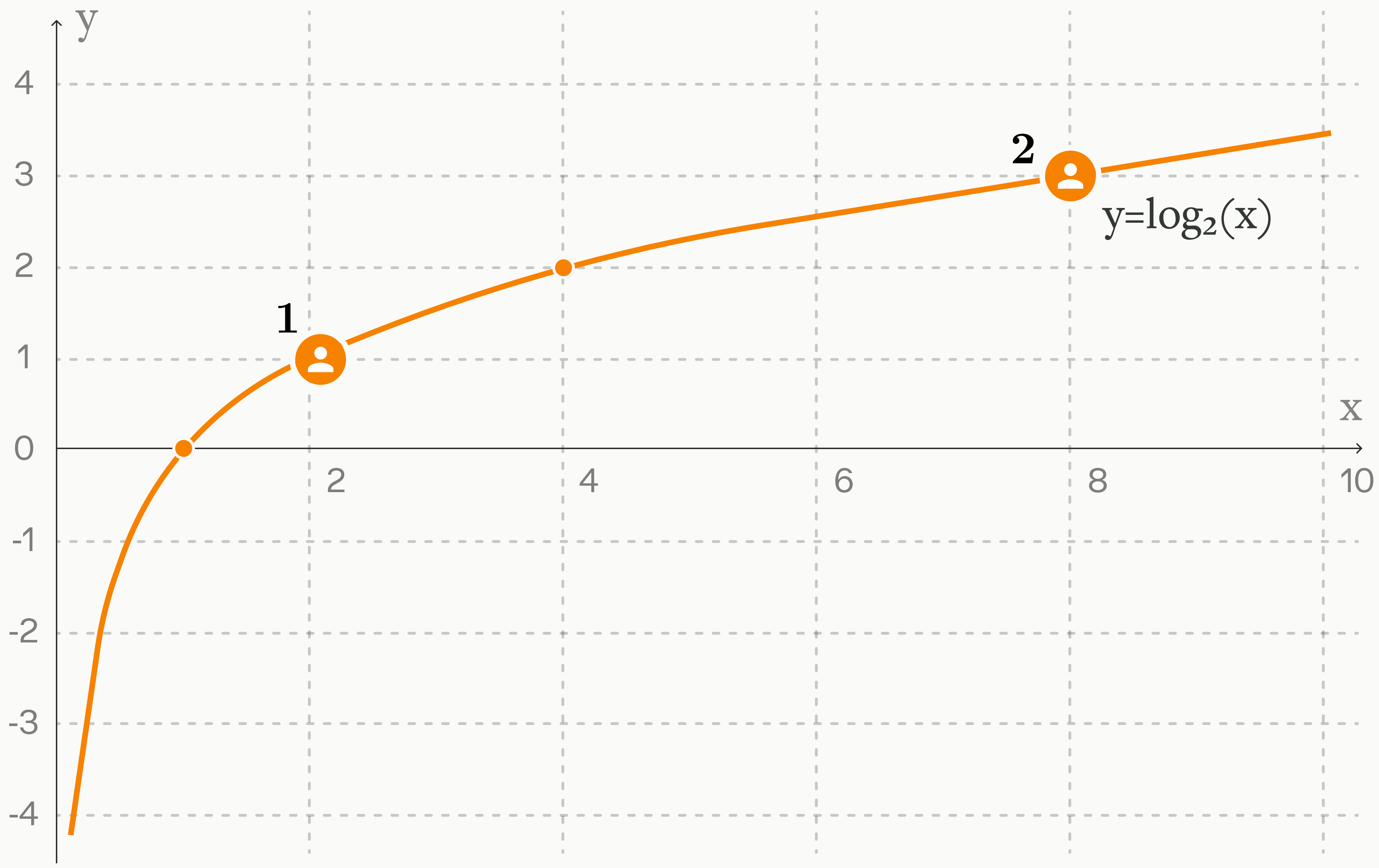
We can see that the reward in scenario 1 is greater than reward in scenario 2.

**Scenario 1:**
High Delay, Low score

$$\delta_x = 0.875$$
$$\delta_y = 3$$

**Scenario 2:**
Low delay, High Score

$$\delta_x = 0.875$$
$$\delta_y = 0.52$$



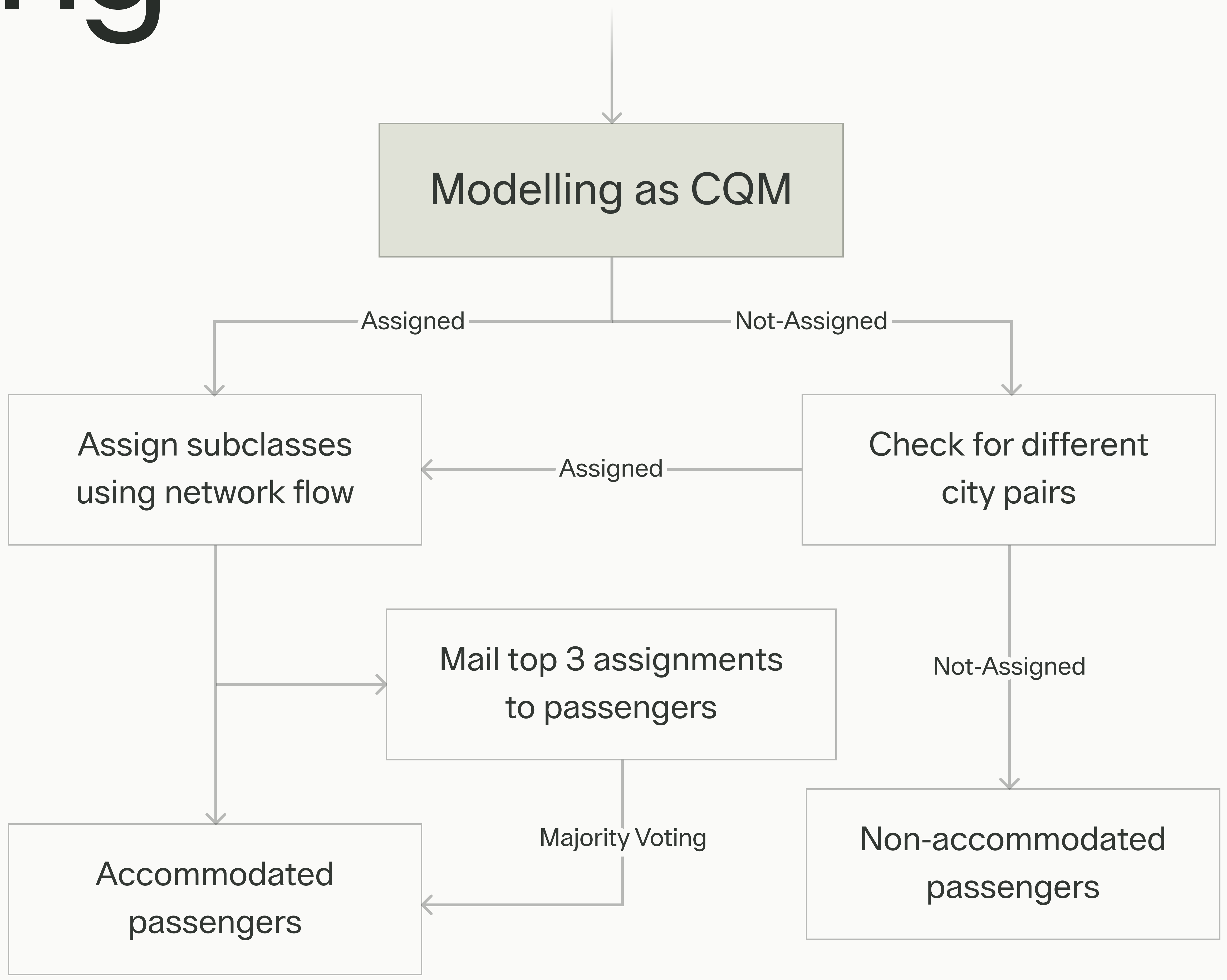
# Quantum Modelling

01.
## Modelling as CQM

02.
## Network Flow

03.
## Different City Pairs

04.
## Customer Feedback



## CQM Modelling

# Why CQM?

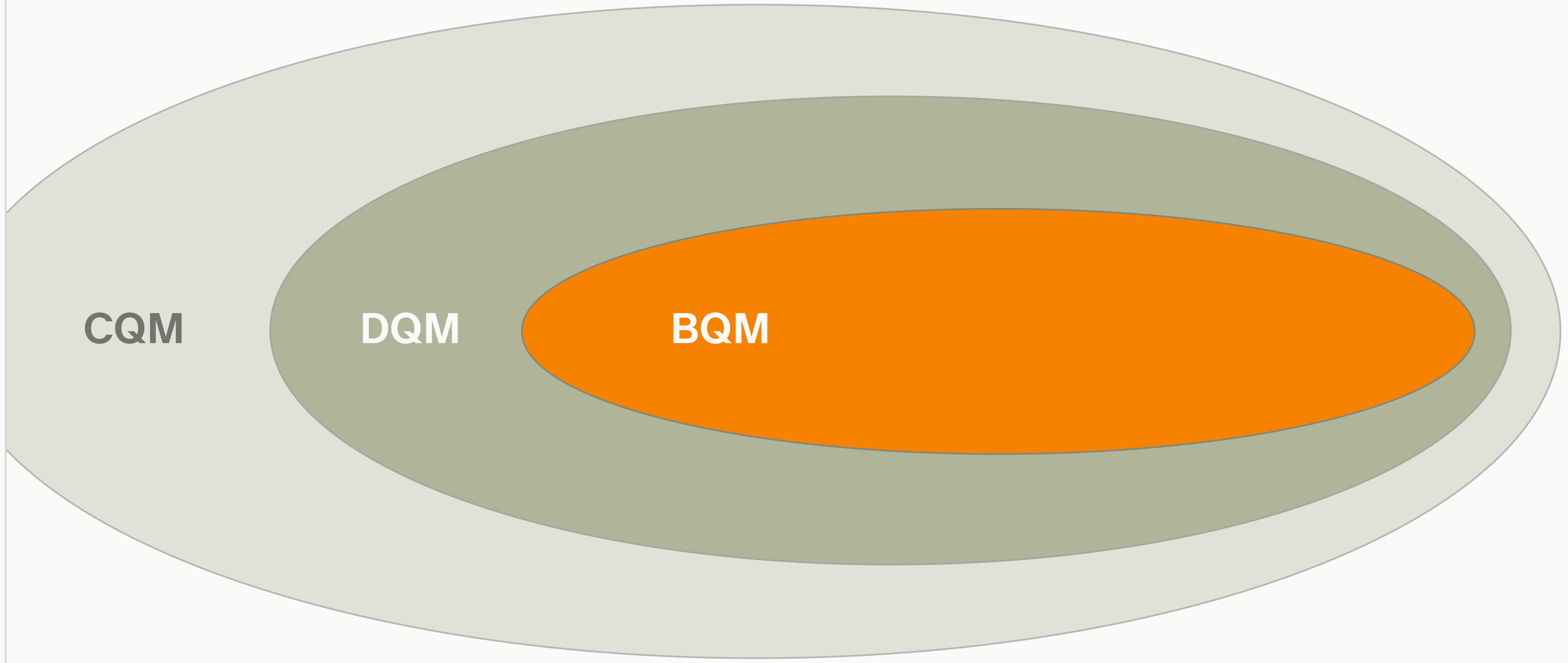
The Optimization Problem was formulated using a Constrained Quadratic Model (CQM) and solved using **Dwave's LeapHybridCQMSampler.**

The CQM model offers a powerful and flexible way of modelling problems with inherent constraints avoiding the need of penalizing each violation of a constraint.

## CQM Modelling

# CQM vs BQM

| Net Impacted PNR | BQM QPU Time (in ms) | CQM QPU Time (in ms) |
|---|---|---|
| 87 | 42.747 | 16.03 |
| 490 | 128.151 | 21.37 |
| 490 | 128.151 | 21.37 |
| 1233 | Could not solve the problem | 16.05 |




Despite tuning BQM's Lagrange Multiplier , it gives **infeasible** solutions sometimes.

BQM has **inferior run time** efficiency and offers less flexibility for modelling problems.

# Objective Function

Maximize:

$$\sum_{i \in I} \sum_{j \in F_i} \sum_{k \in K} C_{ijk} X_{ijk} + \sum_{i \in I} (\text{Non-Assignment-Cost} \times (1 - \sum_{j \in F_i} \sum_{k \in K} X_{ijk}))$$

$C_{ijk}$ represents the cost to accommodate the $i^{th}$ PNR to the $k^{th}$ cabin of the $j^{th}$ flight

$X_{ijk}$ is a decision variable that is 1 when the $i^{th}$ PNR is assigned to the $k^{th}$ cabin of the $j^{th}$ fligh

$b_{jk}$ represents the available inventory in the $k^{th}$ cabin of the $j^{th}$ flight

$F_i$ represents the set of Feasible Flights for the $i^{th}$ PNR

$n_i$ represents the number of passengers in the $i^{th}$ PNR

K represents the set of all cabins

I represents the set of all impacted PNR

# Constraints

## Capacity Constraint

$$\sum_{i \in P_j} X_{ijk} * n_i \leq b_{jk} \quad \forall k \in K \quad \forall j \in F$$

## Assignment Constraint

$$\sum_{j \in F_i} \sum_{k \in K} X_{ijk} \leq 1 \quad \forall i \in I$$

# Quantum Modelling

01. Modelling as CQM

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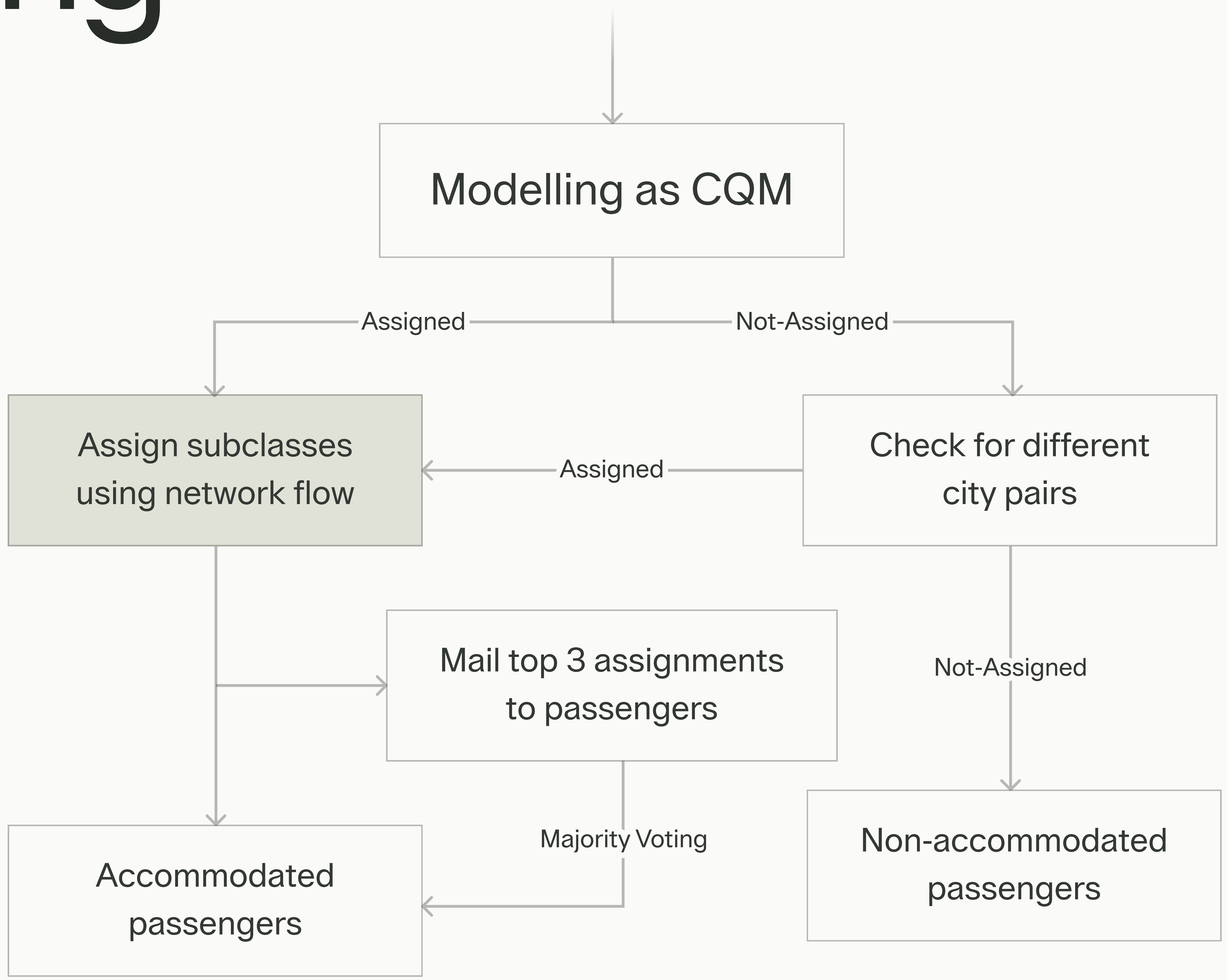
04. Customer Feedback



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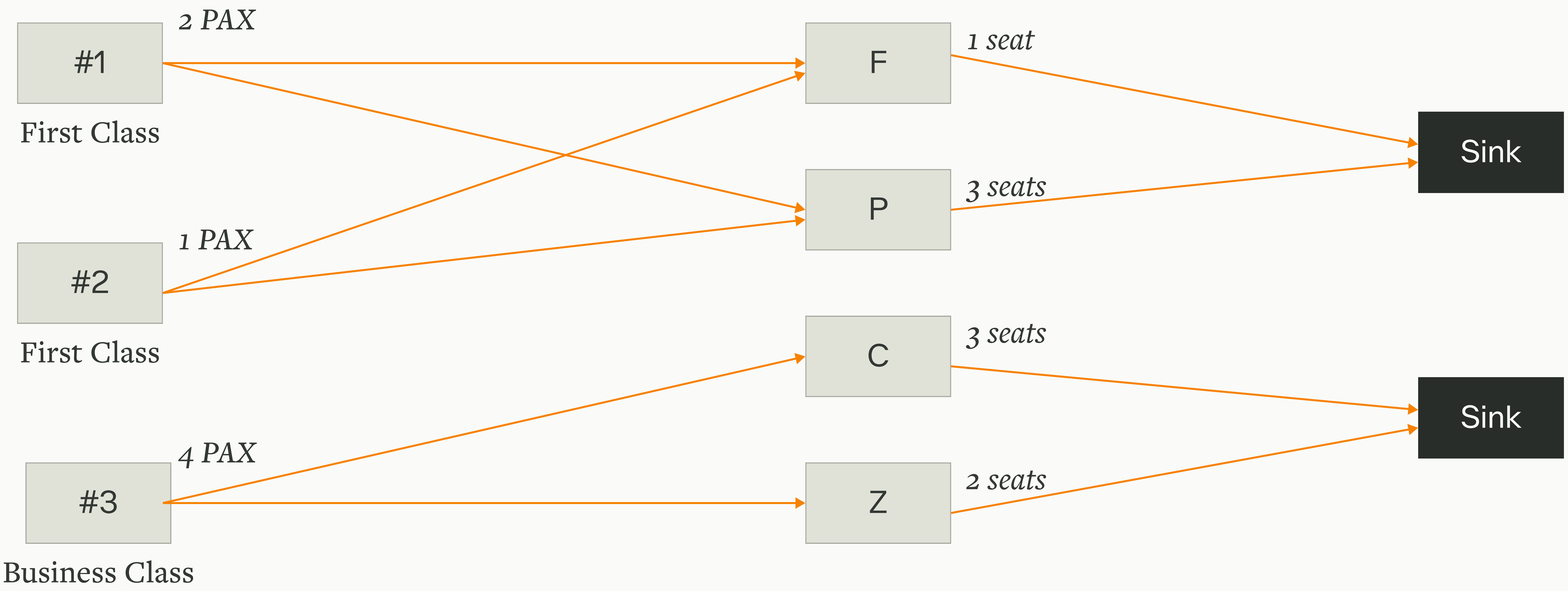
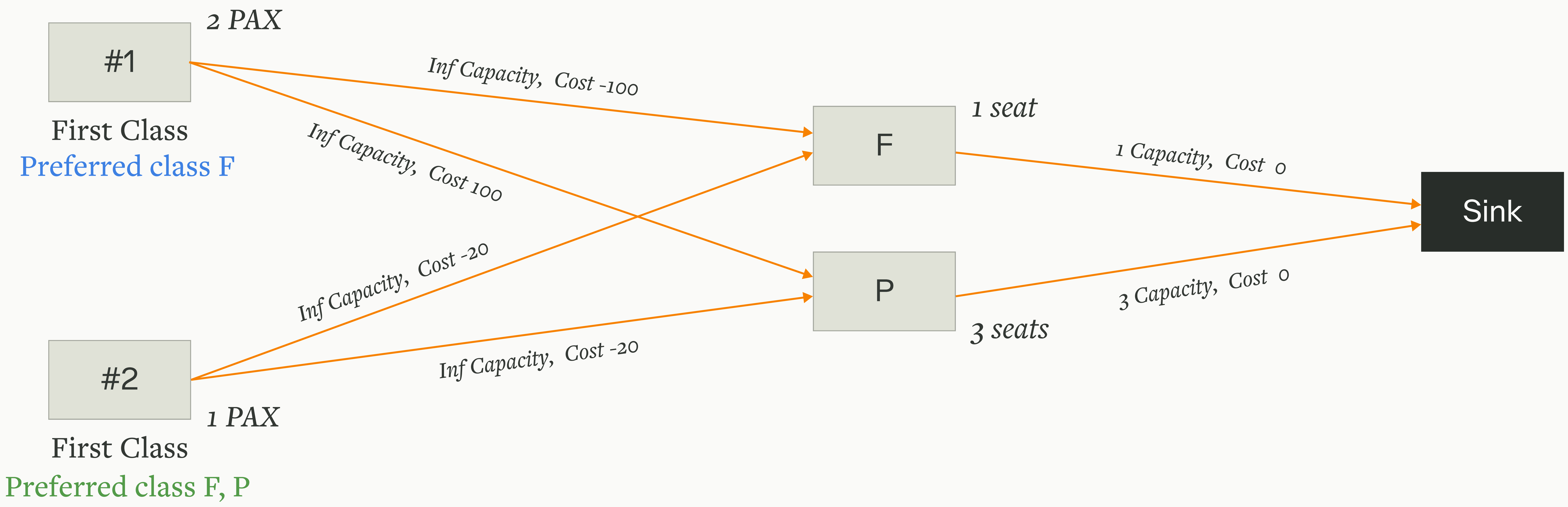
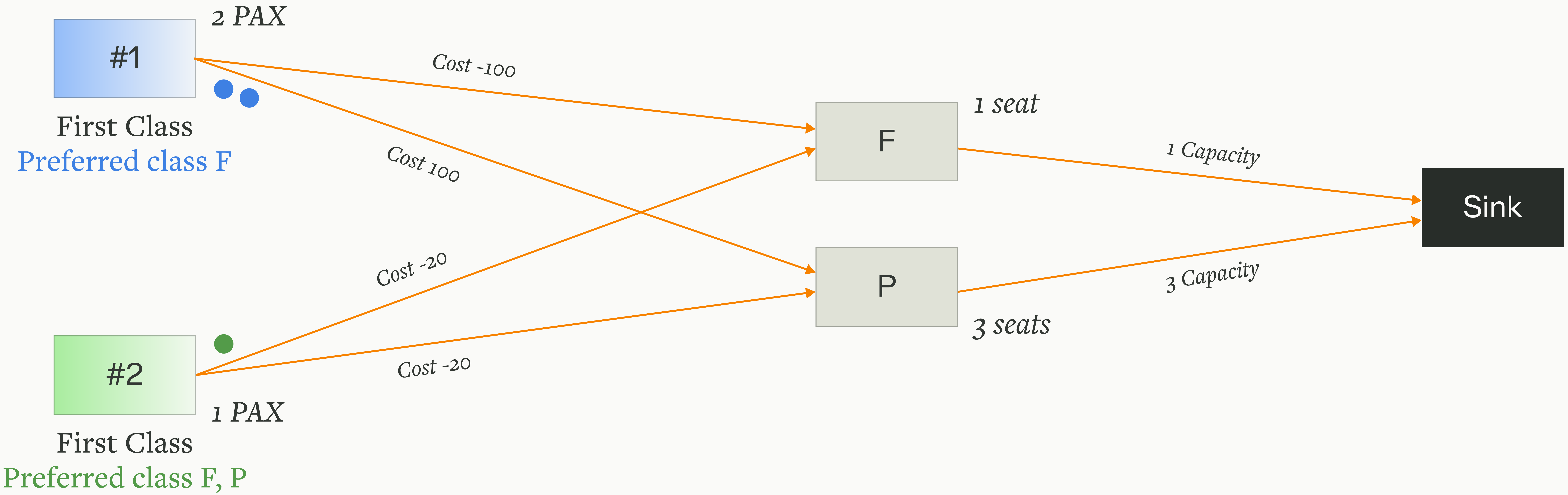
# Cabin to Class mapping using Network Flow



# Cabin to Class mapping using Network Flow



# Cabin to Class mapping using Network Flow



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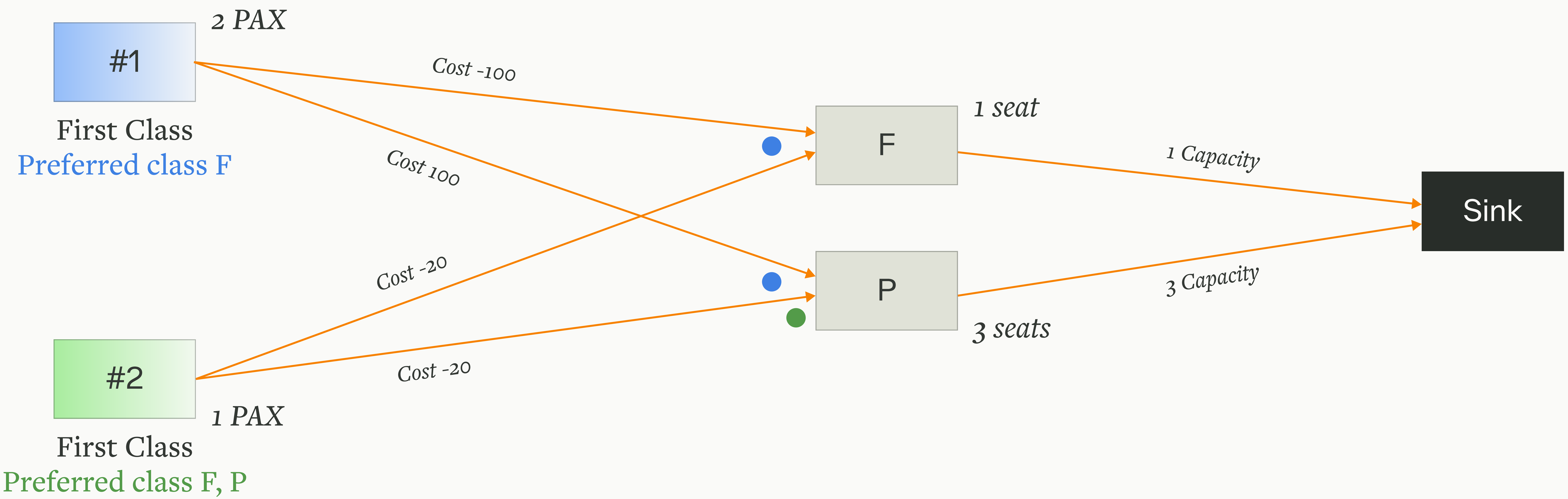
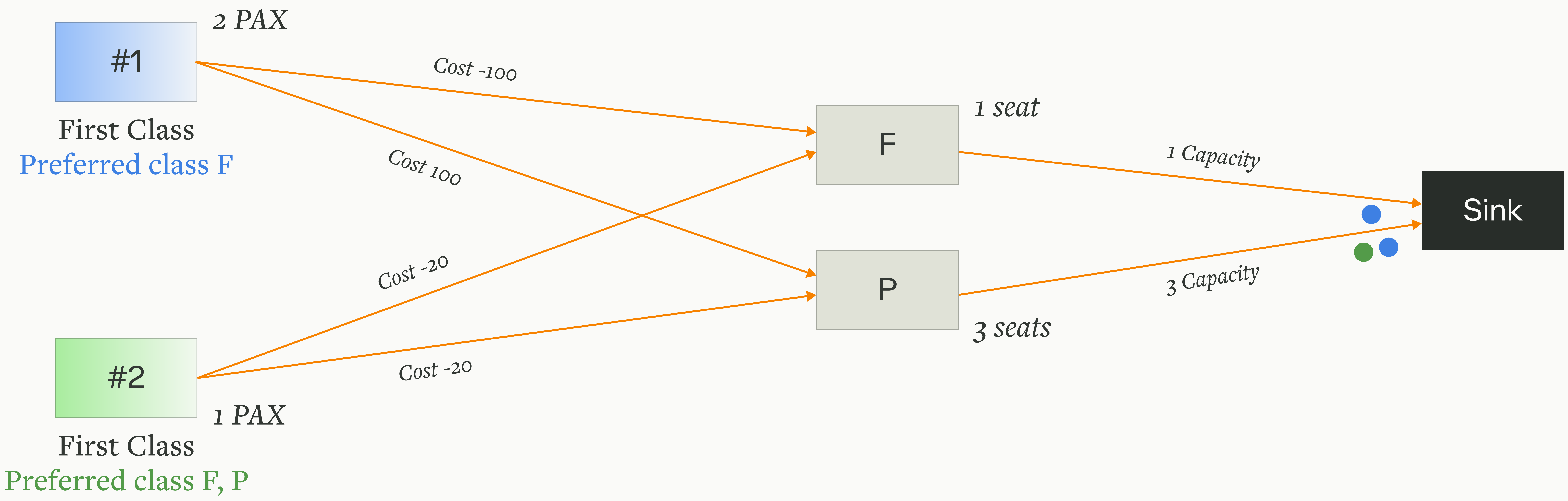
# Cabin to Class mapping using Network Flow

Flow In = Flow Out



# Cabin to Class mapping using Network Flow

Since Capacity constraints are not **violated, max flow-min cost** ensures every PAX is assigned a class.



# Quantum Network Flow Modelling

Objective Function: $\text{Minimize}(\sum C_{ij}X_{ij})$

Supply Constraint: $\forall i \in \text{PNRs} \sum_{j} X_{ij} = n_i$

Demand Constraint: $\forall j \in \text{Classes} \sum_{i} X_{ij} \leq b_j$

$\mathbf{C_{ij}}$ Cost(loss) to accommodate the $i^{th}$ PNR's passenger to the $j^{th}$ Class.

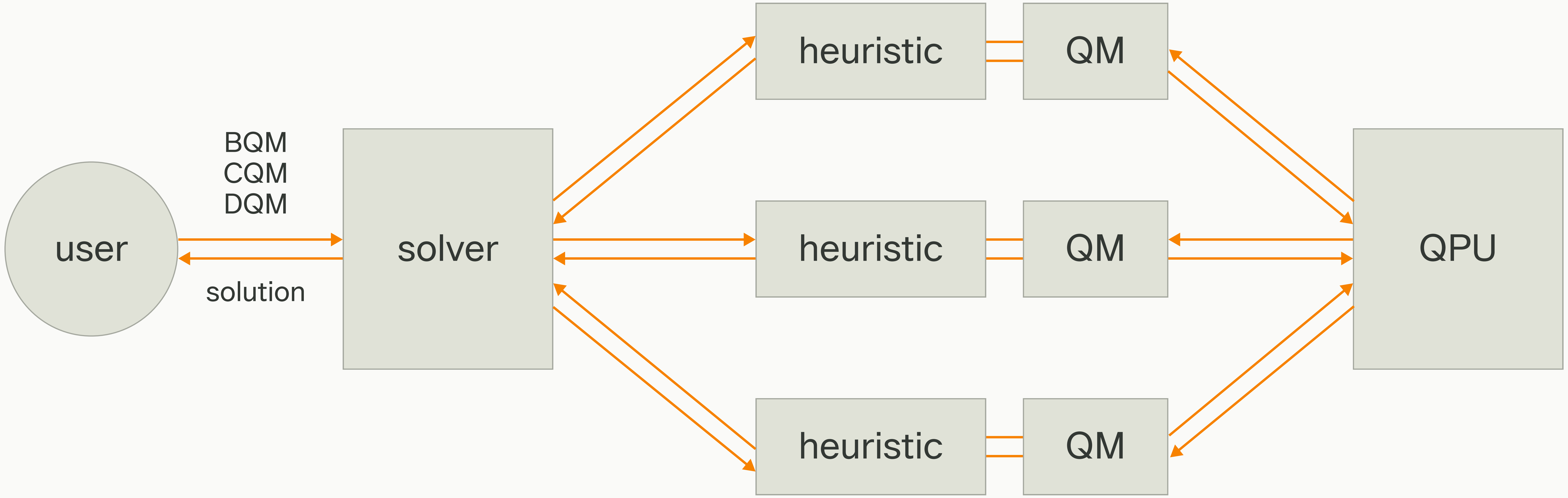
$\mathbf{X_{ij}}$ Number of passengers of the $i^{th}$ PNR accommodated in $j^{th}$ Class.

$\mathbf{n_i}$ Number of passengers in the $i^{th}$ PNR.

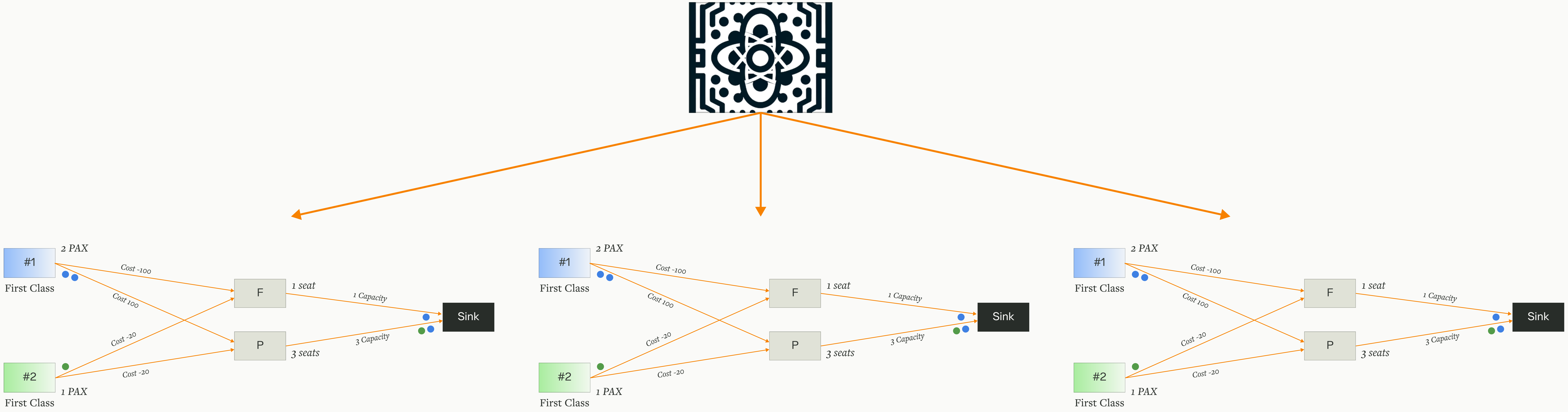
$\mathbf{b_j}$ Number of seats in the $j^{th}$ Class.

# Quantum Network Flow Modelling

This modelled **CQM** is solved effectively using,



# Quantum Network Flow Modelling




...and **Optimized** using **Parallel processing** since assignment of PNR to classes is independent for each flight-cabin pair.

# Quantum Modelling

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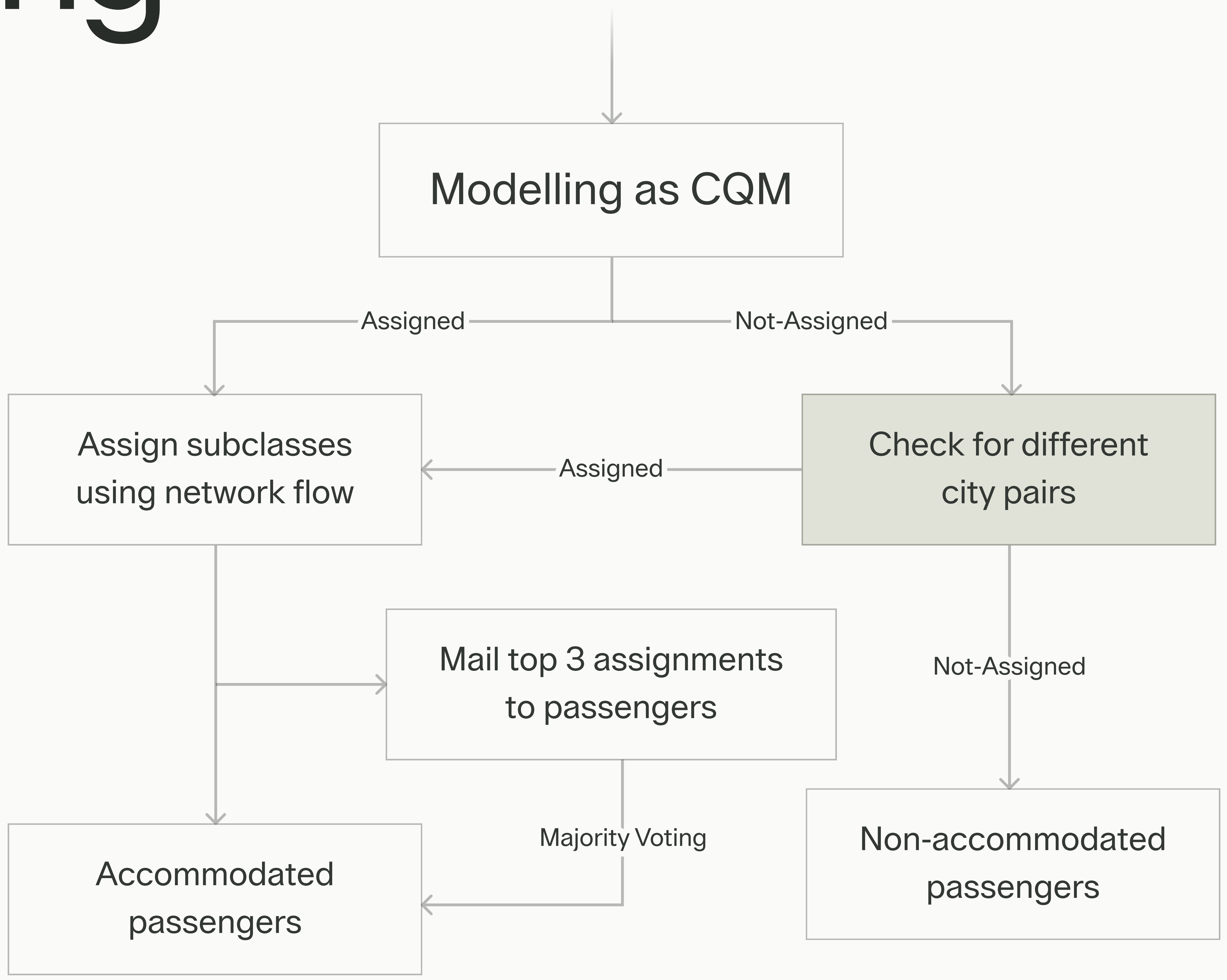


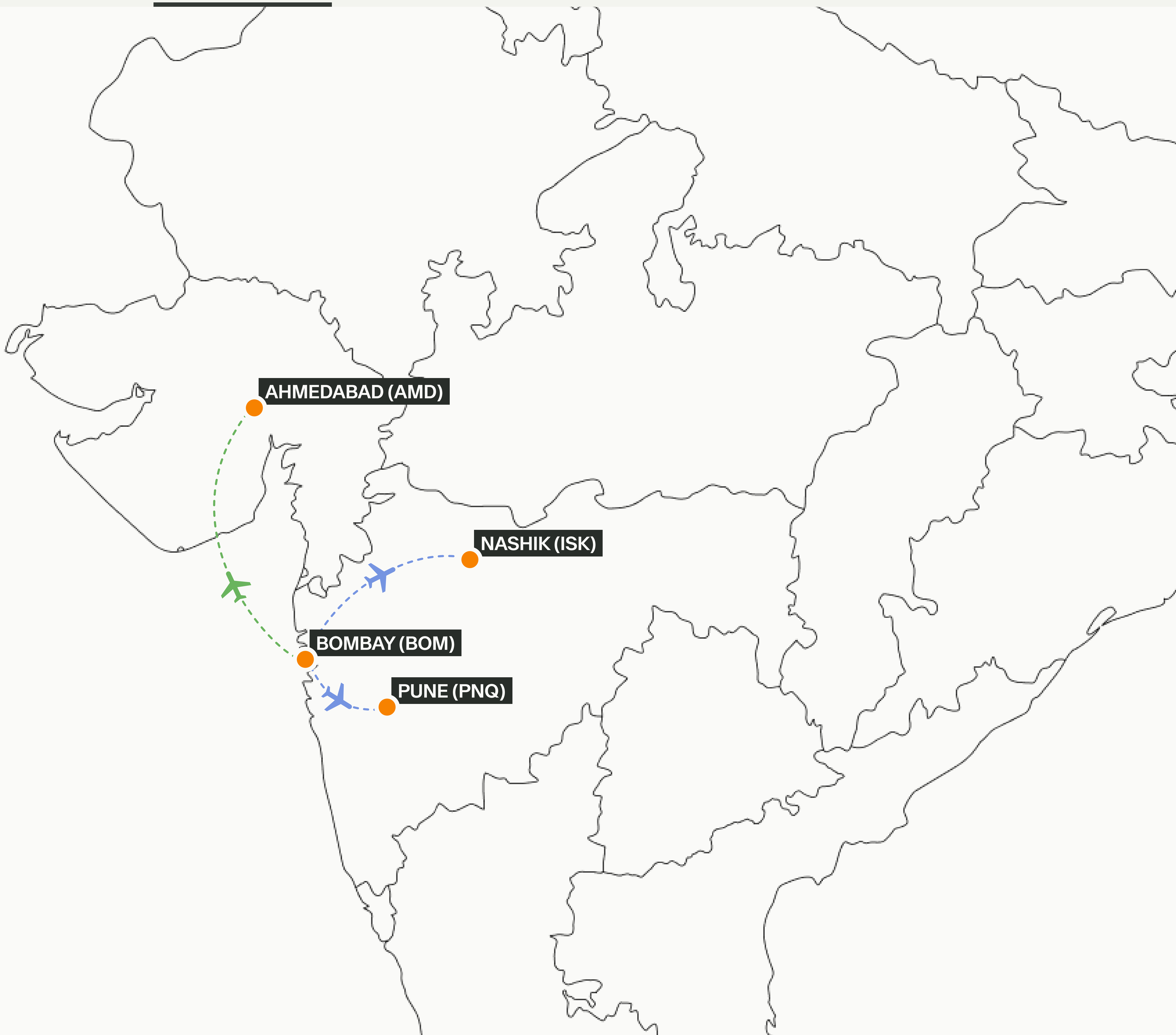
# Handling Un-accommodated PNRs

**Scenario:**
PNR 1 didn't get any accomodation in default solution

Let Bombay (BOM) be its original airport.

# Getting different city pairs

Nearest City Pairs obtained efficiently using **KDTree** Datastructure.



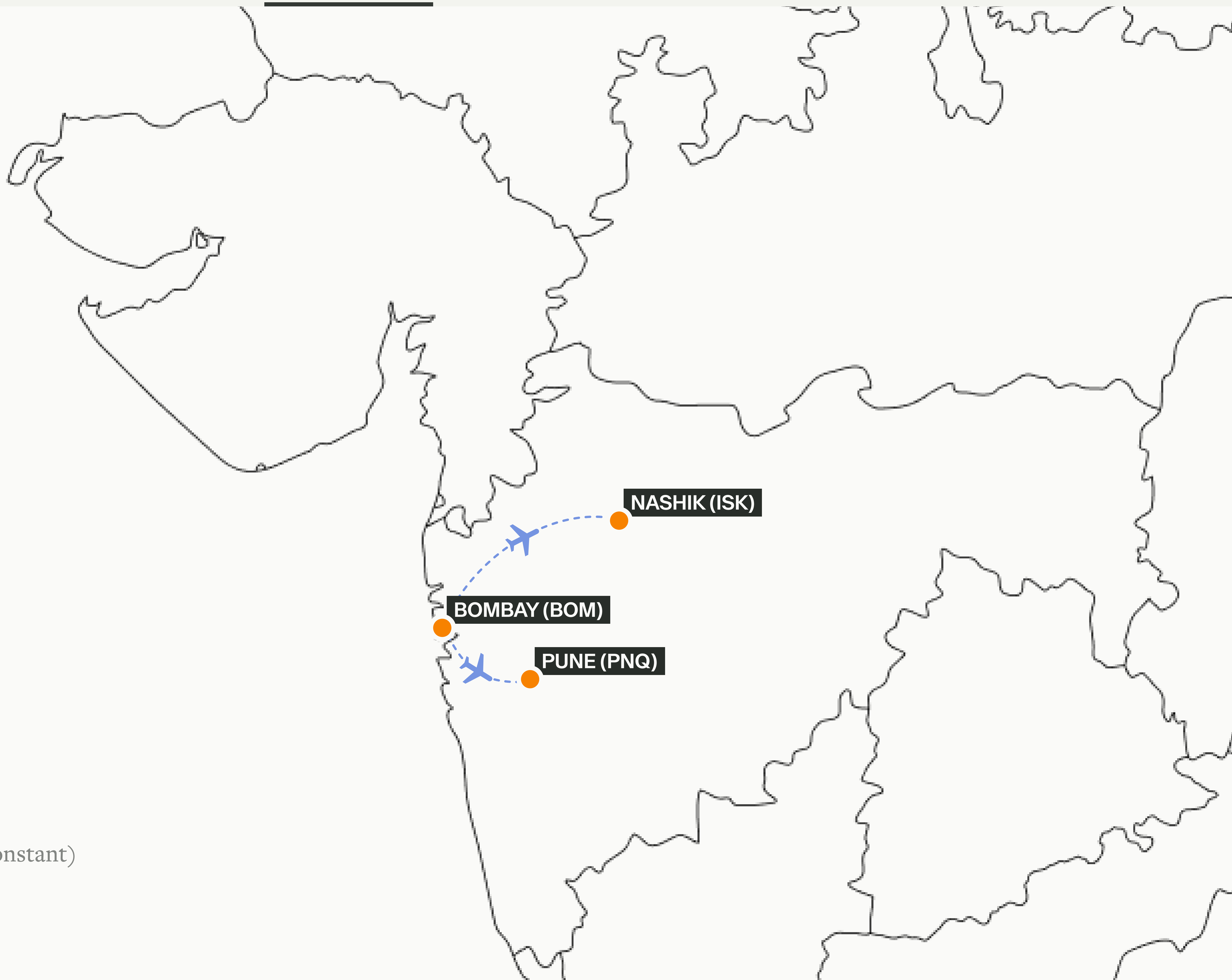
# Filtering different city pairs

Only those airports that are reachable within a **threshold** (8 hours in this case) are returned.

Real time traffic data is used for this through **Distance Matrix API.**

Scores given for different city pairs according to:

$$\frac{1}{\text{distance}^{\alpha} + \text{time}^{\beta} + \epsilon}$$ (small constant)



# Quantum Modelling

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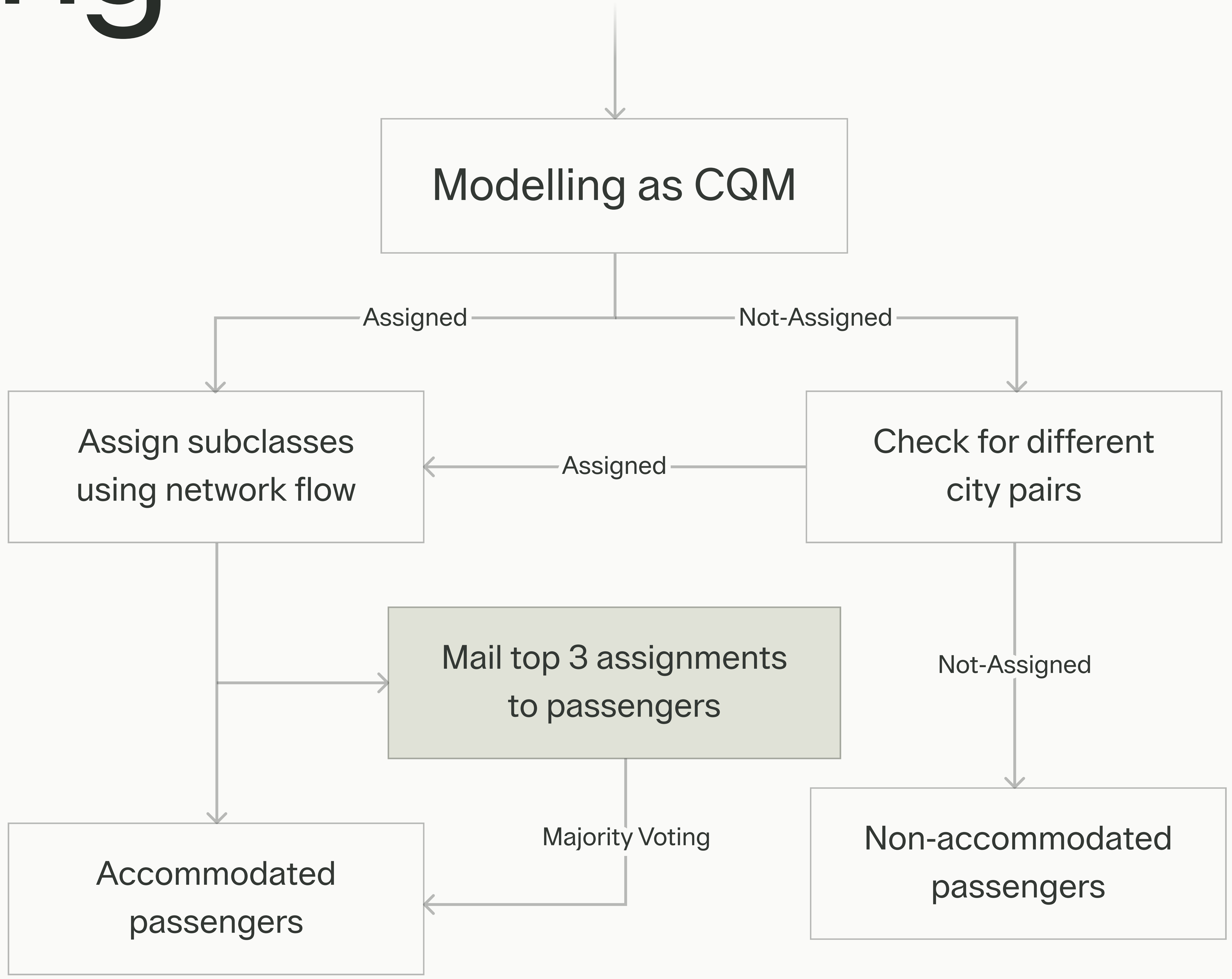
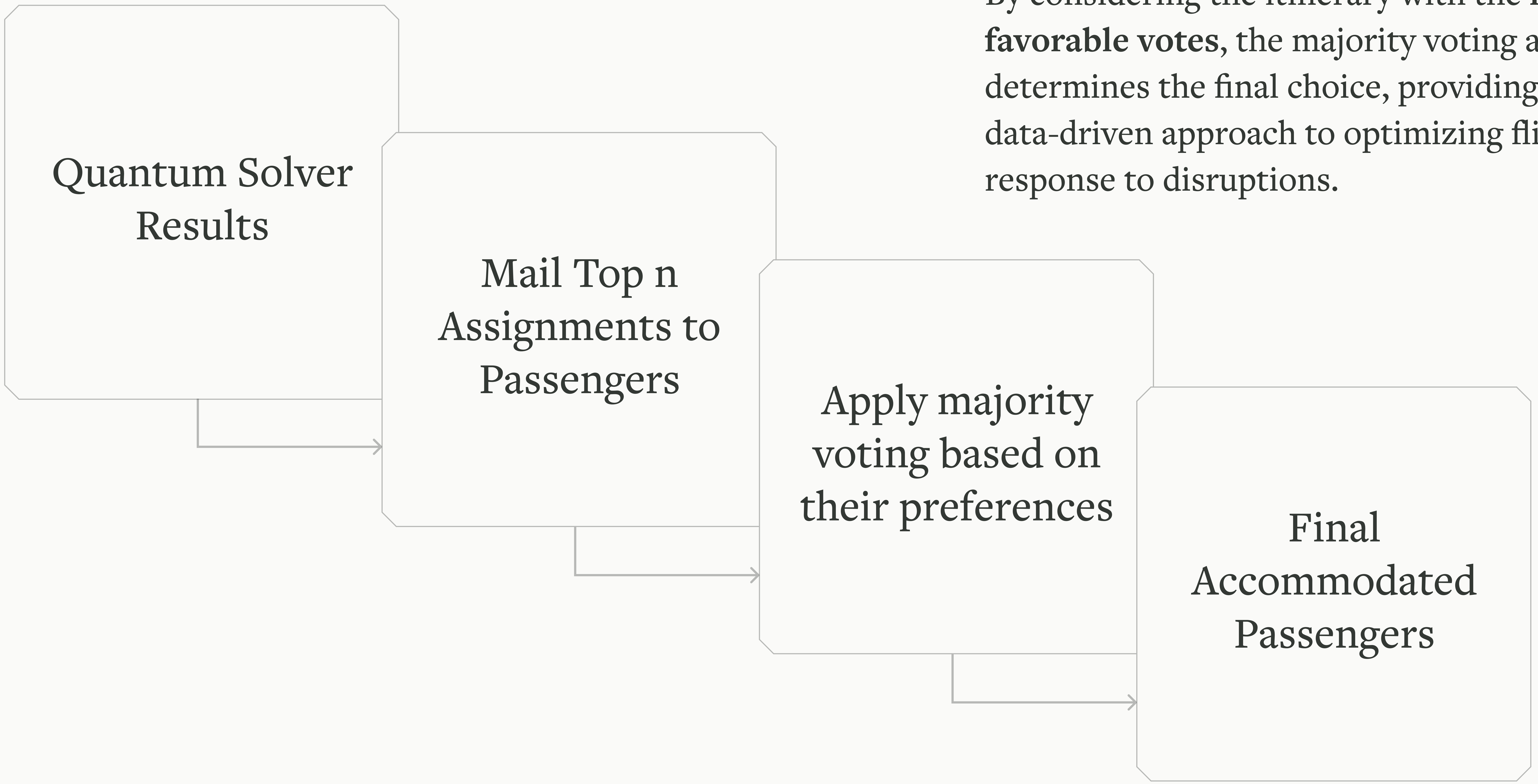


# Customer Feedback




## Majority Voting Algorithm

By considering the itinerary with the **highest number of favorable votes**, the majority voting algorithm efficiently determines the final choice, providing a democratic and data-driven approach to optimizing flight schedules in response to disruptions.

# Customer Feedback

Gmail mockpnr <mockpnr@gmail.com>

**Alternate Flight Options - AVET61**
1 message

**Mock Airlines** <rsinh1140@gmail.com> Sat, Dec 16, 2023 at 4:06 PM
To: mockpnr@gmail.com

**Dear Sir/Ma'am, Thank you for choosing Mock Airlines. Unfortunately, your flight has been cancelled, please find alternate flight details below.**

**PNR Number - AVET61**

Cancelled Flight Details -
Flight Number : 2008.0
Cabin : EC
Class : A, A, A, A, A, A, A, A, A
Arrival Airport : TRV
Departure Airport : MAA
Arrival Time : 2024-04-17 21:44:00
Departure Time : 2024-04-17 02:25:00

Flight Number : 2008.0
Cabin : BC
Class : C, C, J, J, J, J, J, Z, Z
Arrival City : TRV
Departure City : MAA
Arrival Time : 2024-04-18 21:44:00
Departure Time : 2024-04-18 02:25:00

Please click the link given below to choose this flight -
https://forms.gle/8wZmJ5e9szYm37r48
Flight Number : 2047.0
Cabin : BC
Class : C, C, C, C, C, C, C, Z, Z
Arrival City : TRV
Departure City : MAA
Arrival Time : 2024-04-16 02:50:00
Departure Time : 2024-04-15 07:41:00

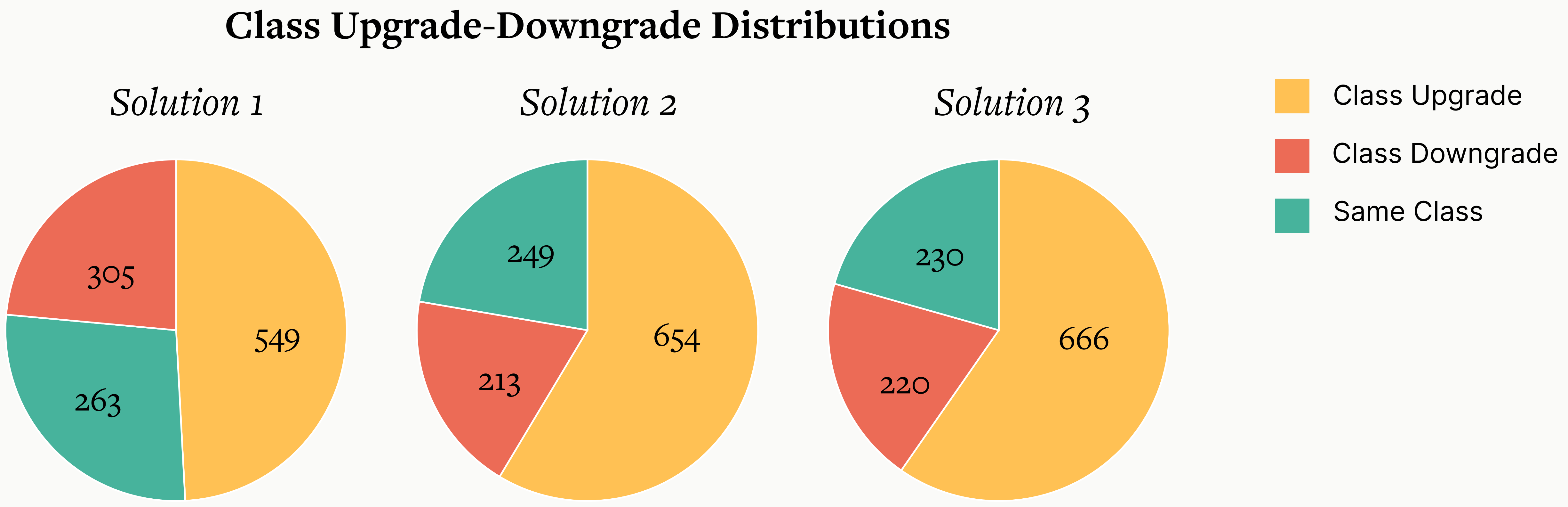
Please click the link given below to choose this flight -
https://forms.gle/q3QrqN8fSHPnkRcq6
Flight Number : 2008.0
Cabin : PC
Class : R, R, R, T, T, H, H, H, H
Arrival City : TRV
Departure City : MAA
Arrival Time : 2024-04-16 21:44:00
Departure Time : 2024-04-16 02:25:00

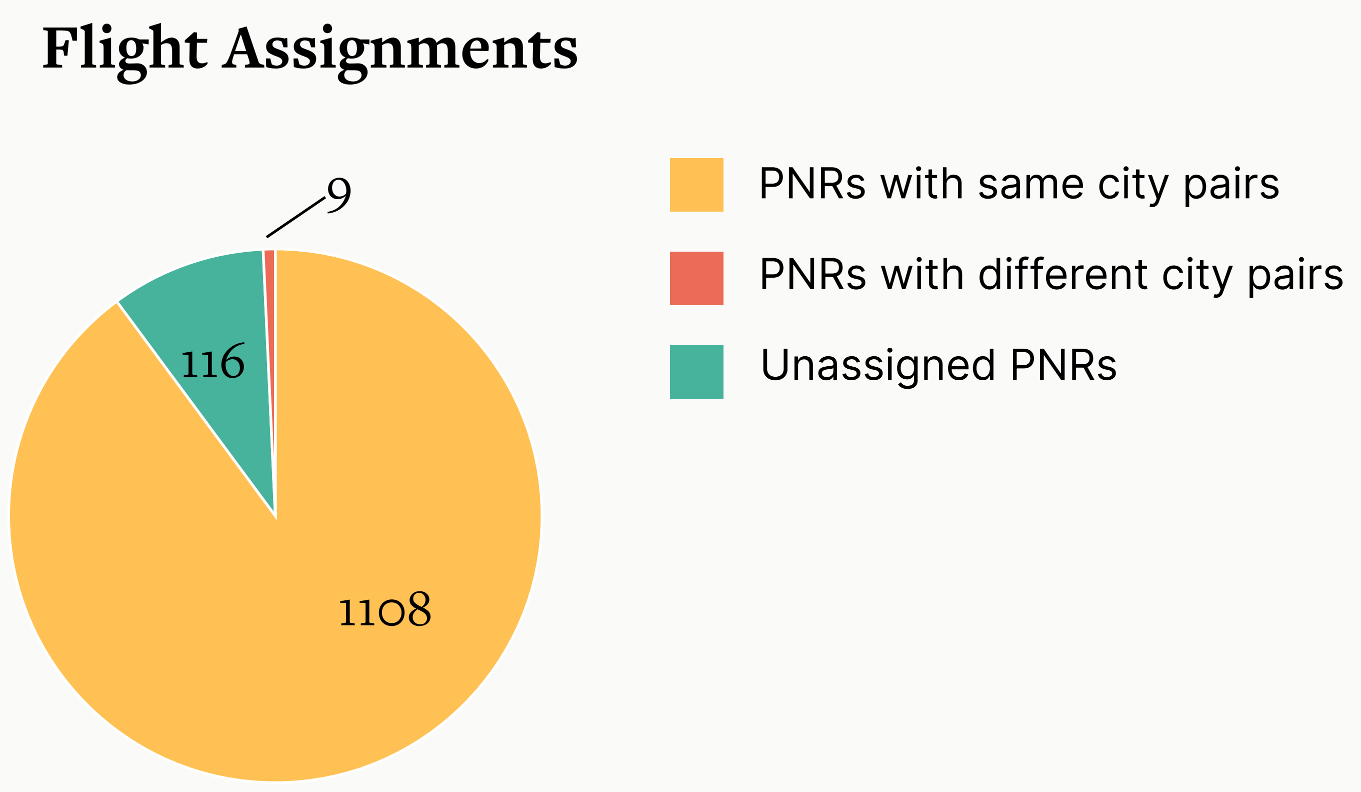
Please click the link given below to choose this flight -
https://forms.gle/bAot7r4sMkporCvt9

If you don't wish to choose any of the alternate flights, you may cancel your flight using the link below -
https://forms.gle/1c94gcb9sMeDU4v96
Have a safe journey.
Regards,
Mock Airlines

# Results generated by our **Hybrid Classical-Quantum Model**

| Net Impacted PNRs | Re- accomodated PNRs | Mean Arrival Delay (hours) |
|---|---|---|
| 87 | 69 | 22.023 |
| 490 | 394 | 25.544 |
| 629 | 629 | 30.356 |
| 1233 | 1118 | 31.563 |



# Thank you.