FLIGHT SCHEDULING AND OPERATIONS

IV B. Tech I semester
(JNTUH-R15)

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UNIT- I

Network Flows And Integer Programming Models

Complexity Of Airline Planning

- Introduction
- Flights
- How airline prices work
- Complexity of travel planning

SanFrancisco to Boston: 2,000 paths

Prices

- Almost all the difficulty in travel planning comes from prices
- ***Fare***: price for one-way travel between two cities (a *market*)
- BOS-SFO H14ESNR $436.28
- Each flight must be covered (paid for) by exactly one fare
- One fare may cover one or more (usually consecutive) flights
- One or more fares are used to pay for a complete journey
- ***Fare component (FC)*** = fare + flights it covers

Fare Rules

- Fare rules restrict use of each fares :

  Passengers

  - Age, nationality, occupation, employer, frequent flyer status

  Fare component

  - Dates, times, locations, airlines, flights, duration of stops

  Price able unit

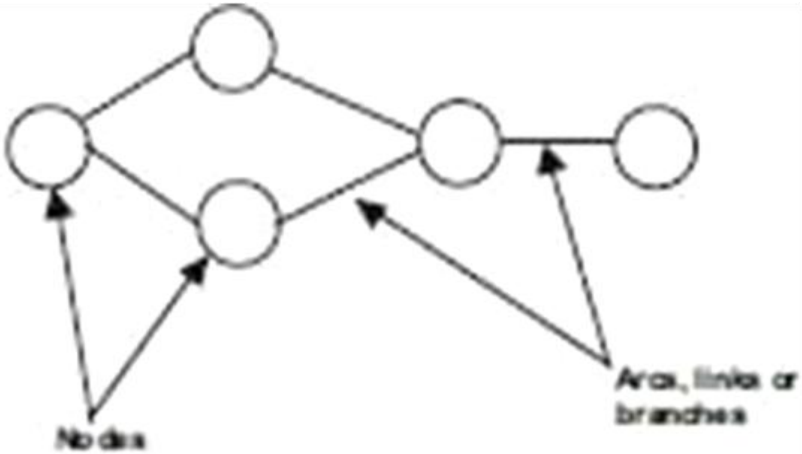
  - Types of priceable units (one way, round trip, open jaw, …)
  - Dates, times, locations, airlines, flights, duration of stops

  Journey

  - Fares and flights in other priceable units (airline and basis codes)

Networks

- A network (also referred to as a graph) is defined as a collection of points and lines joining these points. There is normally some flow along these lines, going from one point to another.



Basic elements of a network

Nodes And Arcs:

- In a network, the points (circles) are called nodes and the lines are referred to as arcs, links or arrows

Flow:

- The amount of goods, vehicles, flights, passengers and so on that move from one node to another.

Directed Arc:

- If the flow through an arc is allowed only in one direction, thenthe arc is said to be a directed arc. Directed arcs are graphically represented witharrows in the direction of the flow.

Undirected Arc:

- When the flow on an arc (between two nodes) can move in either direction, it is called an undirected arc. Undirected arcs are graphically represented by a single line (without arrows) connecting the two nodes.

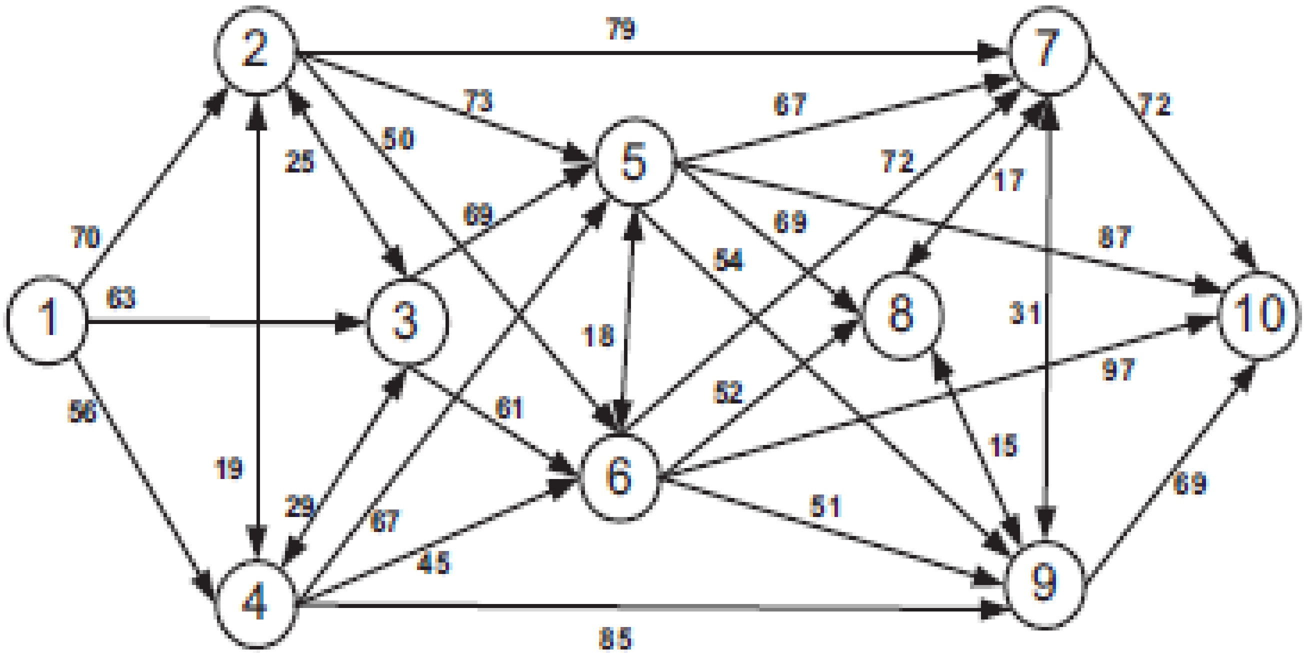
Network Flow Models:

- Shortest Path (Route) Problem
- Minimum Cost Flow Problem
- Maximum Flow Problem
- Multi-Commodity Problem

Shortest Path (Route) Problem:

- This problem attempts to identify a path, from source to destination, within the network, that results in minimum transport time/cost.
- This particular problem should be especially attractive to cargo handlers andorigin/destination scenarios.
- The problem consists of a connected network with knowncosts for each arc in the network.
- The objective is to identify the path with the minimum cost between two desired nodes.

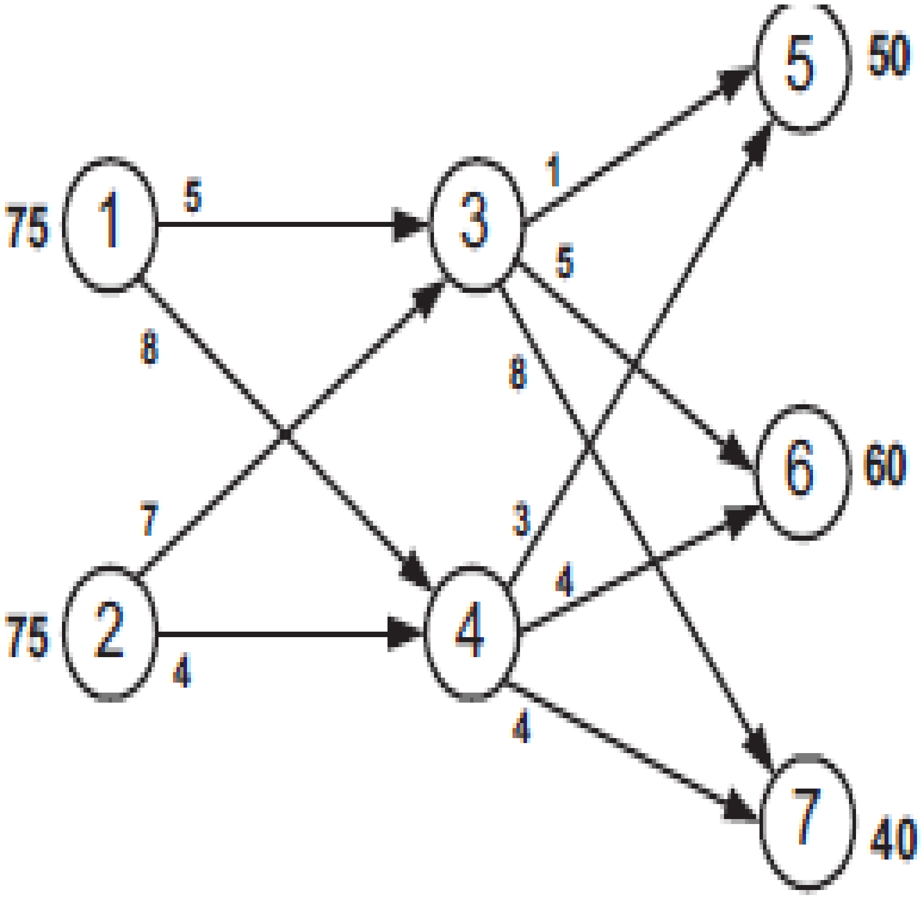
Shortest Path (Route) Problem:



Minimum Cost Flow Problem:

- The minimum cost flow network problem seeks to satisfy the requirements of nodes at minimum cost.
- This is a generalized form of transportation, transshipment, and shortest path problems.
- This problem assumes that we know the cost per unit of flow and capacities associated with each arc.

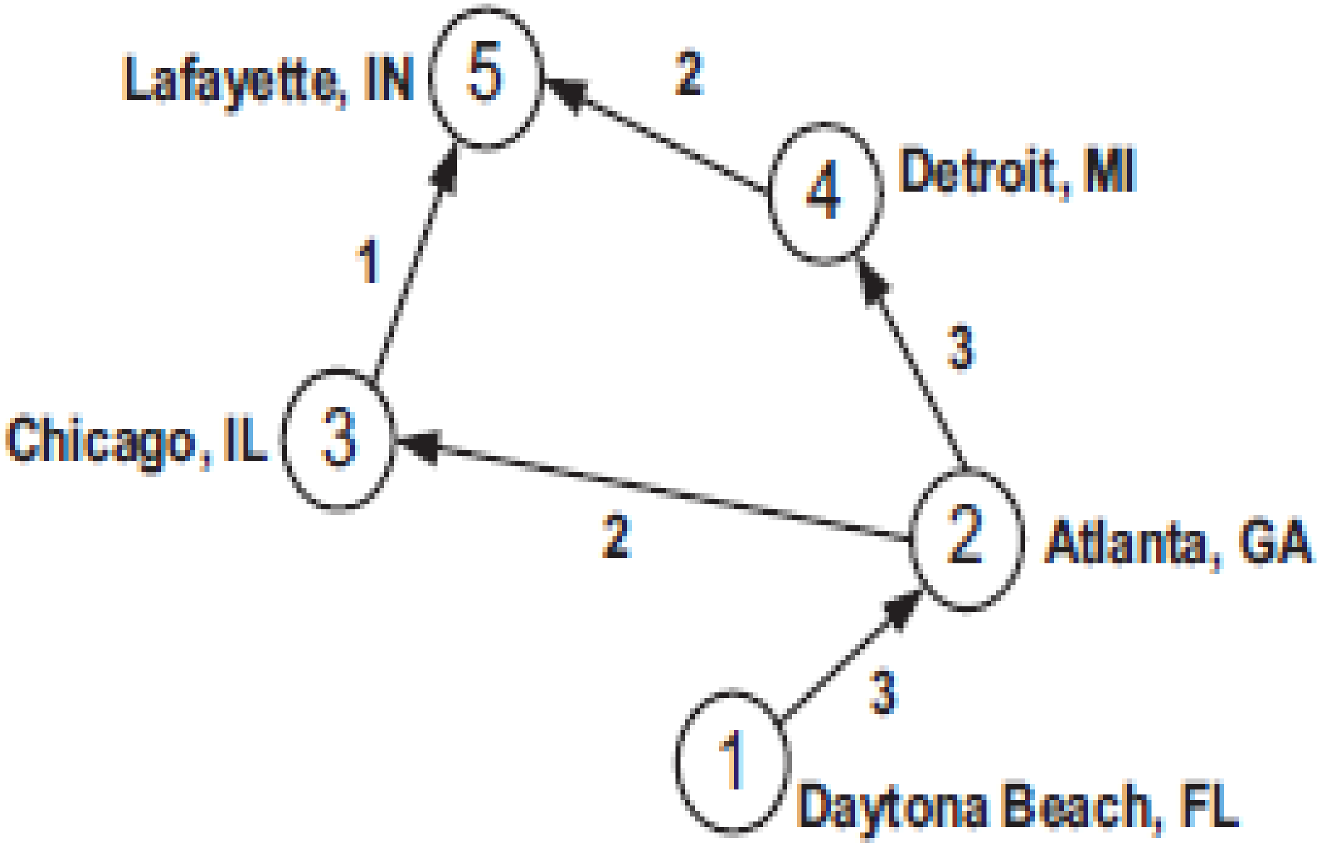
Minimum Cost Flow Problem:



Maximum Flow Problem

- The Maximum Flow problem is a special case of the minimum Cost flow problem.
- It attempts to find the maximum amount of flow that can be sent from one node (source node) to another (destination node) when the network is capacitated .

Maximum Flow Problem



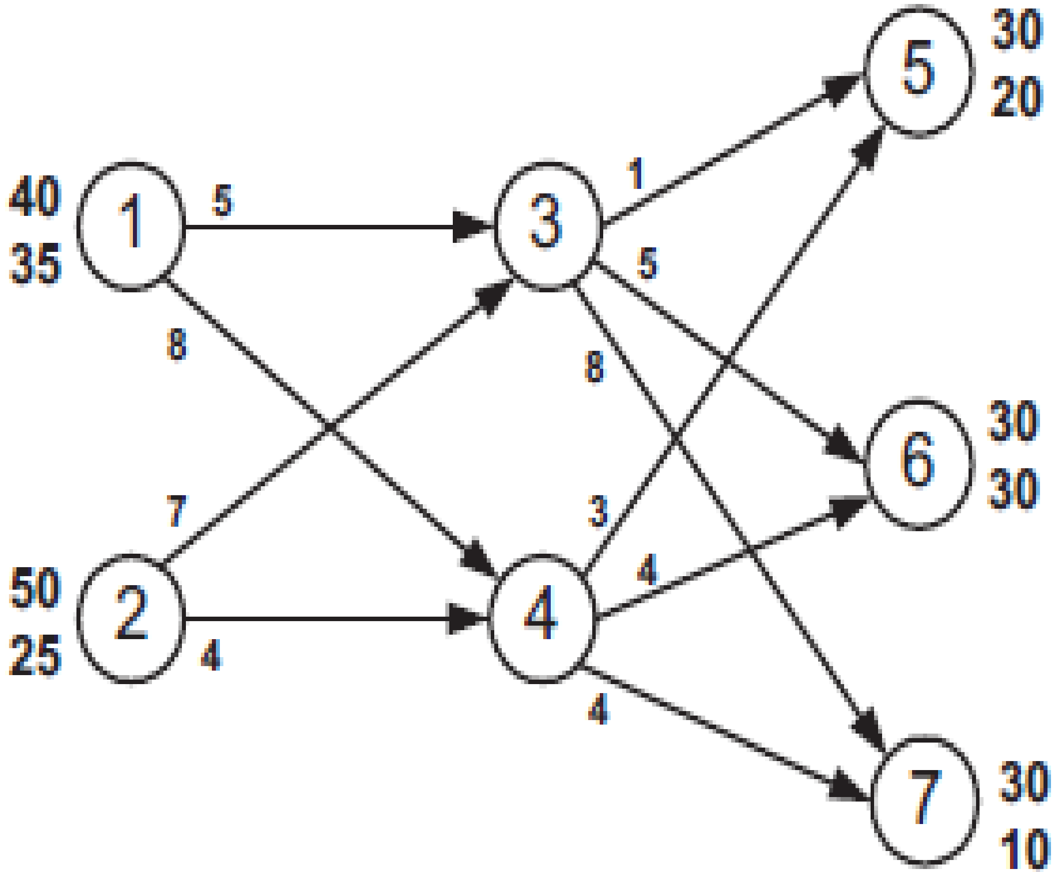
Traveling Salesman Problem:

- The Traveling Salesman problem is a classical problem in operations research, and has received considerable attention in the literature.
- The Traveling Salesman problem is as follows: Starting from his hometown, a traveling salesman wants to visit a series of cities just once, and finally return to his hometown.
- The problem is to determine the best sequence for visiting these cities so that the total cost (total distance or total time traveled) is minimized

Multi-commodity Problem:

- All the network models explained so far assume that a single commodity or type of entity is sent through a network.
- Sometimes a network can transport different types of commodities.
- The multi-commodity problem seeks to minimize the total cost when different types of goods are sent through the same network to formulate crew pairing and fleet assignment models.

Multi-commodity Problem:



Set-covering/Partitioning Problems

- Set-covering problems relate to cases where each member of one set should be assigned/matched to member(s) of another set Examples include the assignment of crew members to flights, aircraft to routes.

- The objective in a setcovering problem is to minimize the total cost of this assignment.

UNIT – II
Aircraft routing and irregular operations

Aircraft Routing

- Aircraft routing is the process of assigning each individual aircraft (referred to as tail number) within each fleet to flight legs.

- The aircraft routing is also referred to as aircraft rotation, aircraft assignment or tail assignment.

- The major goal of this assignment problem is to maximize the revenue or minimize operating cost with the following considerations(Clarke et al. 1997, Gopalan and Talluri 1998, Papadakos 2009)

Flight coverage:

- Each flight leg must be covered by only one aircraft.

Aircraft load balance:

- The aircraft must have balanced utilization loads.

Maintenance requirements:

- Not all the airports that an airline flies to have the capability to perform maintenance checks on all fleet types.

Maintenance Routing

- The mathematical approaches to the aircraft-routing problem typically assume that the same schedule is repeated daily over a period of time.

Routing Cycles

- For Ultimate Air, we assume that only routes with three- day closed cycles are valid.

- A closed cycle is when an aircraft starts from a city, and at the end of the three-day cycle, ends up at that same city to start another cycle.

Route Generators

- For the proposed set-portioning mathematical model, we begin by generating all possible valid aircraft routings.

- It may seem that generating these routes is a very difficult and tedious task. This is certainly the case if we want to enumerate all possible routes manually.

- Automated systems are used extensively to generate and filter these routes for the airlines in a relatively short time.

Problem statement

- Aircraft and crew schedule problem
- Aircraft routing problem statement

Applications of Operations Research to Air Transport

Airline company management

Aircraft and crew scheduling

- Schedule design
- Fleeting
- Aircraft routing
- Crew pairing
- Matriculation
- Crew scheduling

Revenue management

Yield management

- Fare classes
- Overbooking
- Varying prices
- Go/No shows
- etc.

Traffic management

- Air traffic management
- Airport management

The four successive aircraft and crew schedule problems

1. Schedule planning

Schedule planning

Inputs:
OD time dependent demand estimations, previous schedule, etc.
Outputs:
A schedule

The four successive aircraft and crew schedule problems

1. Schedule planning
2. Fleet assignment

Fleet assignment

Inputs:
A schedule, flights cost (depending on demand and airplane type), fleet sizes
Outputs:
A fleeting

The four successive aircraft and crew schedule problems

1. Schedule planning
2. Fleet assignment
3. Aircraft routing

Aircraft routing

Inputs:
A one-fleet schedule,
maintenance constraints,
border conditions
Outputs:
A feasible routing

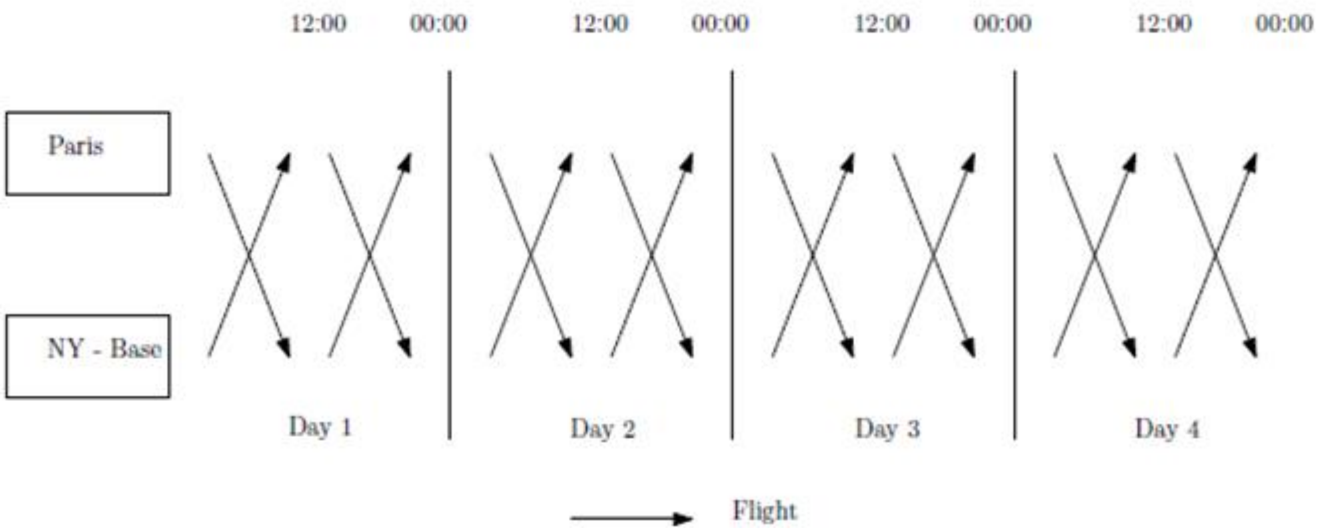
The four successive aircraft and crew schedule problems

1. Schedule planning
2. Fleet assignment
3. Aircraft routing
4. Crew planning

Crew pairing

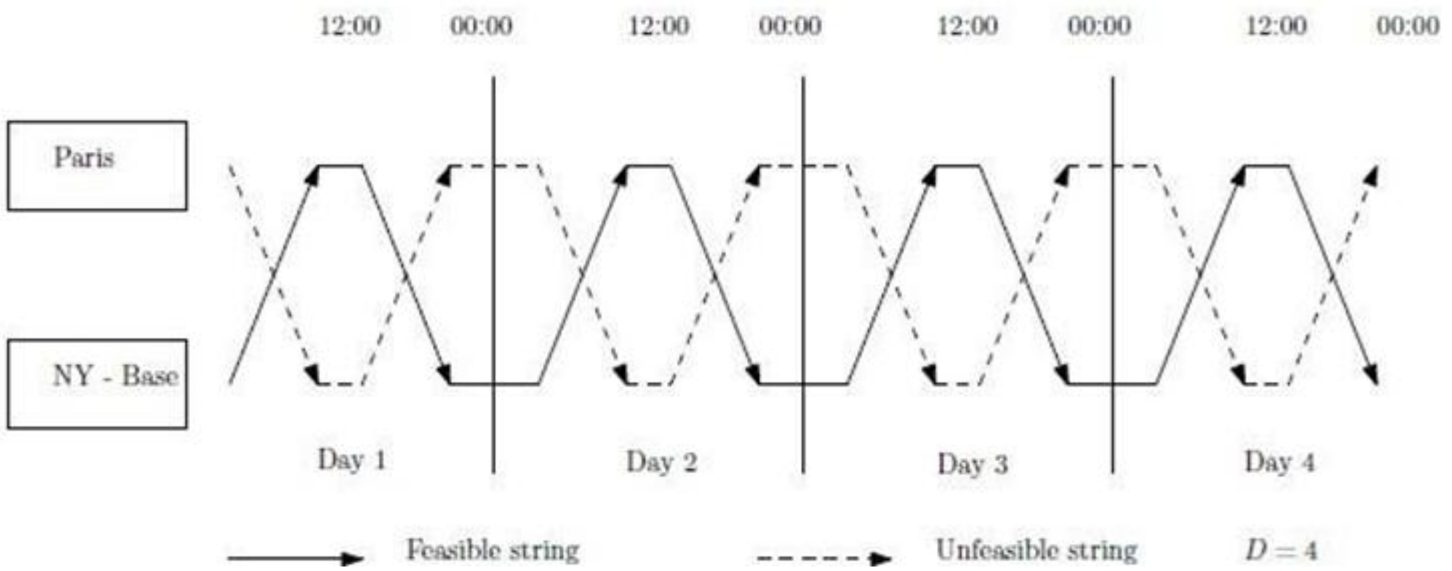
Inputs:
A one-fleet schedule, a routing, crew working rules
Outputs:
A feasible pairing

Feasible string and feasible routing



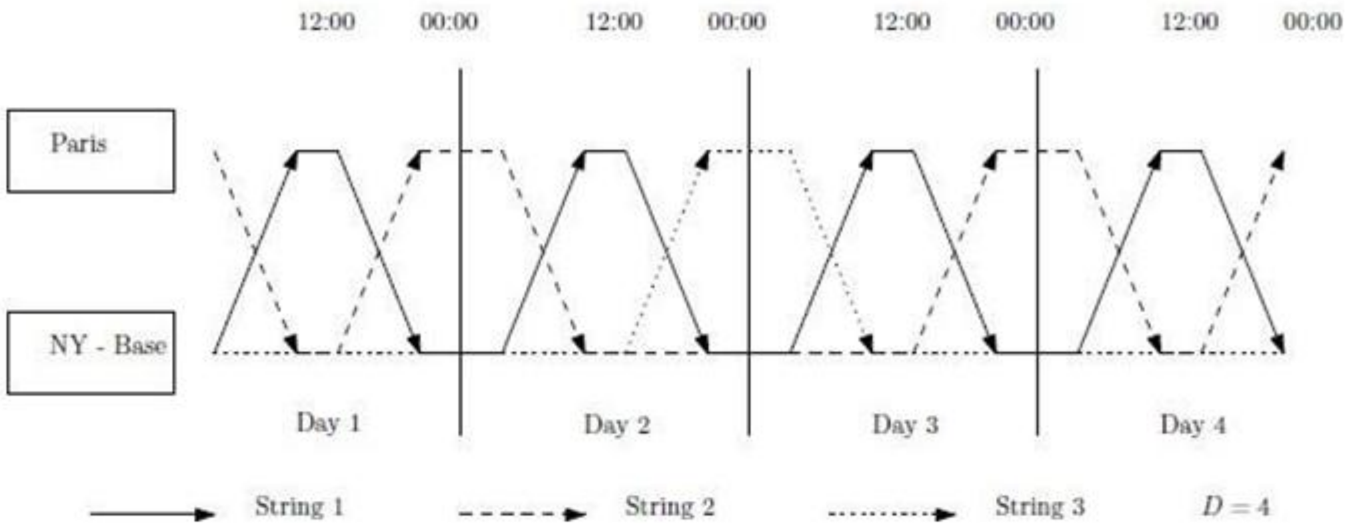
Feasible string and feasible routing

- Cover constraint



Feasible string and feasible routing

- Cover constraint
- Maintenance constraint
- Initial and final conditions



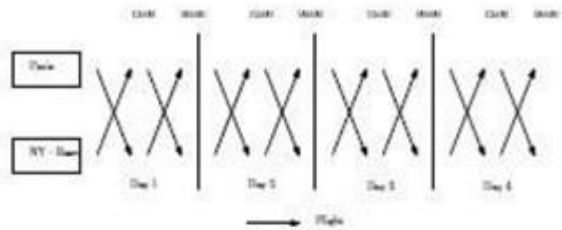
Aircraft routing problem

Instance:

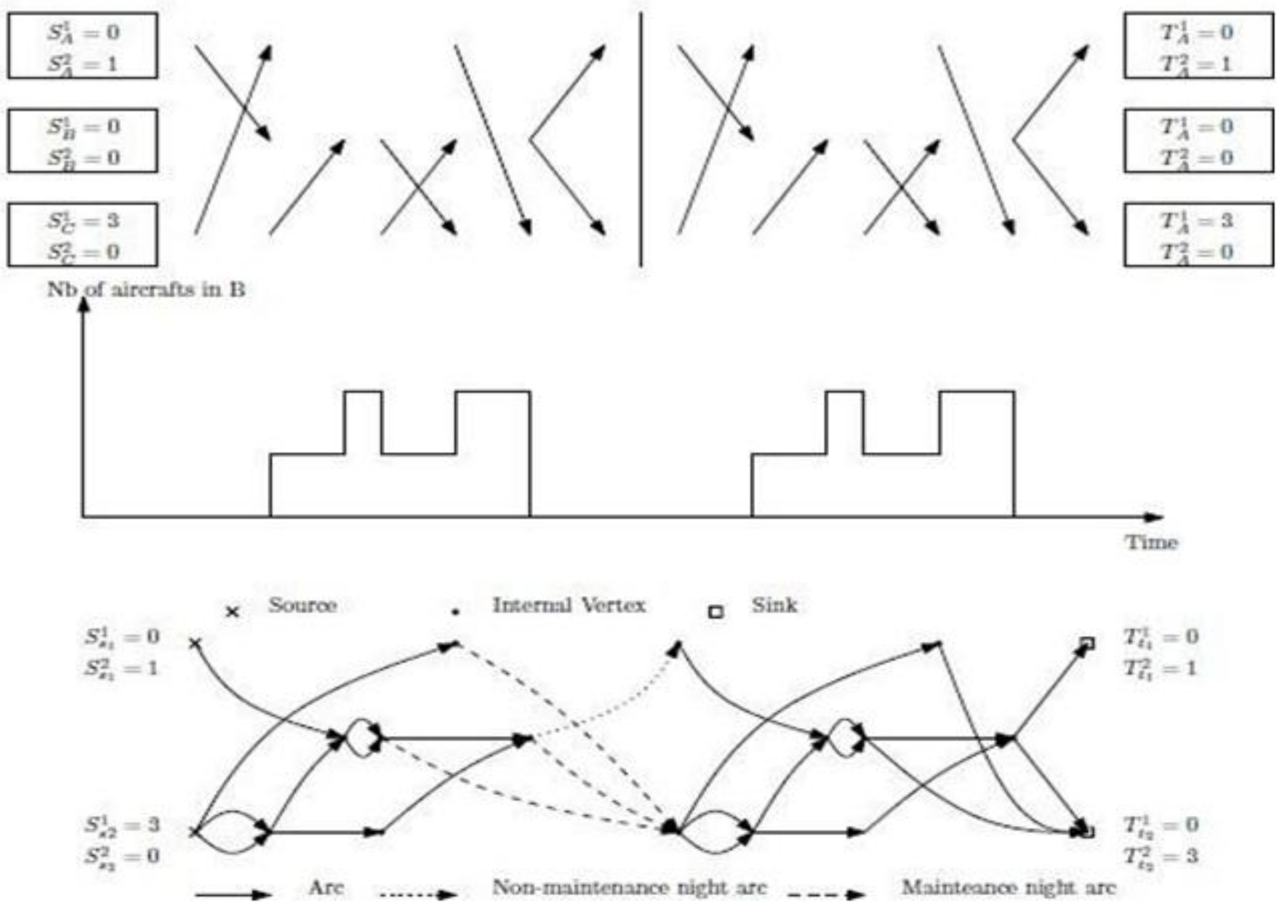
- Horizon H, Time discretization T
- Set of airports A, Set of bases $B \subseteq A$
- Set of flights $F \subseteq (A \times [T] \times [H])^2$
- Maintenance constraint D
- Initial and final conditions S_a^o, T_a^o

Question:

- Does a feasible routing exist?



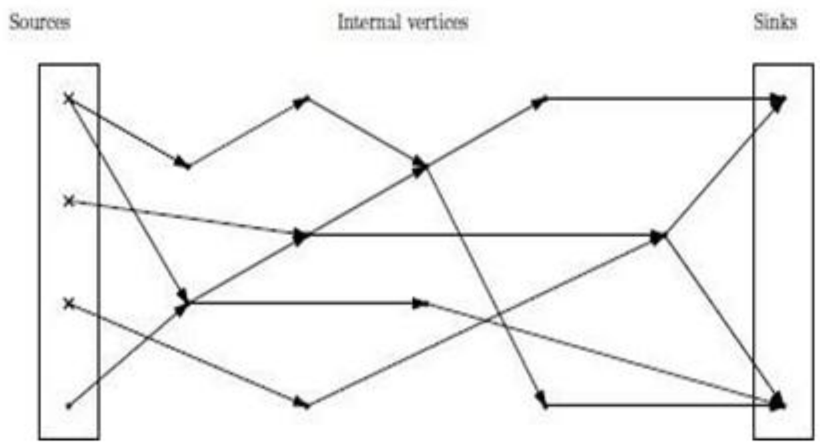
From aircraft routing to graph cover



Equigraph definition

An acyclic directed graph is an *equigraph* if its vertices can be partitioned in three sets:

- Sources $v \in S$ satisfying $\delta^-(v) = \emptyset$ and $\delta^+(v) \neq \emptyset$.
- Internal vertices $v \in I$ satisfying $\delta^-(v) = \delta^+(v) > 0$.
- Sinks $v \in S$ satisfying $\delta^-(v) \neq \emptyset$ and $\delta^+(v) = \emptyset$



Algorithm complexity

The configuration graph G_C is defined as follows:

- Vertices V_C: Pebble configurations
- Arcs A_C: Legal moves. $|A_C| \leq |V| \cdot D^k$

A *path from the source configuration to the sink configurations set* gives a solution to the pebbling game

Theorem

Aircraft routing problem is polynomial when k is fixed. Pebbling game algorithm gives a solution in $O(|F| \cdot D^k)$

Proof.

A path finding algorithm is linear in the number of arcs in an acyclic directed graph. □

Research actually performed

- Generalized framework (network graph / state graph)
  - Crew pairing
  - Aircraft routing with delay
- Integer linear program with fewer variables
- Statistical treatment on delay
- Simultaneous aircraft routing and crew pairing

The Time Band Approximation Model

- An approximation scheme and a greedy randomized adaptive search procedure (GRASP) for the irregular operations aircraft routing problem.

- The objective of this problem is to minimize the costs associated with reassigning aircraft to scheduled flights whenever a shortage of aircraft occurs.

- Flight cancellations, delays and aircraft substitutions are among the costs that must be considered for the new aircraft assignments that put an airline back on schedule by the end of the day's operations.

- A third model, the time band approximation model, is founded on a time-based network representation that approximates the problem.
- In this approach, the time horizon is discretized into fixed length intervals that are used to aggregate local activity into a single point.
- The time bands can be made arbitrarily short to control the tradeoff of problem size and accuracy.

- The GRASP starts with a default solution as input, generates a list of attractive neighboring solutions, randomly moves to a neighbor, and repeats this process until a local minimum is attained.

- This heuristic is polynomial with respect to the number of flights and aircraft and works within the constraints of the resource assignment model.

- For a number of small problems both the GRASP and time-band approximation have been able to generate optimal solutions.

UNIT –III
Flight Scheduling

- The flight schedule is a timetable consisting of what cities to fly to and at what times.

- An airline’s decision to offer certain flights will mainly depend on market demand forecasts, available aircraft operating characteristics, available manpower, regulations, and the behaviour of competing airlines.

- The number of airports and flight frequencies served by an airline usually expresses and measures the physical size of the airline network (Janic2000).

Hub-and-Spoke

- Most airlines adopt some variation of a hub-and-spoke system.
- Major carriers operate up to five hubs, while smaller ones typically have one hub located at the center of the region they serve.

Route Development And Flight-scheduling Process

There are two types of route development activities:

- strategic and
- tactical.

Long-Range Schedule Planning

- Fleet diversity
- Manpower planning
- Protecting hubs
- Adding or changing hubs
- Adequate facilities at airports

Market Evaluations

- Frequency and time of service to each market
- Adding new and dropping existing markets

Pricing policies

- Predicting competitors' behaviors
- Code-sharing agreements and alliances

Schedule Optimization

- Developing initial schedule based on available fleet
- Assigning aircraft to flights
- Evaluating facilities and manpower capabilities

Schedule Issues

- Crew issues
- Arrival departure times
- Maintenance issues

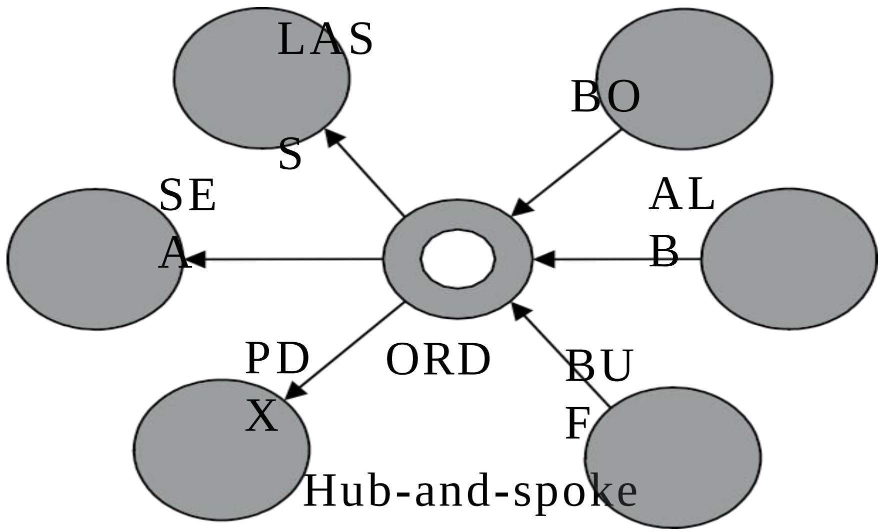
United's Route Network Model

- Air travel is dominated by thousands of small markets where total travel demand does not justify "point-to-point" non-stop flights

Western United States		Eastern United States	
Las Vegas Seattle	(LAS)	Boston	(BOS)
Portland	(SEA)	Albany	(ALB)
	(PDX)	Buffalo	(BUF)

United's Route Network Model

- United has chosen a "Hub-and-spoke" model that maximizes number of markets served with given aircraft assets



United's Scheduling Strategy

- United's scheduling strategy balances marketing goals and operating imperatives to meet financial goals

Marketing goals

- Marketing strategy
- Maintain market share
- Competitive response
- Provide travel day and time flexibility to
  - passengers

Operating imperatives

- Safety/maintenance requirements
- Aircraft availability
- Crew availability
- Other operating restrictions

- Market selection
  - Where should we fly?

Flight frequency/time

- How often should we fly?
- When should we depart/arrive?

Fleet selection

- Which aircraft type should we use?

Financial goals

- Maximize revenue
  - Minimize cost

Profitability

ZEUS Enables All Stages of Planning and Scheduling

	Strategic Planning		Schedule Optimization	
Process	Strategic Planning	Long Term Planning	Mid Term Planning	Operational Planning
Time*	Multi-year	365-108 days	108-80	days
Activities	• Hub Planning • Fleet Plan • Acquisitions • Schedule Structur	• Markets • Frequencies • Schedule e Structure • International Slots	• Fleeting • Crew Interactions • Reliability • Maintenance	• Operability • Aircraft Flows • De-peaking • Reliability • Flight Number Integrity • Weekends, Transition
Key Models	• Profitability Forecast (PFM) • Joint UA-UAX Fleet Planning • Codeshare Optimizer	• PFM • Joint UA-UAX Fleet Assignment	• UA Fleet Assignment • Re-Fleeting • Routing	• Through Assignment / Routing • Flight Number Continuity • Exception Scheduling • De-peaking Suite

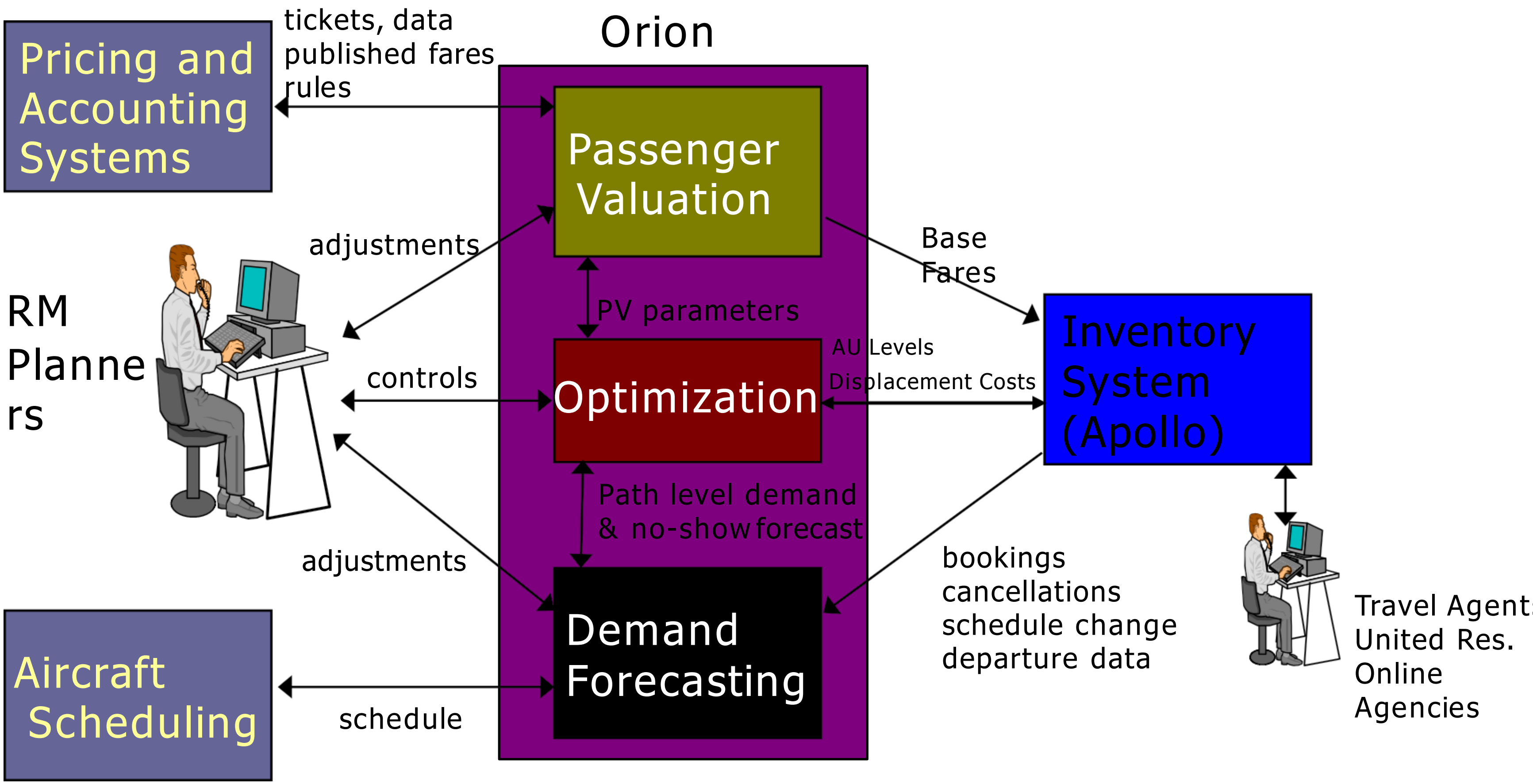
Exception Scheduling Model

Objective:

Optimize exceptions on weekends to improve profitability while adhering to operational constraints

Inputs	Methodology and Key Capabilities	Outputs
UA Schedule	The model uses a Mixed Integer Linear Program to model the weekend schedule and maximize the profitability subject to operational and other constraints Associated business process changes have resulted in independent construction of optimal weekday and weekend schedules	Fully Fleeted Weekend Schedule
Demand and Fare Forecasts	The model ensures that the weekend schedule meshes seamlessly with the surrounding weekday schedules	
Operational Constraints	The model recaptures demands from canceled flights and moves the demand to neighboring flights in the market	

United's Yield Management System -Orion



Flight Network

- **Orion** optimizes revenue on approximately 3,600 UA and UAX daily departures
- About 27,000 unique paths are flown each day by United's customers

Forecast and Optimization Statistics

- Orion produces 13 million forecasts for all 336 future departure dates All future departure dates are optimized every day

UNIT – IV

Fleet Assignment, Crew Scheduling And Manpower Scheduling

- The task of **fleet assignment** is to match each aircraft type in the fleet with a particular route in the schedule.
- It should be noted that this phase of planning concerns only fleet type and not a particular aircraft.
- The goal of fleet assignment is to assign as many flight segments as possible in a schedule to one or more fleet types, while optimizing some objective function and meeting various operational constraints(Abara 1989).

Crew scheduling:

- Crew scheduling involves the process of identifying sequences of flight legs and assigning both the cockpit and cabin crews to these sequences.

- Crew scheduling, like aircraft routing which is normally performed after the fleet-assignment process.

- Total crew cost including salaries, benefits, and expenses, is the second largest cost figure after the cost of fuel, for airlines.

Crew Pairing:

- The first phase in the crew scheduling is to develop crew pairing.
- Crew pairing is a sequence of flight legs, within the same fleet, that starts and ends at the same crew base.
- A crew base is the home station or city in which the crew actually lives.
- Large airlines typically have several crew bases.
- The sequence of crew pairing must satisfy many constraints such as union, government, and contractual regulations.

Duty:

- A working day of a crew may consist of several flight segments.
- The length of a duty is determined by Federal Aviation Regulations (FAR) in the United States, as well as by individual airline rules.
- Under the Federal law, airline pilots cannot fly more than 8 hours in a 24-hour period.
- They also must be able to rest for 8 hours in that same time span.

Sit connection:

- A connection during duty is called a sit connection.
- This involves the waiting times, on the part of the crew, for changing planes onto their next leg of duty.
- Normally, airlines impose minimum and maximum sit connection times, typically between 10 minutes and 3 hours.

Rest:

- A connection between two duties is referred to as rest, overnight connection or layover.

Pairings Generators:

- The pairings are generated based on rules and regulations.
- These pairings just show the sequence of flights assigned to crew members.
- It starts with a crew base and adds all the feasible flight legs according to the specified rules.
- Some of the rules in generating the feasible pairings include the total daily flight time, and minimum and maximum sit-connection times. daily flights, the number of pairings generated becomes very large (billions of legal pairings).

The following represents the crew pairing requirements for Ultimate Air:

- Each duty should not exceed 8 hours of flight time.
- A maximum length of two days is allowed for a routing.
- The minimum and maximum sit-connection times are 10 minutes and 3 hours respectively.

Crew Rostering:

- Once the crew pairing problem is solved, the second phase is crew rostering.

- Crew rostering is the process of assigning individual crew members to crew pairings.

- Some airlines, mainly European, allow their crews to select a number of pairings as identified in the first phase together with rest periods on specific days to construct their monthly personalized schedule.

Crew Rostering:

- Assigning high priority employees to high priority pairings.

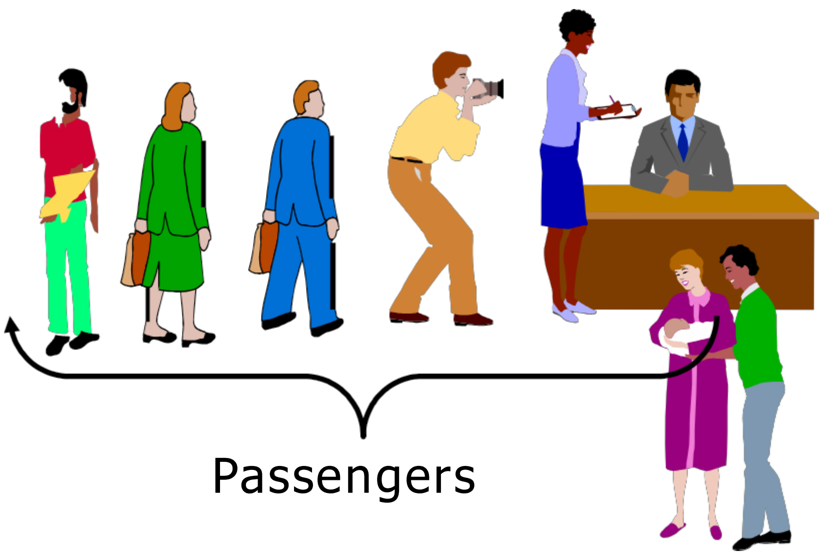
- Developing monthly rosters for individual crew members based on their requests.

- Developing monthly rosters for each day of the month without considering the crew requests.

Manpower Scheduling

Airport Manpower Assignment Models

How many employees do we need at the airport for daily Operations?



Input

Demand & Schedule

OR-Based Assignment Model

Output

How many employees?

Their respective assignments

Customer Service

Gate Agents

Baggage Handlers

Airport Employees

- **Considerations**
- Multiple start times
- Overtime/Parttime

  Employees call in sick IRROPS (Bad Weather)

Real-time ERRORS Management Models

Q: When things go "wrong" on the day-of-operations, what is the best way to "Respond and Recover" ?

What cango wrong?

- **Bad Weather (60 days out of 360 days)**
- **Aircraft needs maintenance**
- **Crew shortage**
- **Runway closedowns**

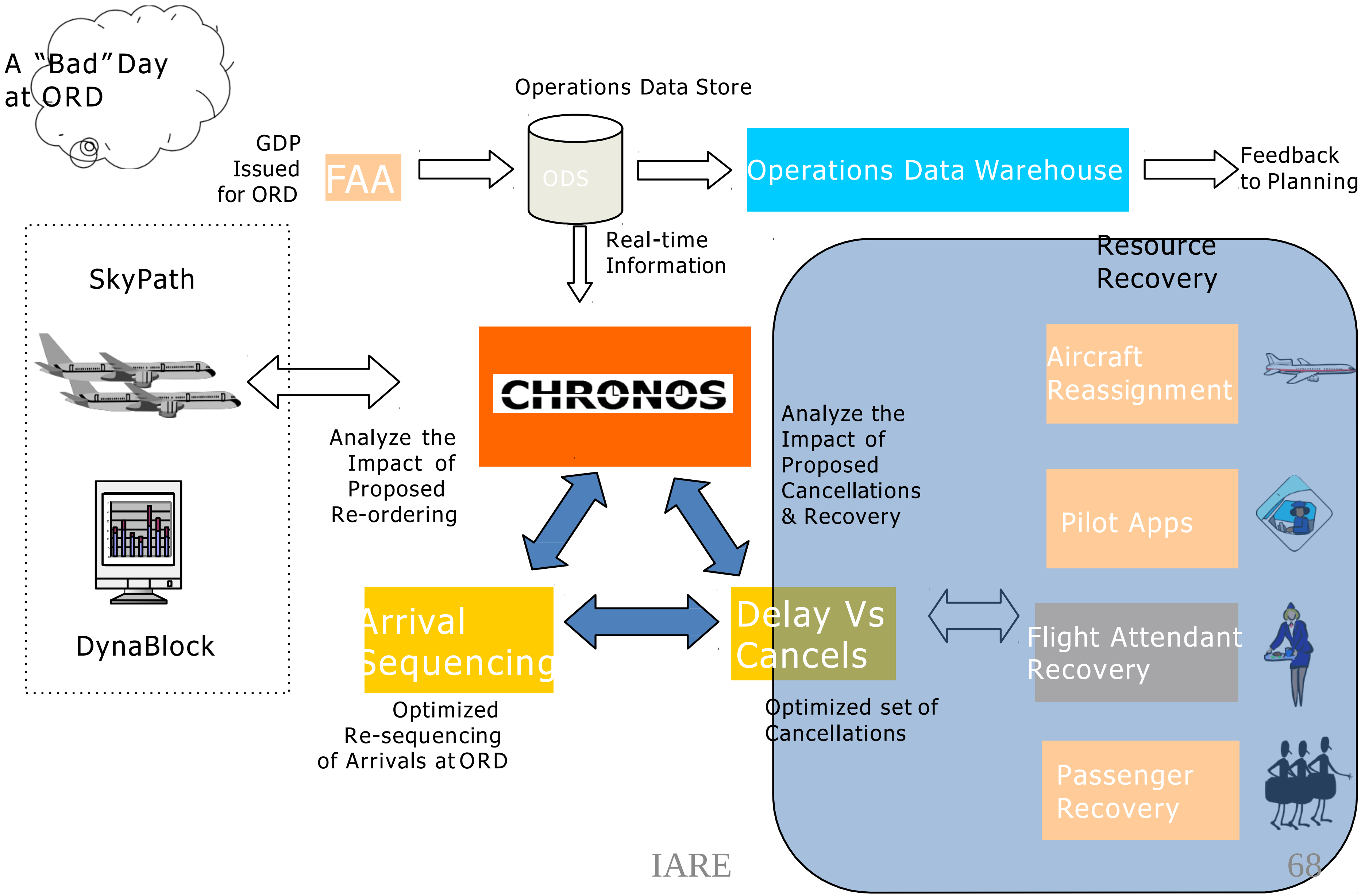
What are the choices?

- **Cancel the flight(s)**
- **Delay a flight**
- **Get a Spare Aircraft**
- **Get Reserve Pilots/Flight attendants**

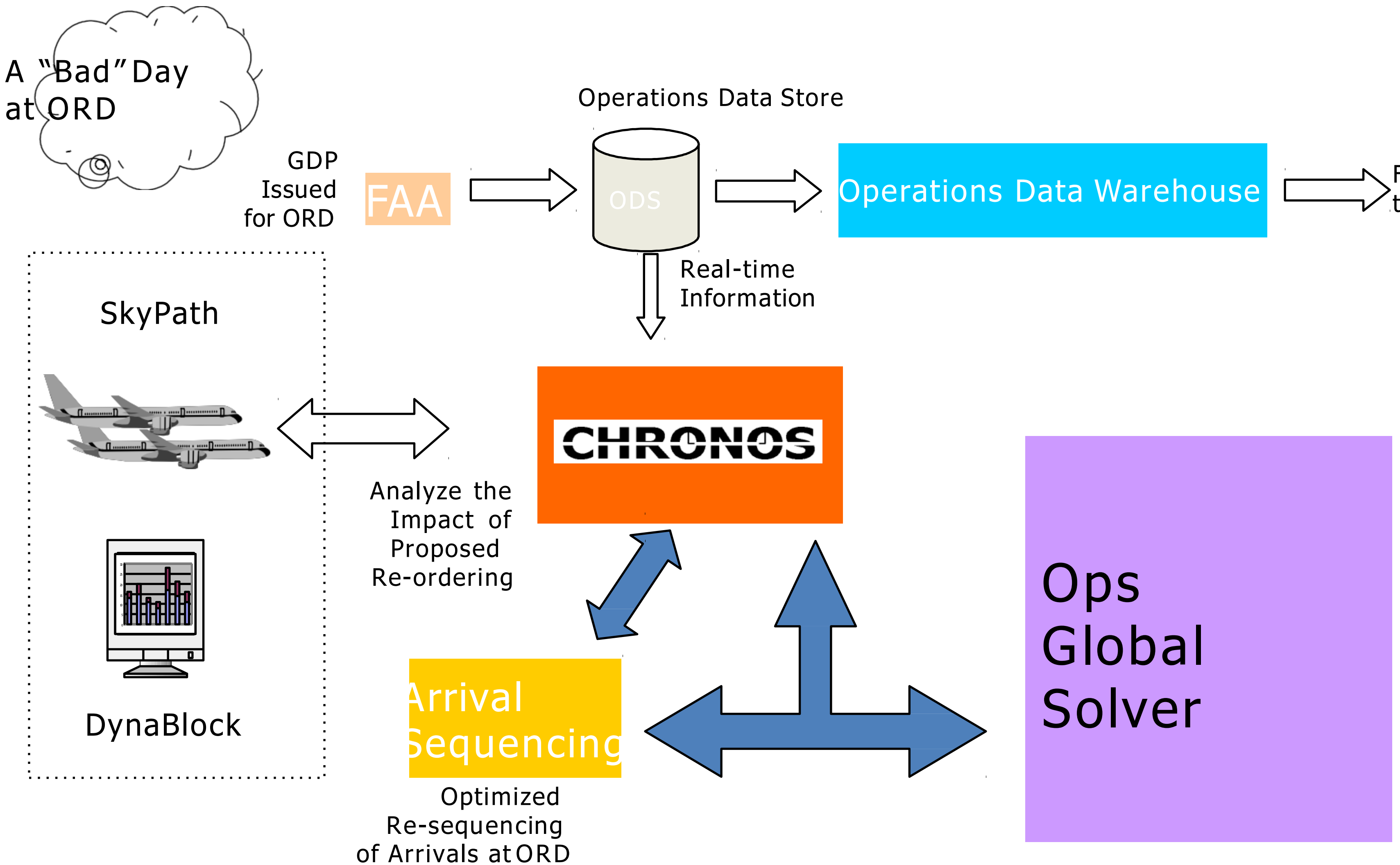


Challenges:

- **All of this has to be done in close to "real time"**
- **All Resources have to be "re- positioned" so that the next**
- **day Operations can run smoothly**



A "Bad" Day at ORD
GDP Issued for ORD
FAA
Operations Data Store
ODS
Operations Data Warehouse
Feedback to Planning
Real-time Information
SkyPath
DynaBlock
CHRONOS
Analyze the Impact of Proposed Re-ordering
Resource Recovery
Aircraft Reassignment
Analyze the Impact of Proposed Cancellations & Recovery
Pilot Apps
Arrival Sequencing
Delay Vs Cancels
Flight Attendant Recovery
Optimized Re-sequencing of Arrivals at ORD
Optimized set of Cancellations
Passenger Recovery



At United, we are working on building this "Global Solver"

UNIT – V

Gate Assignment And Aircraft Boarding Strategy

- The hub-and-spoke system has resulted in a large volume ofbaggage and passengers transferring between flights.

- Assigning arriving flights to airport gates is therefore an important issue in daily efficiency of flight schedule sand passenger satisfaction. operations of an airline.

- Although the costs of these activities are generally small portions of the overall airline operation costs, they have a major impact on maintaining the aircraft

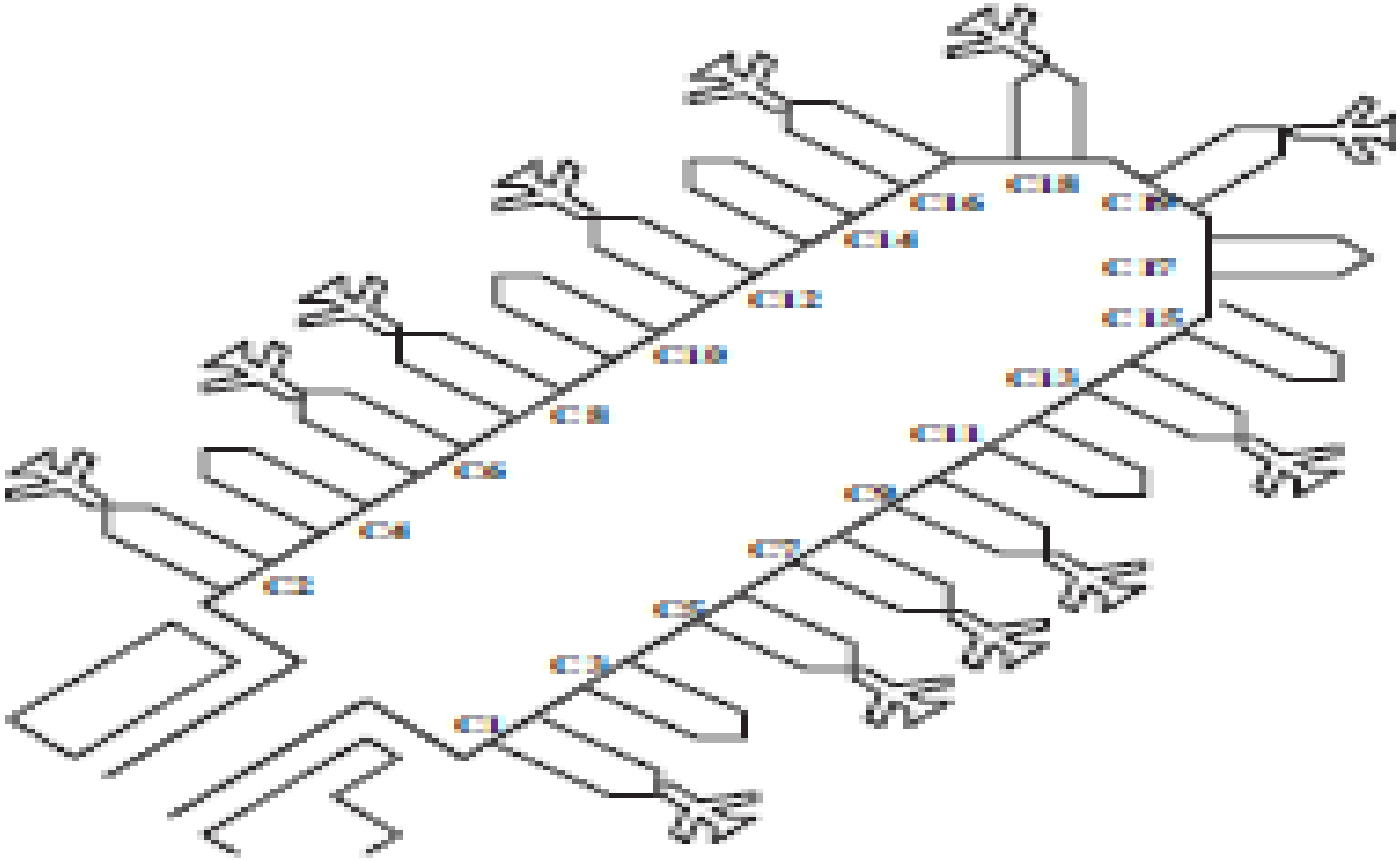
- Some of the factors that impact the assignment of gates to arriving flights include:

- Aircraft size.
- Passenger walking distances.
- Baggage transfer.
- Ramp congestion.
- Aircraft rotation.
- Aircraft service requirements.

Mathematical Model for a Case Study

- The following case study (not related to Ultimate Air!) involves the assignment of flights to gates.
- The C Concourse at San Francisco (SFO)Airport, which has 19 gates (C1-C19).
- There are already 12 aircraft at the gates(as shown) getting ready for their departures.
- Within the next 15 minutes seven flights will be arriving in this concourse that should be assigned to the remaining gates.

Gate Assignment



Baggage Handling

- The introduction of hub and spoke concept has represented the airlines with challenging and demanding task of baggage handling for transit passengers.

- Unlike the passengers who can typically walk from one gate to another, the bags actually need to be transported from one gate to another for these transit passengers.

Aircraft boarding strategy

Common Strategies for Aircraft Boarding Process:

- Airlines seem to adopt different aircraft boarding strategies based on airline culture and service level.

- Some airlines do not impose any strategy and let the passengers board randomly.

- Others arrange passengers into groups, zones or call-offs based on specific boarding strategy adopted by the airline.

- Each of these groups is then called to board the aircraft in sequence.

- The following represents some of the popular boarding strategies adopted by many of the airlines:

Back-to-Front:

- Back-to-front (BF) boarding strategy is widely adopted by many airlines for both narrow and wide-body aircraft.

- In this strategy, first class, business class, and special-need passengers are boarded first. Then as the name implies, passengers start filling up the aircraft from back to front.

- Passengers are called to board the aircraft based either on their seat row numbers or by groups or zones.

Window-Middle-Aisle:

- Window-middle-aisle boarding strategy (or sometimes called out-in), as the names implies, boards the passengers in window seats, middle seats and finally in the aisle seats. Passengers are usually divided into four groups to follow this boarding strategy.

- First, business class and special need passengers are assigned to group 1 and board first.

- Then all the economy class passengers in window, middle, and aisle seats are assigned to groups 2, 3,and 4 respectively and board the aircraft according to their assigned groups

- A major disadvantage of this boarding strategy is that the passengers in parties of two or more seated next to each other board the aircraft separately and at different times.

- This boarding process may not appeal to either passengers and/or airlines.

Random:

- In random boarding strategy, no specific strategy is used and all passengers board the aircraft in one zone randomly.

Rotating Zone

- In rotating zone, passengers are grouped into zones and board the aircraft first in the front, then in the back, then front again, then back in a rotating manner.

- In this boarding strategy, passengers sitting in the middle of the aircraft are seated last.

Interferences:

- Boarding interferences occur when a passenger blocks another passenger from proceeding to his or her seat.

- Two types of interferences, seat interferences and aisle interferences may occur.

Seat interferences:

- occur when a passenger blocks another passenger assigned to the same row for passengers in rows 16, 19, and 22. In all these cases, the blocking passenger(s) need to exit, for the passengers assigned to the middle or window seats to be seated.

Aisle interferences:

- occur when a lower row passenger is in front of the higher row passengers while boarding the aircraft.

- In this case, the passenger in the lower row will block all the passengers behind him or her to stow baggage in the overhead bin (if any) and be seated.

Aisle- and Middle-Seat Passengers Blocking Window-Seat Passenger:

- Having established the above seat interferences, we do not need to express a specific set of constraints for a window-seat passenger when both middle- and aisle-seat passengers have already been seated.

- This type of interference has already been addressed in the form of two separate constraints (interferences) discussed above.

- These two interferences are window with middle and window with aisle seats.

Within-Groups Seat interferences:

- This type of interference occurs among passengers boarding in the same group.
- We assume the sequence in which the passengers within a group board the aircraft is random.
- For example, passengers in seats 16A and 16B are boarding in the same group.
- When their group is called, passenger 16A may board first and be in front of 16B in the respective group or vice versa.

- In the former case when the passenger in seat 16A boards before 16B, no interference occurs.
- However, in the latter case when the passenger in 16B boards before 16A, there will be a seat interference.
- Adopting the same argument as between groups seat interference, we denote the binary variable SWi,BC,k to represent the seat interference between the aisle (seat C) and middle seat (seat B), who board in the same group.

Aisle Interferences:

- The aisle interferences are Similar to seat interferences.

- There are two types of aisle interferences within groups and between groups.

Within-Groups Aisle Interferences

- This common type of aisle interference relates to cases where passengers assigned to the same group block each other.

- This occurs when a passenger in a lower row blocks and other passengers behind him or her in order to be seated

- The problem becomes compounded when the passenger has multiple bags to store in the overhead bin.

- We further break down these within group aisle interferences into interferences with lower rows and interferences with same rows.

Summary

- The airline industry presents many high-value opportunities for Operations Research systems
- United has historically invested, and continues to heavily invest in state-of-the-art tools
- United has also consistently partnered with academia to develop cutting edge models
- Increasing computing power at lower cost of many high value opportunities remain