# Fleet Assignment and Bank Structure Integration in Airline Scheduling Problem

Dr. Enis ÇİFTÇİ

Assoc. Prof. Dr. Vildan ÖZKIR

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# Muharrem Enis Çiftçi

Marketing and Business Development Manager
**Procenne Digital Security - 1 year**

**PhD Operations Research**

with background

MSc Operations Research
BSc Industrial Engineering
BSc Management (Double Major)

**Network Planning Analyst**
- Junior ~ 3 Years
- Senior ~ 4 years

Roles in
Master Planning
Advanced Data Analytics

**Research Assistant** - 1 year

Assoc. Prof. Vildan Çetinsaya Özkır
**Lecturer - Researcher**

PhD. Industrial Engineering

MSc. Systems Engineering

BSc. Industrial Engineering

Multiple Criteria Optimization

Environmentally Conscious Supply Chains

Airline Optimization Problems

# Supports And Provided Opportunities For This Study

TÜBİTAK

TÜRKİYE BİLİMSEL ve TEKNOLOJİK ARAŞTIRMA KURUMU


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    - *Integrations*
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  - Obstacles for the perfect bank structure
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- **Case Study**
  - Sabiha Gökçen Airport Bank Structure
  - Impact on the ScheduleResults
- **Conclusion**
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# 01

# INTRODUCTION

## Objective of the Study

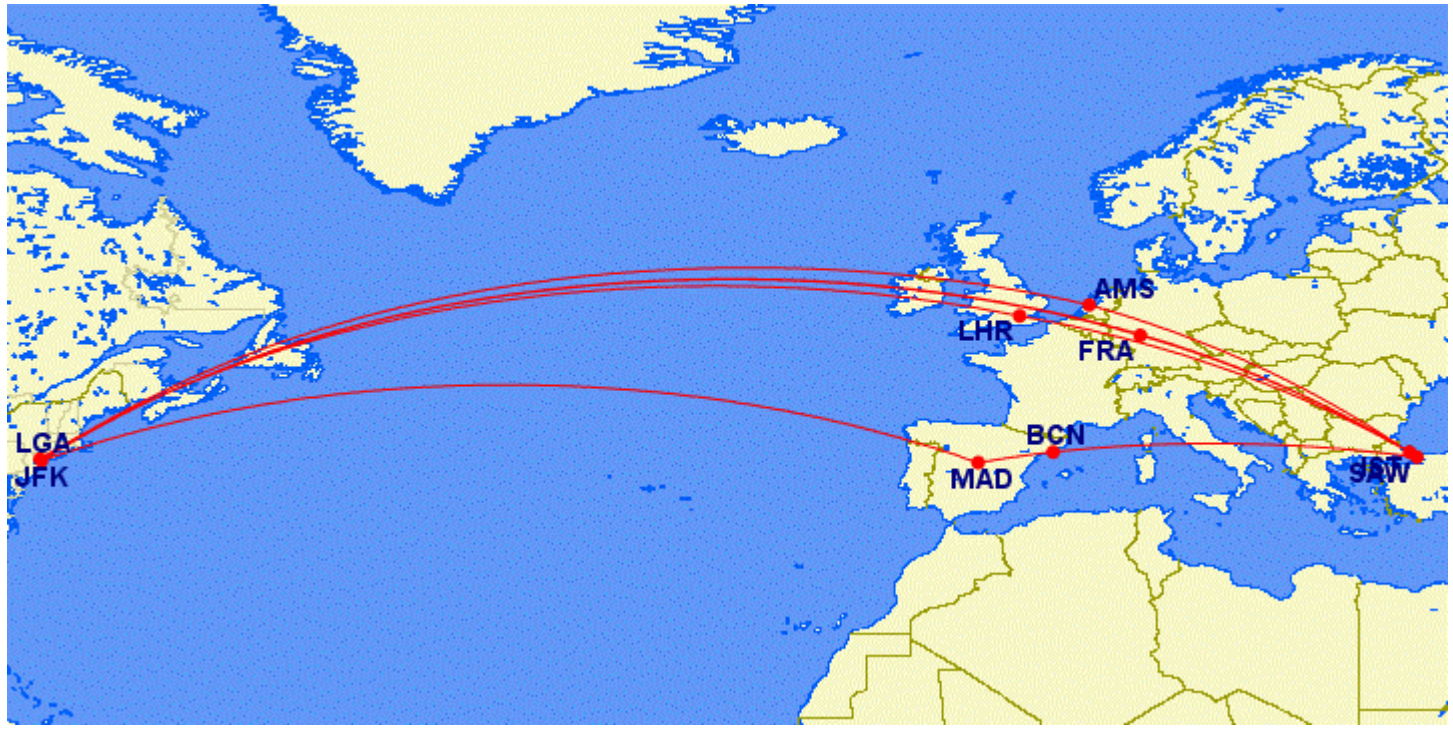
- Investigate the opportunities/risks in bank structure.
- Generate a rotational, commercially attractive and applicable schedule.
- Propose an efficient methodology to solve fleet assignment problem in a banked hub environment.
- Optimize connection times in the bank structures.

## Background and Study Area

- "point to point " & "hub and spoke" depending on global liberalization developments.
  *(Delta, Lufthansa, Turkish Airlines, Emirates, Singapore, etc)*

- Flight clusters, wave structure (bank) in the central bases.

# How do we choose an airline for a trip?




## Alternatives

IST – JFK → Direct Flight | Turkish Airlines | 8047 km **(Fastest One but Expensive)**

IST – AMS – JFK → Connected Online Flight | KLM | 8051 km **(Night Departure)**

IST-LHR-LGA → Connected Interline Flight | Turkish Airlines + British Airways | 8045 km

IST-FRA-JFK→ Connected Codeshare Flight | Turkish Airlines + Lufthansa| 8047 km **(Morning Arrival)**

SAW-BCN-MAD-JFK→ Self Connected Flight |PC + FR + IB | 8538 km **(Cheapest one, hassle for conn..)**

## Factors

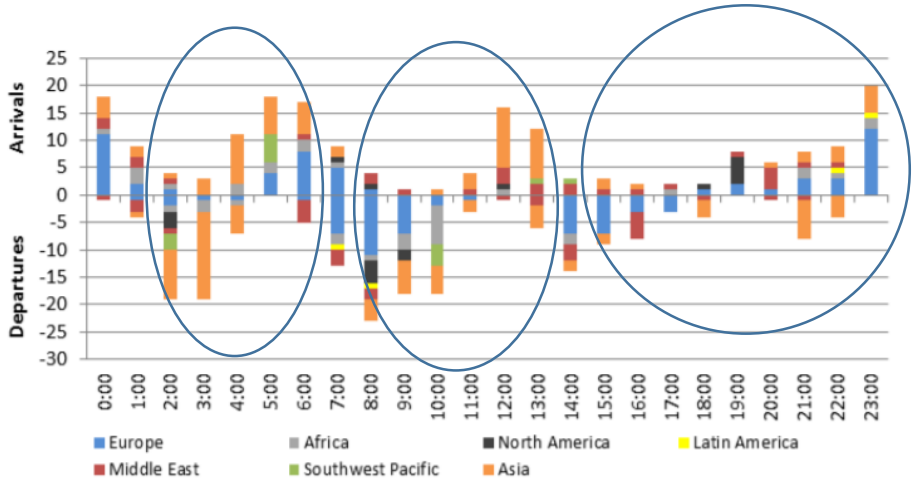
**Qualitative**

- Airline Reputation
- Departure Airport (IST or SAW)
- Arrival Airport (JFK or LGA)
- Product (meal, inflight equipment, wifi, lounge, on time perf etc)
- Loyalty Programs (miles, bonus etc)

**Quantitative**

- Departure Time
- Arrival Time
- Total Elapse Time (Travel Time including connection times) !
- Detour (Total Flown Km/Direct Distance)
- Price
- Number of Connections
- Connection Type (Online, Interline, CS)

# Introduction

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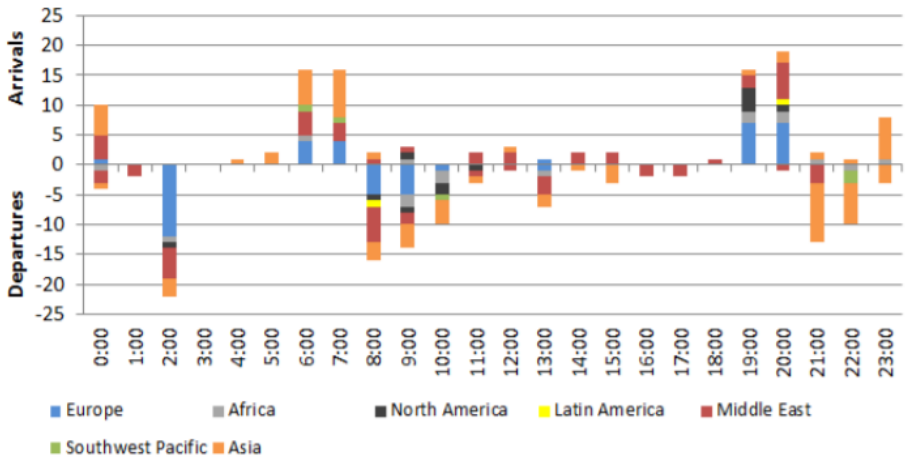


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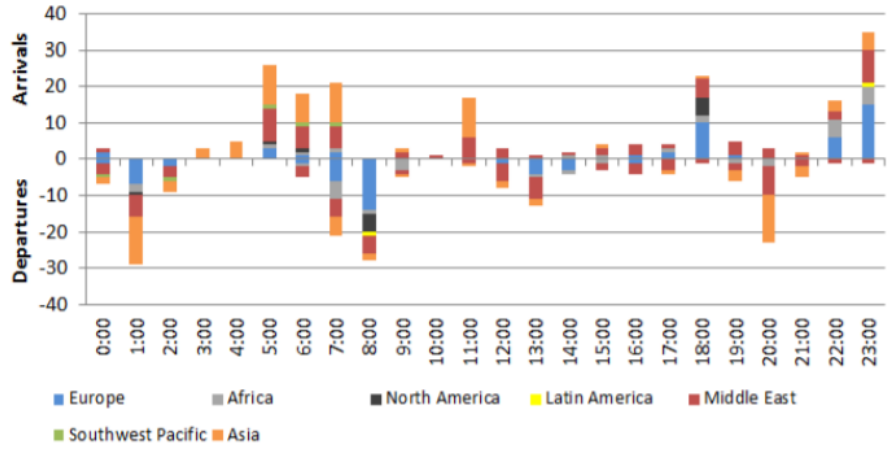
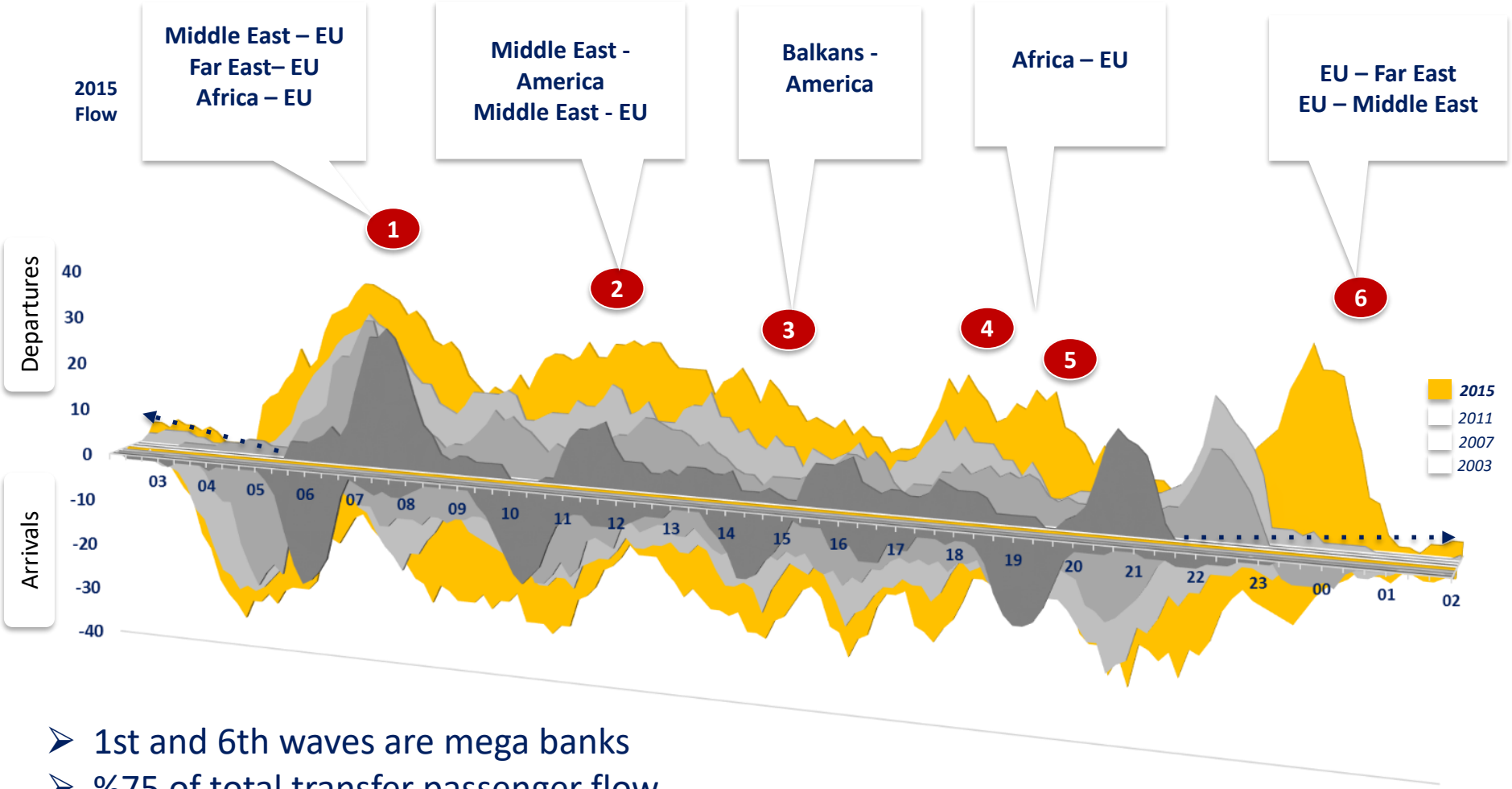


# Introduction

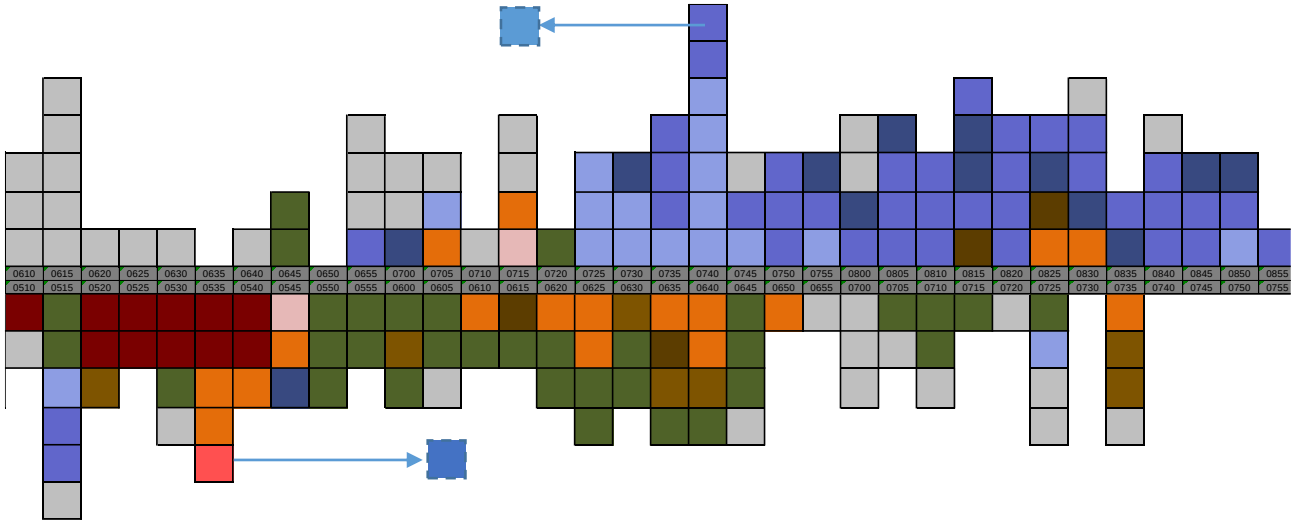



- 1st and 6th waves are mega banks
- %75 of total transfer passenger flow

# Current Industry Challenges

- covering a rotation of about 300 aircraft
- more than 1000 flights per day of a network carrier
- several optimization software are available for fleet assignments but their primary focus is to reduce operational costs(fuel cost etc..)
- many manual process can not be modelled because of runway, terminal issues, meteorological constraints.
- operational constraints, cargo revenue, passenger revenue, cost structure of aircrafts can be estimated and feasibility studies prepared
- there is no optimality guarantee, most of the solutions are human based and away from optimality, just feasible...

# Research Questions (a close look into a bank)




- Are the flights positioned in the right place on each wave?
- Is current fleet assignment maximise the number of passengers and revenue on transfer itineraries?
- Current industry approach is to solve these two problem in a sequence (step by step). Is it possible to solve these problems as one problem which is integrated way ?

Main objective is to determine routes that are in the banks are planned with the correct aircraft type, right departure and arrival time so as to maximize the passenger flow and the revenue flow of the <u>all destinations across the bank structure.</u>.

# 02

# LITERATURE REVIEW

# Airline Planning Framework

| Horizon | Time Frame | Questions to Answers |
|---|---|---|
| Long Term | • 2-10 Years | • Business Model<br>• Network Strategy<br>• Fleet Strategy |
| Medium Term | • 6-24 Months | • Network Planning<br>• Fleet Planning<br>• Schedule Design |
| Short Term | • 3 Day-6 Months | • Fleet Assignment<br>• Aircraft Routing<br>• Crew Scheduling<br>• Pricing and Revenue Management<br>• Ground Resource Management |

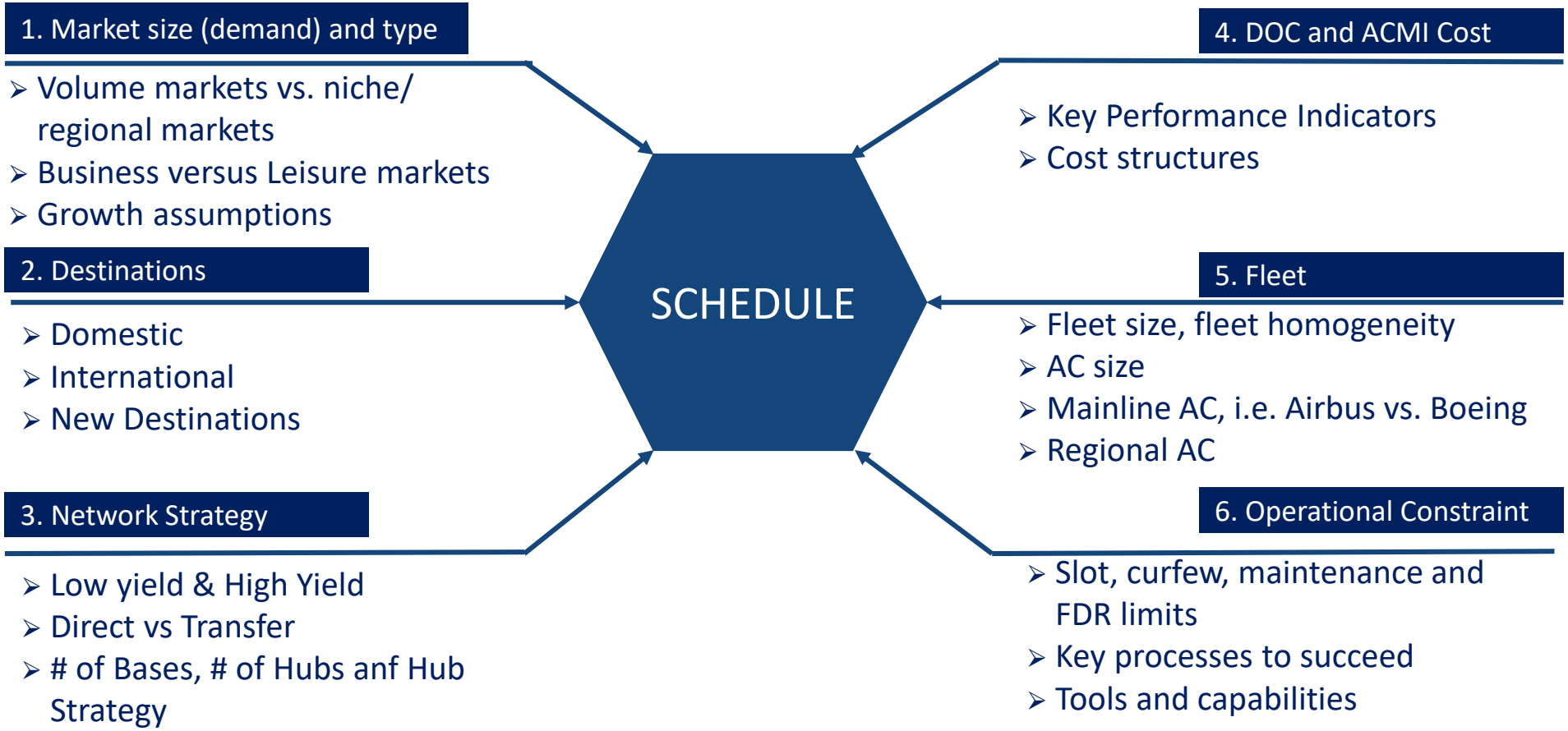
# Airline Planning Problems

| | | |
|---|---|---|
| Network Design | • Airports<br>• 5-10 years | Which airports are going to be served?<br>Hub and spoke or Point to point? |
| Fleet Design | • Size and composition of aircrafts<br>• 5-10 years | Which type of the aircraft is going to acquire? How many aircraft is going to be in the airline's fleet?<br>When is it planned to phase in or phase out (retirement etc)?<br>What type of payment method is utilized (buy, financial lease, wet lease, dry lease etc) |
| Flight Schedule | • when and how often should each leg flight be operated<br>• 1 year | How many frequencies per week, Which Departure and Arrival Time, Utilization of the Aircraft? |
| Fleet Assignment | • Aircraft type of routes<br>• 1 season | Which type of aircraft for which route ? |
| Aircraft Routing | • Designing the sequence of flight legs<br>• 3 day to 6 month | Sequence of the routing of tails |
| Crew Management | • work schedule of each crew member<br>• 1 month | Which crew will operate which route? |

For the airlines, the most costly problem among these problems are **aircraft** and crew related problems due to high ownership costs.

Therefore, fleet assignment and scheduling are one of the most important problems. (Ozdemir et al, 2012).

# SCHEDULE PLANNING DETAILS



# Airport Capacity Management & Bank Design

1

**AIRPORT CAPACITY**

Airport capacity can be defined as maximum number of operations that can take place in one hour **(Ates and Uzulmez, 2016).**

2

**SLOT**

Slot is a permission given by a coordinator for a planned operation to use the full range of airport infrastructure necessary to arrive or depart at a Level 3 airport on a specific date and time **(IATA Worldwide Slot Guidelines, 2015)**

3

**FACTORS**

Runway capacity, airport plan and design, terminal capacity, apron capacity, airside capacity, accessibility between apron and terminal are the factors that have influence on the airport capacity **(ACI, 2013).**

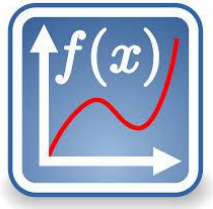
- **Jiang and Barnhart (2013)** proposed first and only scheduling approach that has a mathematical model which modifies current de-banked schedule.
- Model creates new flight schedule while satisfying the limit of the number of flight departures and arrivals per unit time at the hub.
- They have suggested to define additional metrics and measure their effectiveness for generating flight schedules for future research directions
- **Brueckner and Lin (2016)** introduces two spatial models, continuous and discrete, to illustrate the trade-off between airport congestion and convenient connection.

# Fleet Assignment Literature

## LITERATURE

**Start from Abara 1989, Hane et al 1995..**

**Sherali et al 2006..**




## MATHEMATICAL MODELS

**2 Different Models**

(Connection Network, Time&Space)

## CASE STUDIES

**Many Applications**

Delta, Emirates, British Airways, Turkish Airlines

## EXTENSION AND INTEGRATIONS

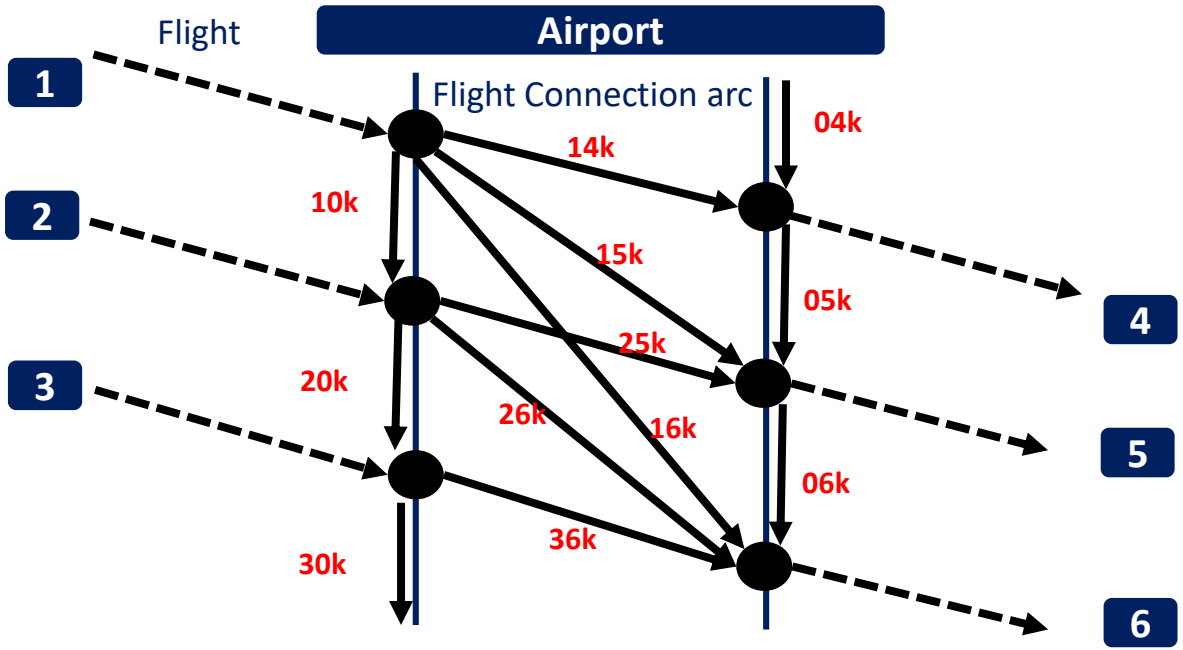
**Different areas of aviation**

(Maintenance, scheduling, frequency planning, homogeniety in fleet (dedication), crew…)

# Fleet Assignment Models

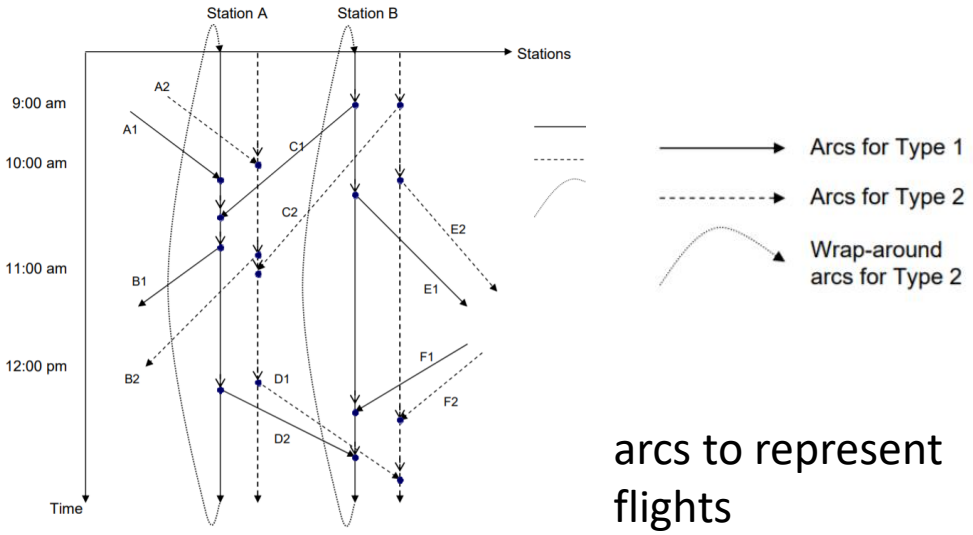
## CONNECTION NETWORK (ABARA, 1989)

- Min **AssignmentCost**
  - Cover
  - Aircraft Flow Balance
  - **Schedule Balance**
  - Aircraft Inventory




## TIME SPACE NETWORK (HANE ET AL., 1995)

The problem is described by **Lohatepanont (2002)** as follows : "**Given a flight schedule with fixed departure times** and costs (fleet and flights specific operating costs and spill costs), find the **minimum cost assignment** of aircraft types to flights, such that : each flight is **covered** exactly once by an aircraft, **flow balance** of aircraft by type is conserved at each airport, and only the **available number of aircraft** of each type are used.




arcs to represent flights

arcs to represent connection and all connections must be feasible in terms of turn time.. Preprocessing required..

# Integrated Fleet Assignment Studies

**Maintenance Operations**

Rushmeier and Kontogiorgis (1997)
Berge and Hopperstad (1993)
Clarke et al (1996)
Winterer (2004).
Sherali et al. (2006)

**Crew**

Rushmeier and Kontogiorgis (1997)
Clarke et al (1996)
Ahuja et al. (2004)
Papadakos (2009)
Ruther (2010)
Sherali et al. (2013)

**Aircraft Rotation**

Desaulnier et al. (1997)
Barnhart et al. (1998)
Ahuja et al. (2004)
Yan et al. (2006)
Papadakos (2009)
Jamili (2017)

**Scheduling**

Rexing et al. (2000)
Lohatepanont and Barnhart (2004)
Yan et al. (2006)
Jiang and Barnhart (2013)
Dong et al. (2016), Gürkan et al. (2016), Kenan et al. (2018), Khanmirza et al. (2020).
Barnhart et al. (2012)

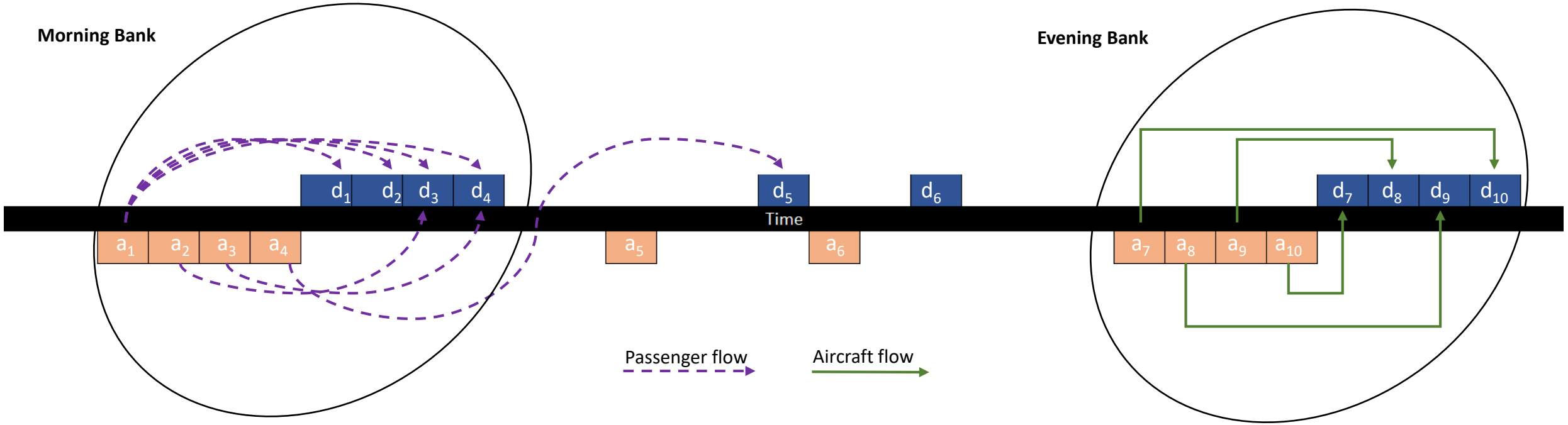
**Network Planning**

Farkas (1996)
Kliewer (2000)
Cadarso and Marin (2013)
Cadarso and de Celis (2017)

# 03

# PROBLEM DEFINITION

# Understanding the Bank Structure




- A bank is a group of incoming and outgoing segments, whereby the incoming flights all arrive at a hub within a short time period, and the connecting outgoing segments depart from the hub within a short time period once most or all of the incoming flights have arrived.

- A bank structure allows the connection of many incoming and outgoing flights with a low detour factor, which is the in-flight time for an indirect flight compared with the direct flight time

- Mostly, segments in the incoming banks are similar to each other in terms of passenger behaviour, geography and economy (Goedeking, 2010).

# Obstacles for Creating the Perfect Bank Structures

1

**SLOT**

Unavailable arrival or departure slots at the hub/spoke airport for creating connection..

2

**AIRCRAFT**

Aircraft availability at the hub airport.

3

**RESOURCE**

Night curfews, unavailable equipment, required workforce, terminal facility at the desired timings.

- increase in demand for airport resources at the hub airport, as runways, taxiways and gates become over-congested during the bank timings.
- Airlines cannot sell transfer tickets because of misconnected arrival and destination city pairs.
- Passengers spends more time at the airports than needed time for the transfer process from one flight to another.

(Goedeking, 2010)

# 04

# MATHEMATICAL MODELLING

# Bank Optimization Notation

**Sets**

| | |
|---|---|
| F | Set of flights |
| S | Set of slots |

**Index**

| | |
|---|---|
| i | Arrival flights |
| k | Departure flights |
| j | Arrival slots |
| l | Departure slots |

**Parameters**

| | |
|---|---|
| $C_{ijkl}$ | Connection value of flight i arrives at slot j and flight k departs at slot l. |
| $K_{jl}$ | Binary minimum connection time feasibility parameter between arrival and departure slots. it has value of 1 if time difference between arrival slot j and departure slot k is higher than minimum connection time; 0 otherwise. |
| $A_j$, $D_l$ | Number of available slots for arrival/departure flights. |
| P | Penalty cost for exceeding slot capacity. |
| h | Upper limit for exceeding slot capacity. |
| $M$ | Big number |

**Decision variables**

| | |
|---|---|
| $\alpha_j$, $\delta_l$ | Exceeding slot capacity for arrivals/departures. |
| $x_{ij}$ | =1 if flight i is assigned to slot j; 0, otherwise. |
| $y_{kl}$ | =1 if flight k is assigned to slot l; 0, otherwise. |
| $z_{ijkl}$ | =1 if flight i arrives at slot j and flight k departs from slot l, provided that the connection time value between these flights is higher than the minimum connection time. |

$$C_{ijkl} = \frac{D_{ik} R_{ik}}{T_{jl}} \quad (4.10)$$

The parameter $C_{ijkl}$ , which denotes the connection value of arriving flight $i$ at slot $j$ to departure flight $k$ departing at slot $l$

Where $D_{ik}$ represents passenger demand from city $i$ to city $k$, $R_{ik}$ denotes revenue per passenger from city $i$ to city $k$, and $T_{jl}$ is the connection time between arrival slot $j$ and departure slot $l$. The parameter $C_{ijkl}$ encourages shorter connection times by generating high values

# Bank Optimization Mathematical Model

$$max \quad \sum_{i \in F} \sum_{j \in S} \sum_{k \in F} \sum_{l \in S} C_{ijkl}\, z_{ijkl} - \sum_{j \in S} P\, \alpha_j - \sum_{l \in S} P\, \delta_l \qquad (4.1)$$

Maximise revenue and demand weighted connection time and penalise the overused slots

$$st. \quad \sum_{j \in S} x_{ij} = 1 \qquad \forall i \in F \qquad (4.2)$$

$$\sum_{l \in S} y_{kl} = 1 \qquad \forall k \in F \qquad (4.3)$$

Slot Assignment constraints

$$M\left(K_{jl}\right) \geq \sum_{i \in F} \sum_{k \in F} z_{ijkl} \qquad \forall j, l \in S \qquad (4.4)$$

$$x_{ij} + y_{kl} \geq 2\, z_{ijkl} \qquad \forall i, k \in F, \forall j, l \in S \qquad (4.5)$$

Connection constraints

$$\sum_{i \in F} x_{ij} \leq A_j + \alpha_j \qquad \forall j \in S \qquad (4.6)$$

$$\sum_{k \in F} y_{kl} \leq D_l + \delta_l \qquad \forall l \in S \qquad (4.7)$$

Slot capacity constraints

$$x_{ij}, y_{kl}, z_{ijkl} \in \{0,1\} \qquad (4.8)$$

Binary decision variables

$$0 \leq \alpha_j, \delta_l \leq h \text{ and integer} \qquad (4.9)$$

Slot allowance constraint

# Additional Notation for Integrating Fleet Assignment

**Sets**

| | |
|---|---|
| F | Set of flights |
| S | Set of slots |
| A | Set of fleet |

**Index**

| | |
|---|---|
| i | Arrival flights |
| k | Departure flights |
| j | Arrival slots |
| l | Departure slots |
| f | Index for fleet |

**Decision variables**

| | |
|---|---|
| $\alpha_j, \delta_l$ | Exceeding slot capacity for arrivals/departures. |
| $x_{ij}$ | =1 if flight i is assigned to slot j; 0, otherwise. |
| $y_{kl}$ | =1 if flight k is assigned to slot l; 0, otherwise. |
| $z_{ijkl}$ | =1 if flight i arrives at slot j and flight k departs from slot l, provided that the connection time value between these flights is higher than the minimum connection time. |
| $rot_{ikf}$ | =1 if rotation pair of flight i and flight k assigned to fleet type f. |

**Parameters**

| | |
|---|---|
| $C_{ijkl}$ | Connection value of flight i arrives at slot j and flight k departs at slot l. |
| $K_{jl}$ | Binary minimum connection time feasibility parameter between arrival and departure slots. it has value of 1 if time difference between arrival slot j and departure slot k is higher than minimum connection time; 0 otherwise. |
| $A_j, D_l$ | Number of available slots for arrival/departure flights. |
| P | Penalty cost for exceeding slot capacity. |
| h | Upper limit for exceeding slot capacity. |
| $M$ | Big number |
| $L_i$ | Leg distance for flight i, k. |
| $J_i$ | Revenue per available seat per km for flight i, k. |
| $U_f$ | Cost per available seat per km for fleet type f. |
| $Y_f$ | Seat capacity for fleet type f. |
| $N_f$ | Number of aircraft in each fleet type f |
| $O_{ikf}$ | Cost of assigning a rotation pair of flight i and flight k to fleet type f |
| $E_{ikf}$ | Revenue of assigning a rotation pair of flight i and flight k to fleet type f |

# Integrated Model

$$max \quad \sum_{i\in F}\sum_{j\in S}\sum_{k\in F}\sum_{l\in S} C_{ijkl}\, z_{ijkl} - \sum_{j\in S} P\,\alpha_j - \sum_{l\in S} P\,\delta_l + \sum_{i\in F}\sum_{k\in F}\sum_{f\in A} rot_{ikf} * (E_{ikf} - O_{ikf}) \qquad (6.1)$$

$$st. \quad \sum_{j\in S} x_{ij} = 1 \qquad \forall i \in F \qquad (6.2)$$

$$\sum_{l\in S} y_{kl} = 1 \qquad \forall k \in F \qquad (6.3)$$

$$M\,(K_{jl}) \geq \sum_{i\in F}\sum_{k\in F} z_{ijkl} \qquad \forall j,l \in S \qquad (6.4)$$

$$x_{ij} + y_{kl} \geq 2\, z_{ijkl} \qquad \forall i,k \in F, \forall j,l \in S \qquad (6.5)$$

$$\sum_{i\in F} x_{ij} \leq A_j + \alpha_j \qquad \forall j \in S \qquad (6.6)$$

$$\sum_{k\in F} y_{kl} \leq D_l + \delta_l \qquad \forall l \in S \qquad (6.7)$$

$$\sum_{k\in F}\sum_{f\in A} rot_{ikf} = 1 \qquad \forall i \in F \qquad (6.8)$$

$$\sum_{i\in F}\sum_{f\in A} rot_{ikf} = 1 \qquad \forall k \in F \qquad (6.9)$$

$$\sum_{i\in F}\sum_{k\in F} rot_{ikf} \leq \mathrm{N}_f \qquad \forall f \in A \qquad (6.10)$$

$$x_{ij}, y_{kl}, z_{ijkl}, rot_{ikf} \in \{0,1\} \qquad (6.11)$$

$$0 \leq \alpha_j, \delta_l \leq h \text{ and integer} \qquad (6.12)$$

Maximise bank optimiser and fleet assingment profit (revenue-cost)

Since rotation continuity is satisfied with the rotation decision variable of the hub airport, balance constraint is not defined.

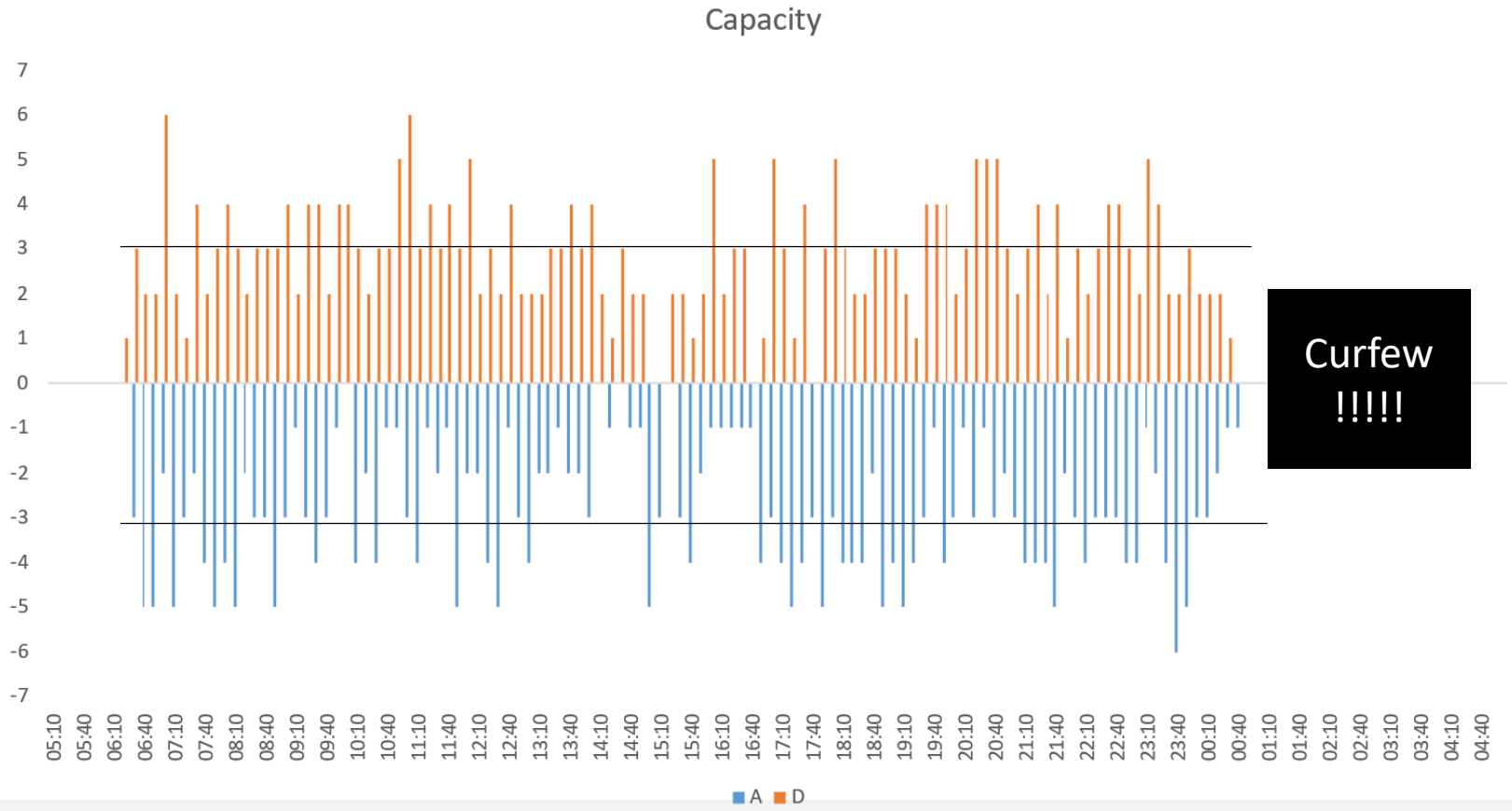
Cover constraints

Availability constraint

# 05

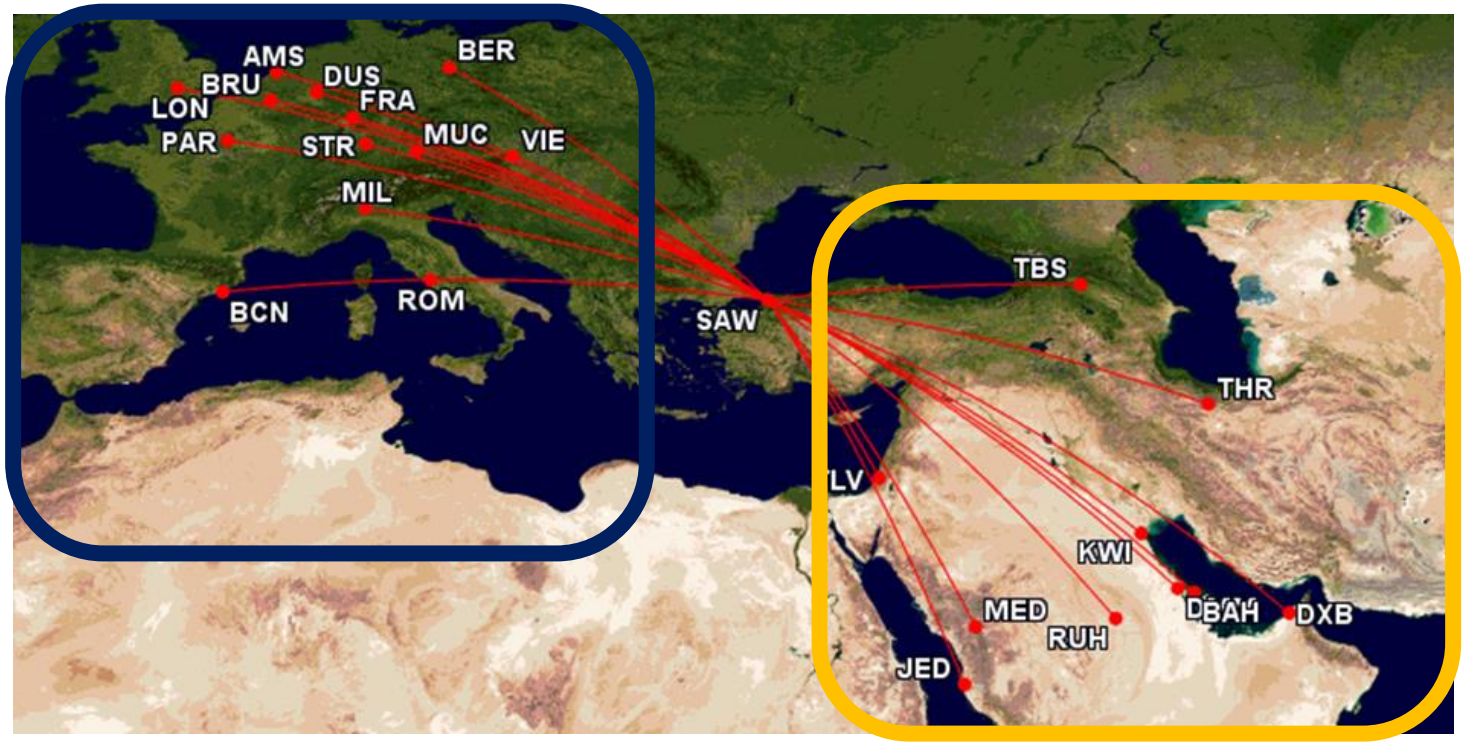
# CASE STUDY

# Capacity Limitations for Sabiha Gokcen Airport




- Has one runway (06/24) with limited capacity
- Three base carrier operations PGS and Turkish Airlines (also sub brand AnadoluJET),
- One of the fastest growing airport in the Europe and reached the limits;
- Level 3 airport (fully coordinated) demand exceeds the airport capacity supply
- Runway is closed temporarily to departure and arrival traffic at the midnights due to maintenance and repairs.

# THY Sabiha Gökçen Airport Network Structure




- Hub and spoke network serves the Europe, Middle East, Central Asia and North Africa regions.
- 23 Airport and 13 aircraft.
- There are 2 banks in the current structure (morning and evening)
- Model changes the departure and arrival times under the given parameters, to decrease the connection times objective function subject to constraints.

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Departure | | | | | | WEST | | | | | | | | | EAST | | | | | |
| Hub Time | 06:00 | 07:00 | 08:00 | 09:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 | 00:00 | |
| Arrival | | | EAST | | | | | | | | | | WEST | | | | | | | |

# Impact on the Schedule

## Previous Connection Times

| | DEST | AMS | BCN | BRU | CDG | DUS | FCO | FRA | LGW | MUC | MXP | STR | TXL | VIE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ORIG | SLOT | 19 | 23 | 21 | 18 | 26 | 31 | 27 | 17 | 27 | 25 | 29 | 22 | 28 |
| BAH | 2 | 170 | 210 | 190 | 160 | 240 | 290 | 250 | 150 | 250 | 230 | 270 | 200 | 260 |
| DMM | 5 | 140 | 180 | 160 | 130 | 210 | 260 | 220 | 120 | 220 | 200 | 240 | 170 | 230 |
| DXB | 9 | 100 | 140 | 120 | 90 | 170 | 220 | 180 | 80 | 180 | 160 | 200 | 130 | 190 |
| IKA | 1 | 180 | 220 | 200 | 170 | 250 | 300 | 260 | 160 | 260 | 240 | 280 | 210 | 270 |
| JED | 8 | 110 | 150 | 130 | 100 | 180 | 230 | 190 | 90 | 190 | 170 | 210 | 140 | 200 |
| KWI | 4 | 150 | 190 | 170 | 140 | 220 | 270 | 230 | 130 | 230 | 210 | 250 | 180 | 240 |
| MED | 3 | 160 | 200 | 180 | 150 | 230 | 280 | 240 | 140 | 240 | 220 | 260 | 190 | 250 |
| RUH | 8 | 110 | 150 | 130 | 100 | 180 | 230 | 190 | 90 | 190 | 170 | 210 | 140 | 200 |
| TBS | 11 | 80 | 120 | 100 | 70 | 150 | 200 | 160 | 60 | 160 | 140 | 180 | 110 | 170 |
| TLV | 16 | n/a | 70 | n/a | n/a | 100 | 150 | 110 | n/a | 110 | 90 | 130 | 60 | 120 |

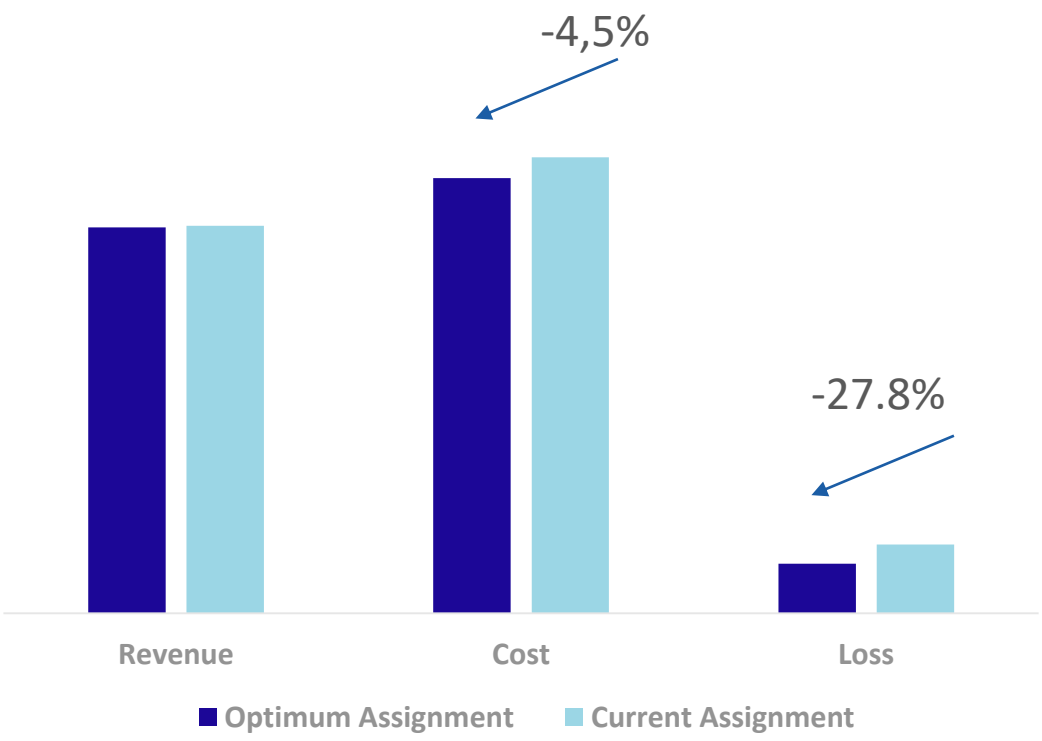
| | AMS | BCN | BRU | CDG | DUS | FCO | FRA | LGW | MUC | MXP | STR | TXL | VIE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BAH | 110 | 140 | 120 | 100 | 150 | 230 | 170 | 90 | 160 | 160 | 180 | 120 | 180 |
| DMM | 60 | 90 | 70 | 50 | 100 | 180 | 120 | 40 | 110 | 110 | 130 | 70 | 130 |
| DXB | 30 | 60 | 40 | 20 | 70 | 150 | 90 | 10 | 80 | 80 | 100 | 40 | 100 |
| IKA | 110 | 140 | 120 | 100 | 150 | 230 | 170 | 90 | 160 | 160 | 180 | 120 | 180 |
| JED | 30 | 60 | 40 | 20 | 70 | 150 | 90 | 10 | 80 | 80 | 100 | 40 | 100 |
| KWI | 80 | 110 | 90 | 70 | 120 | 200 | 140 | 60 | 130 | 130 | 150 | 90 | 150 |
| MED | 80 | 110 | 90 | 70 | 120 | 200 | 140 | 60 | 130 | 130 | 150 | 90 | 150 |
| RUH | 30 | 60 | 40 | 20 | 70 | 150 | 90 | 10 | 80 | 80 | 100 | 40 | 100 |
| TBS | 10 | 40 | 20 | 0 | 50 | 130 | 70 | -10 | 60 | 60 | 80 | 20 | 80 |
| TLV | New | -10 | New | New | 0 | 80 | 20 | New | 10 | 10 | 30 | -30 | 30 |

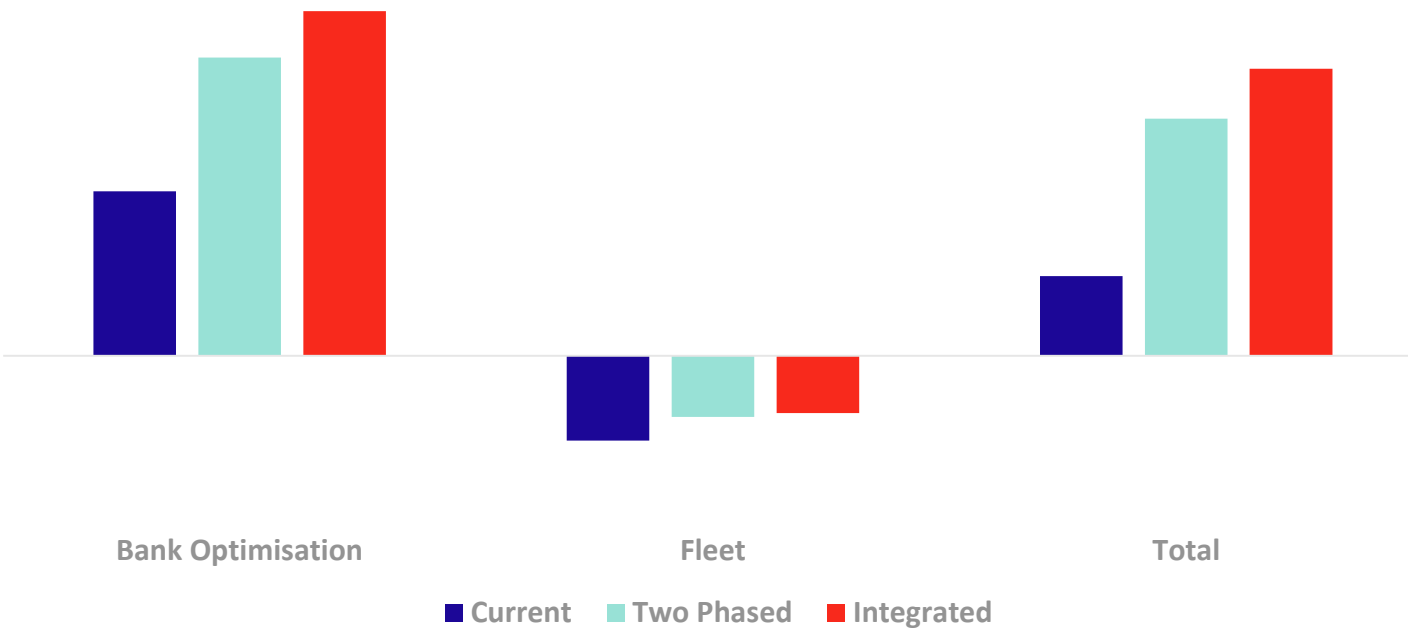
## Optimised Connection Times

| | DEST | AMS | BCN | BRU | CDG | DUS | FCO | FRA | LGW | MUC | MXP | STR | TXL | VIE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ORIG | SLOT | 9 | 10 | 10 | 9 | 12 | 9 | 11 | 9 | 12 | 10 | 12 | 11 | 11 |
| BAH | 3 | 60 | 70 | 70 | 60 | 90 | 60 | 80 | 60 | 90 | 70 | 90 | 80 | 80 |
| DMM | 1 | 80 | 90 | 90 | 80 | 110 | 80 | 100 | 80 | 110 | 90 | 110 | 100 | 100 |
| DXB | 2 | 70 | 80 | 80 | 70 | 100 | 70 | 90 | 70 | 100 | 80 | 100 | 90 | 90 |
| IKA | 2 | 70 | 80 | 80 | 70 | 100 | 70 | 90 | 70 | 100 | 80 | 100 | 90 | 90 |
| JED | 1 | 80 | 90 | 90 | 80 | 110 | 80 | 100 | 80 | 110 | 90 | 110 | 100 | 100 |
| KWI | 2 | 70 | 80 | 80 | 70 | 100 | 70 | 90 | 70 | 100 | 80 | 100 | 90 | 90 |
| MED | 1 | 80 | 90 | 90 | 80 | 110 | 80 | 100 | 80 | 110 | 90 | 110 | 100 | 100 |
| RUH | 1 | 80 | 90 | 90 | 80 | 110 | 80 | 100 | 80 | 110 | 90 | 110 | 100 | 100 |
| TBS | 2 | 70 | 80 | 80 | 70 | 100 | 70 | 90 | 70 | 100 | 80 | 100 | 90 | 90 |
| TLV | 2 | 70 | 80 | 80 | 70 | 100 | 70 | 90 | 70 | 100 | 80 | 100 | 90 | 90 |

4 new connection
123 improved connection time.
3 deteriorated connection time
Average improvement is 91 minutes.

# Objective Function Values for FA and Integrated Models




**Fleet Assignment**
Yearly Operating Cost Saving
**More than 2 M USD**

**Integrated model**
performs better than the two phased approach

06

# CONCLUSION

# Limitations

- Demand is given and assumed that it is fixed for a change in the Schedule.
- Flight frequencies are assumed one per day for each destination for the simplicity of the model.
- Slots at the spoke cities are assumed always available. However, there are highly slot constrained airports for minor schedule changes.
- These airports can be simply assumed as frozen in the schedule as an alternative approach.
- Belly cargo revenue of passenger aircraft is not considered.
- The revenue from business and economy passengers are aggregated to a single passenger type as a weighted average

# Conclusion

## Regulation

- Characteristically regulated as a highly competitive and global industry
- Requires high capital investment and has a very thin profit margin
- Complex and long planning process

## Airline Planning Process

- to meet the passenger demand and manage capacity supply in the long term
- in medium and short term, aims to maximise passenger utility, flight revenue and minimise cost
- Utilise the optimal departure&arrival times and deploying the right fleet.

## Bank Structures

- Bank structures are the essential parts of the network carriers. They increase connectivity for passengers, increase congestion at the gates, runway and slots.
- The bank optimisation problem determines the arrival and departure times of flights within a predefined bank, subject to available slot capacities, in order to minimise connection times between arrival and departure flights.

## Fleet Assignment

- Fleet assignment models commonly include objective functions to minimise operating maintenance cost and spill cost or to maximise fare revenues.
- The main goal of the models is to cover all flights using the available fleet within a set of constraints

# Conclusion

## Integration

- Among airline planning challenges, aircraft- and crew-related issues are critical due to high ownership costs.
- As the scale of the industry and competition increase, operations research tools and techniques are gaining importance in more integrated ways

## Mathematical Model

- A novel mathematical model to optimise the flight schedule of an airline at its hub airport
- To design the flight bank with the optimal departure and arrival times of the flights in the predefined bank structure
- Shortening transfer passengers' connection times and decrease the congestion level in the hub airport.

## Integrated Model

- Bank structures are the essential parts of the network carriers
- Increase connectivity for passengers, increase congestion at the gates, runway and slots.
- Slots are becoming critical barriers for schedule building processes in bank optimisation..

# Contributions

- Introduction of the bank optimisation problem to the literature.
- Fitting slot and capacity constraints of hub airports by shifting and retiming the flight legs
- To design the optimal bank with the best arrival and departure times while assigning the most profitable rotations to the aircrafts in the predetermined fleet.
- Integration of a particular flight scheduling problem with a strategic airline planning problem
- To present a real-world case study using data from a major Turkish carrier to exhibit the competence of the integrated model in generating schedules that outperform existing schedules.