AIRCRAFT MAINTENANCE BASE PLANNING

Term Project

IENG 3305 – Computational Methods and Algorithms for IE

Airline industry Planning and Scheduling Process

- Flight Schedule Development
- Fleet Assignment
- Aircraft routing
- Crew/flight attendant scheduling
- Day off planning
- …

The Airline Planning Process

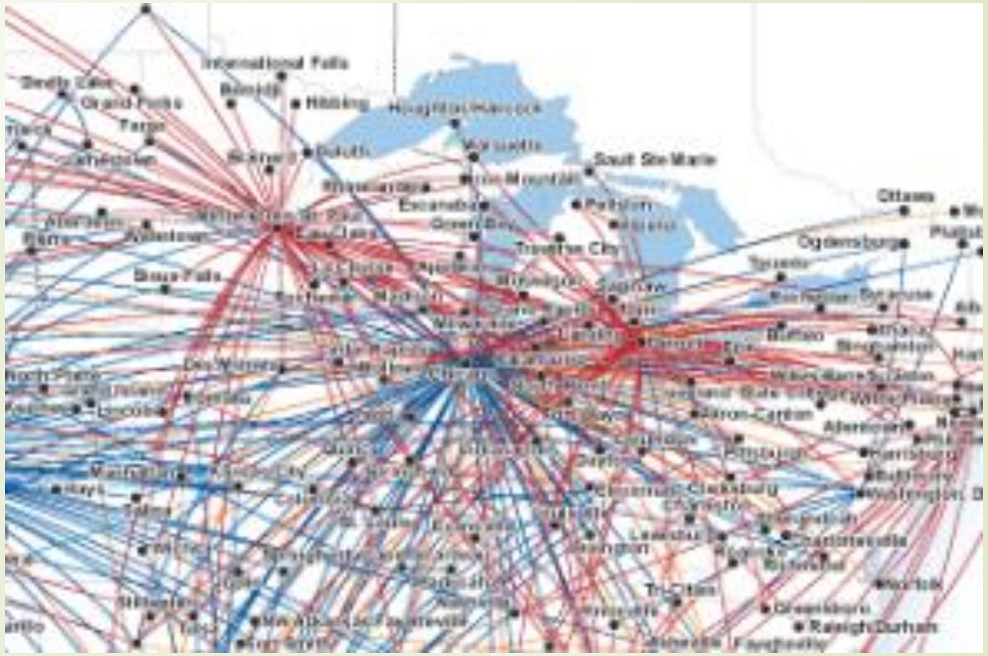
- Flight Schedule Development
  - Given:
    - historical data on passenger Origin and Destination demand
    - air traffic and airport restrictions
    - aggregate aircraft availability
  - Find:
    - departure/arrival cities/times to maximize potential revenue
  - State of Practice
    - schedules are usually generated by marketing department with little or no input from operations

The Airline Planning Process

- **Fleet Assignment**
  - Given:
    - Flight Schedule
      - Each flight covered exactly once by one fleet type
    - Number of Aircraft by Equipment Type
      - Can't assign more aircraft than are available, for each type
    - Other Restrictions: Gate, Noise, Runway, etc.
    - Operating Costs, Total Potential Revenue of Flights, by Fleet Type
  - Find:
    - Cost minimizing (or profit maximizing) assignment of aircraft fleets to scheduled flights such conservation of flow (balance) of aircraft is achieved, and the number of aircraft used does not exceed the number available (in each fleet type)

The Airline Planning Process

- **Aircraft routing**
  - Given:
    - set of flight legs assigned to each aircraft type
  - Find a routing that:
    - Produces valid **aircraft turns**
    - provides sufficient **maintenance opportunities**
    - **Maximizes/minimize total revenue/cost**



The Airline Planning Process

- <u>Crew/flight attendant </u>scheduling
  - Given:
    - flight segments covered by a single fleet
    - aircraft turns
    - contractual/FAA work rules
  - Find:
    - minimum cost set of crew itineraries or *pairings* that covers each flight exactly once

Airline maintenance requirement

Aircraft maintenance takes place in a series of checks of increasing diligence with the exception of unscheduled fixes.

The frequency of these checks depends on the combination of flight hours and number of take-off and landing cycles and may be performed at any site appropriately equipped.

Major types of check (inspection) mandated

Type A check: every 65 flight-hours, or about twice a week.	**Type B check:** every 300–600 flight-hours (about every 8 weeks)	**Type C and Type D check:** about once every 1 to 4 years

Maintenance types

- **Type A check:**
  - mandated by the FAA Federal Aviation Administration
  - occurs at every 65 flight-hours
  - inspection of major systems (landing gear, engines and control surfaces)
  - Normally done overnight
- **Type B check:**
  - every 300–600 flight-hours
  - thorough visual inspection plus lubrication of all moving parts
  - Normally done overnight
- **Type C and Type D check:**
  - once every one to four years, respectively
  - out of service for up to a month

airplane inspection scheduling

- the problem faced by an airline needing to **construct a 7-day planning** horizon cyclic schedule with maintenance constraints for a **homogenous (heterogenous) fleet of aircraft**.

- The goal of airplane inspection scheduling is to achieve a balanced pattern of flights that results in a timetable consistent with the FAA regulations and airline policies.

- Since maintenance checks are done during night, the problem of concern is where the aircraft spends the night each day in a 7-day cyclic schedule rather than intermediate stops. Assuming no flight at night.

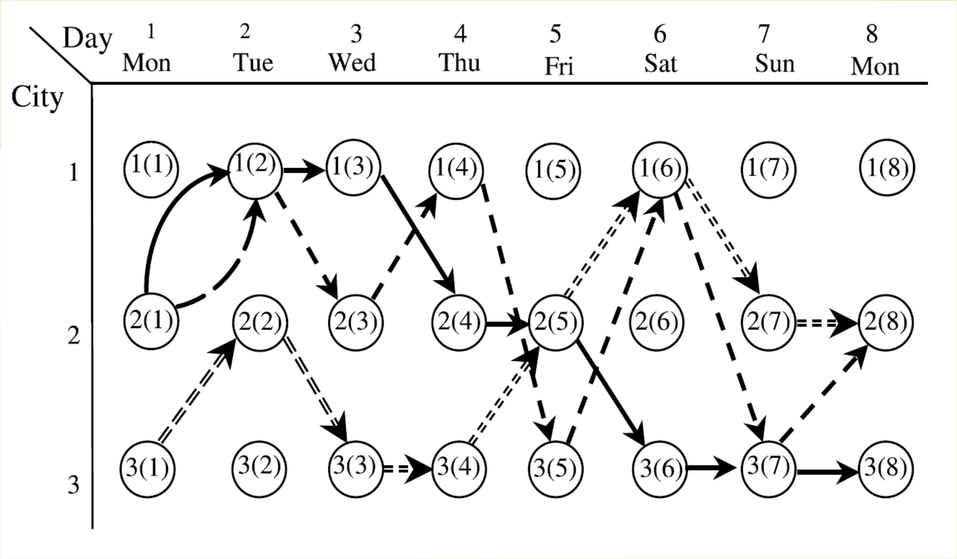
- a sequence of flight legs to which an aircraft is assigned for any given day can be considered as one trip identified as an Origin Destination (OD) pair.

AIRCRAFT MAINTENANCE (INSPECTION) BASE PLANNING

- A typical weekly flight schedule showing the individual legs or segments over the course of a day:
  - The primary data fields include flight no., departure city and time, arrival city and time, equipment type, and frequency.
  - Each block of data in Table 1 represents the itinerary for one plane for one day (an arrow in the figure).

Portion of American Airlines Flight Schedule

Leg	Flt No.	Dpt City	Dpt Time	Time Zone	Arv City	Arv Time	Time Zone	Fly Time	Days of Week	Equip Type
1	540	ORD	7:00	18	DAY	9:00	17	60	0000001	727
2	923	DAY	10:39	17	ORD	10:40	18	61	0000001	727
3	923	ORD	11:35	18	HDN	13:29	19	134	0000001	727
4	926	HDN	15:38	19	DFW	18:30	18	72	0000001	727
1	925	DFW	8:40	18	HDN	9:56	19	96	1000000	727
2	924	HDN	10:50	19	ORD	14:05	18	95	1000000	727
3	397	ORD	15:00	18	TUL	16:47	18	67	1000000	727
4	418	TUL	17:32	18	ORD	19:25	18	73	1000000	727
5	418	ORD	20:00	18	CLT	22:42	17	62	1000000	727
6	418	CLT	23:07	17	CAE	23:43	17	36	1000000	727
1	146	DFW	8:45	18	JAX	11:51	17	86	1111110	727
2	131	JAX	12:40	17	SAV	13:12	17	32	1111110	727
3	131	SAV	13:42	17	DFW	15:16	18	114	1111110	727
4	131	DFW	16:07	18	LBB	17:10	18	63	1111110	727
5	538	LBB	18:01	18	DFW	19:06	18	65	1111110	727
6	538	DFW	19:51	18	HSV	21:26	18	95	1111110	727

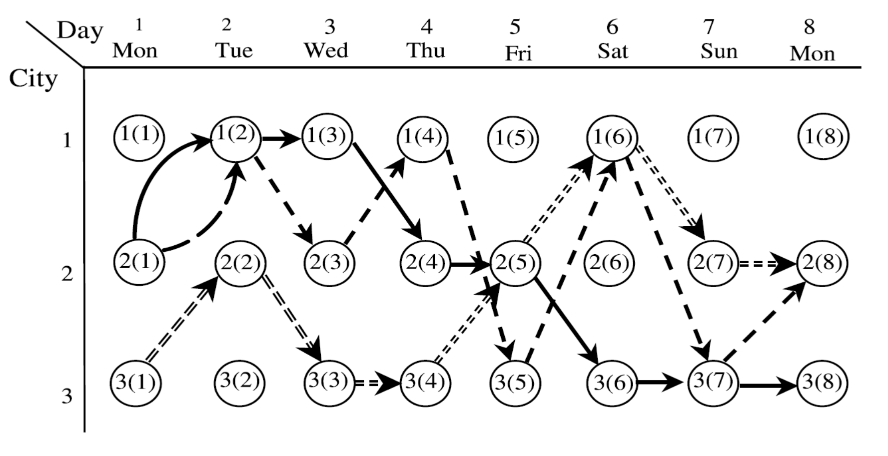


Objectives and scope

- To determine which aircraft should fly which OD pair and when and where each aircraft should undergo maintenance **checks of Type A and B.**
- Objective is to **minimize the maintenance cost** and **the penalty incurred during the re-assignment** of aircraft to the OD pairs
- the **cyclical schedule** for weekly domestic flight schedules.

- **Assumptions:**

1. maintenance is routinely performed during the period of flight inactivity
2. Unexpected maintenance requirements are not being considered
3. heterogeneity in the fleet
4. Pre-existing maintenance base facility (located at airports) for different aircraft type and different costs

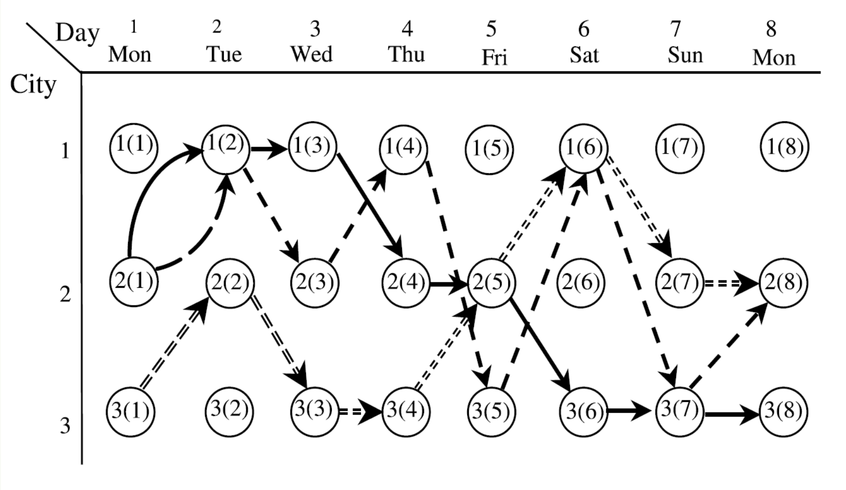


Problem formulation

- n_d: the planning horizon
- n_c: as the number of cities in the OD schedule.
- The total number of nodes in the underlying graph is $n_d n_c$.
  - But not necessarily each node should have input and output arcs.
- n_p : the total number of planes in the fleet
  - then the total number of arcs is $n_d n_p$.
- **Origin** is the airport where an aircraft leaves in the early morning after spending previous night.
- **Destination** is the airport where the aircraft spends the night for that day.
- **Each arc in the network represents a unique OD trip** assigned to an aircraft in the flight schedule.
  - In case of two aircrafts having the same Origin and Destination for any given day, then each trip of those aircraft for that day is identified by the subscript r.

Problem Decision Process

- Nodes (2(1), 1(2), 2(5), 1(6) & 3(7)) have more than one incoming and outgoing arcs. Therefore, only at these nodes a decision must be made regarding which incoming aircraft should be assigned to which outgoing arc.



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An optimization model for aircraft maintenance scheduling and re-assignment

Chellappan Sriram [1], Ali Haghani *

Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742, USA

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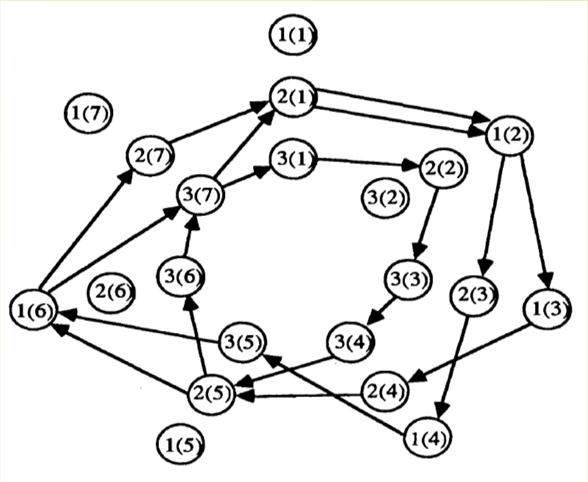
Abstract

The aircraft maintenance scheduling is one among the major decisions an airline has to make during its operation. Though maintenance scheduling comes as an end stage in an airline operation, it has potential for cost savings. Maintenance scheduling is an easily understood but difficult to solve problem. Given a flight schedule with aircraft assigned to it, the aircraft maintenance-scheduling problem is to determine which aircraft should fly which segment and when and where each aircraft should undergo different levels of maintenance check required by the Federal Aviation Administration. The objective is to minimize the maintenance cost and any costs incurred during the re-assignment of aircraft to the flight segments.

This paper provides a complete formulation for maintenance scheduling and a heuristic approach to solve the problem. The heuristic procedure provides good solutions in reasonable computation time. This model can be used by mid-sized airline corporations to optimize their maintenance costs.

Keywords: Aircraft; Maintenance; Scheduling; Optimization; Heuristic

Solution approach



- This search technique is a combination of **depth first search** and **random search**.
- First a randomly sorted list of aircraft and city-day nodes are made.
- The first aircraft and the first node are chosen from the respective list.
- Then an **exhaustive depth first search** is performed from the node to **find the best cyclic schedule** for the chosen aircraft.
- Then the **assigned links are removed** from the network.
- Now the second aircraft and city-day node are chosen from the list, again a depth first search is performed to find the best cyclic schedule for the second aircraft.
- This procedure is repeated until there is no more aircraft or nodes in corresponding list.

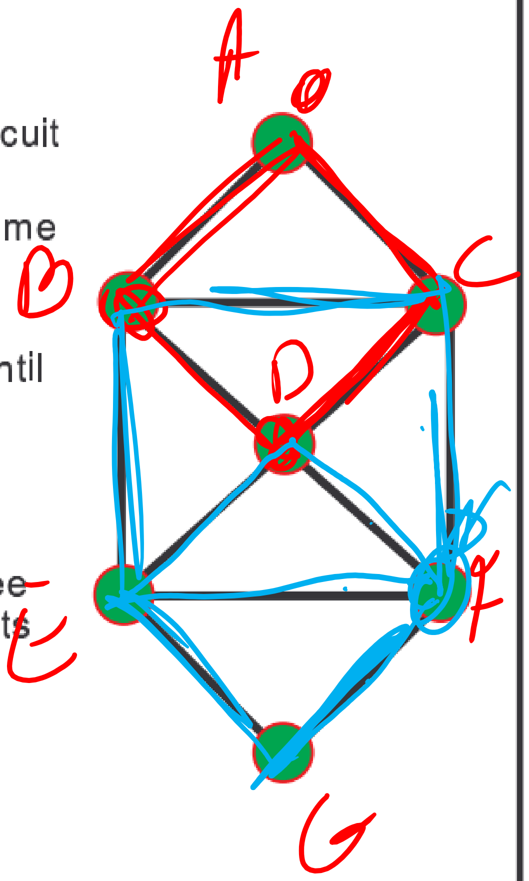
Solution approach – cont.

- After processing all the aircraft in the above-mentioned procedure, a feasible schedule and the objective function value is found.
- For the next iteration the node list and aircraft list are perturbed (shuffled). The procedure is performed for the new list of nodes and aircraft.
- This objective value is compared with the objective value obtained from the previous iteration and the better solution is saved.

Finding Euler Cycle

Finding Euler Circuits

- Given a graph G = (V,E), find an Euler circuit in G
  - Can check if one exists in O(|V|+|E|) time (check degrees)
- Basic Euler Circuit Algorithm:
  1. Do an edge walk from a start vertex until you are back to the start vertex. You never get stuck because of the even degree property.
  2. The walk is removed leaving several components each with the even degree property. Recursively find Euler circuits for these.
  3. Splice all these circuits into an Euler circuit
- Running time = O(|V| + |E|)



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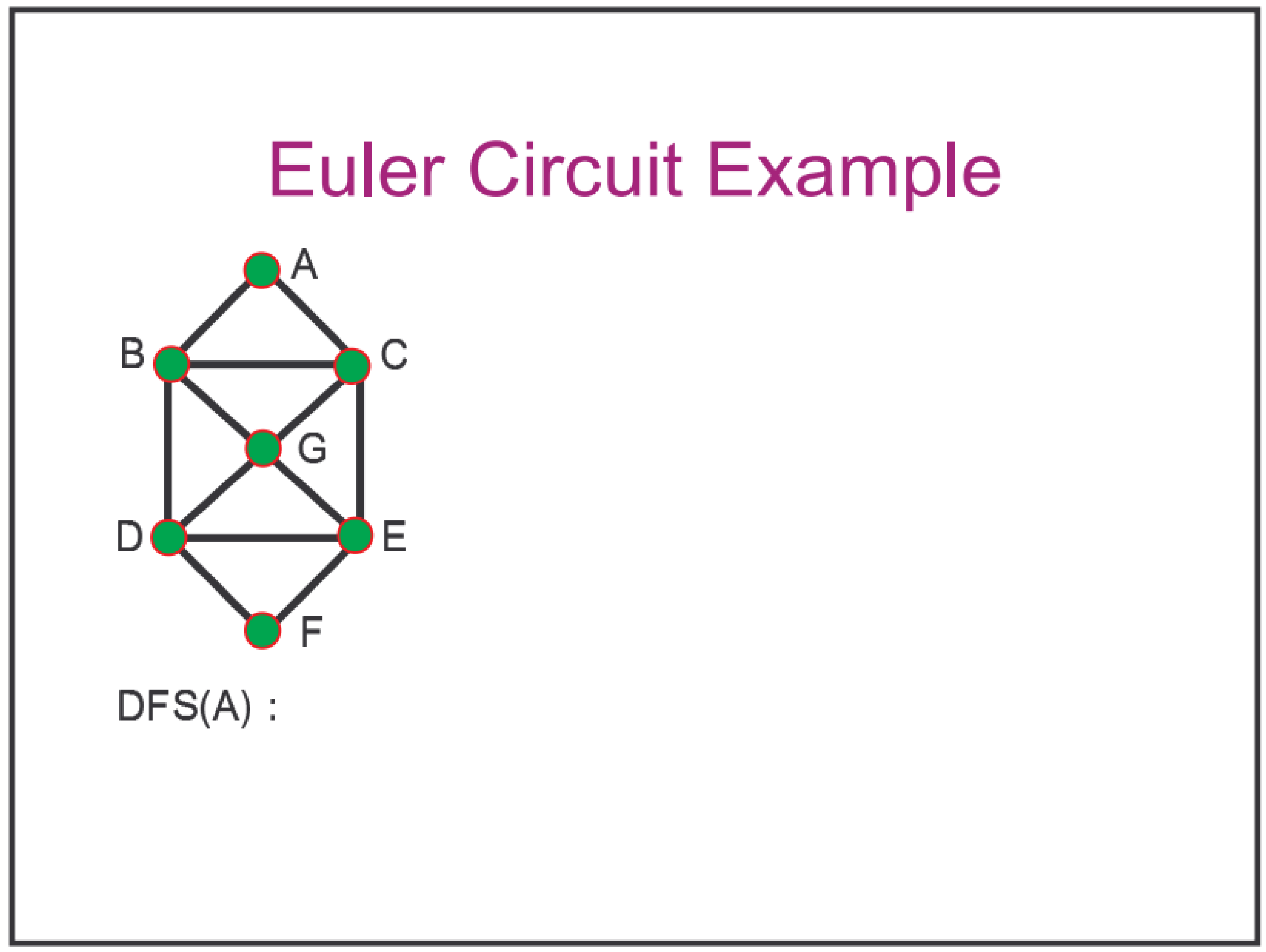
Finding Euler Cycle



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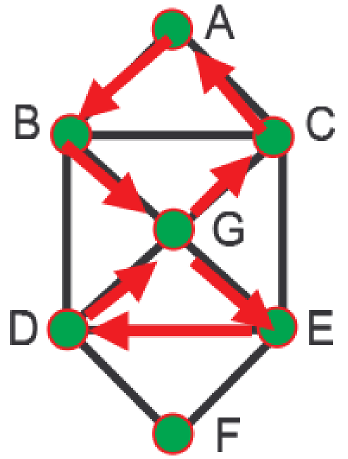
Finding Euler Cycle

Euler Circuit Example



Euler(A) :
A B G E D G C A

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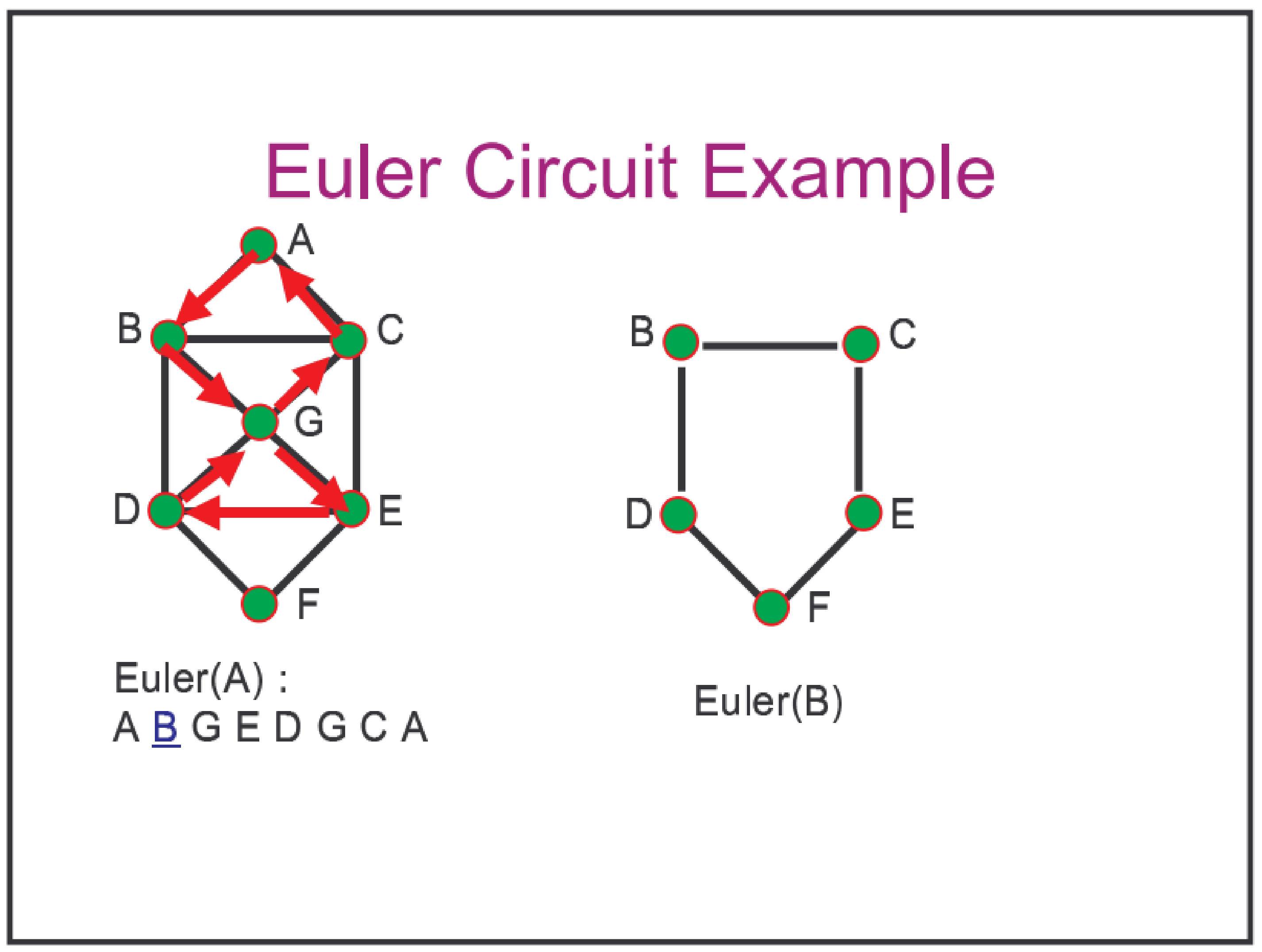
Finding Euler Cycle



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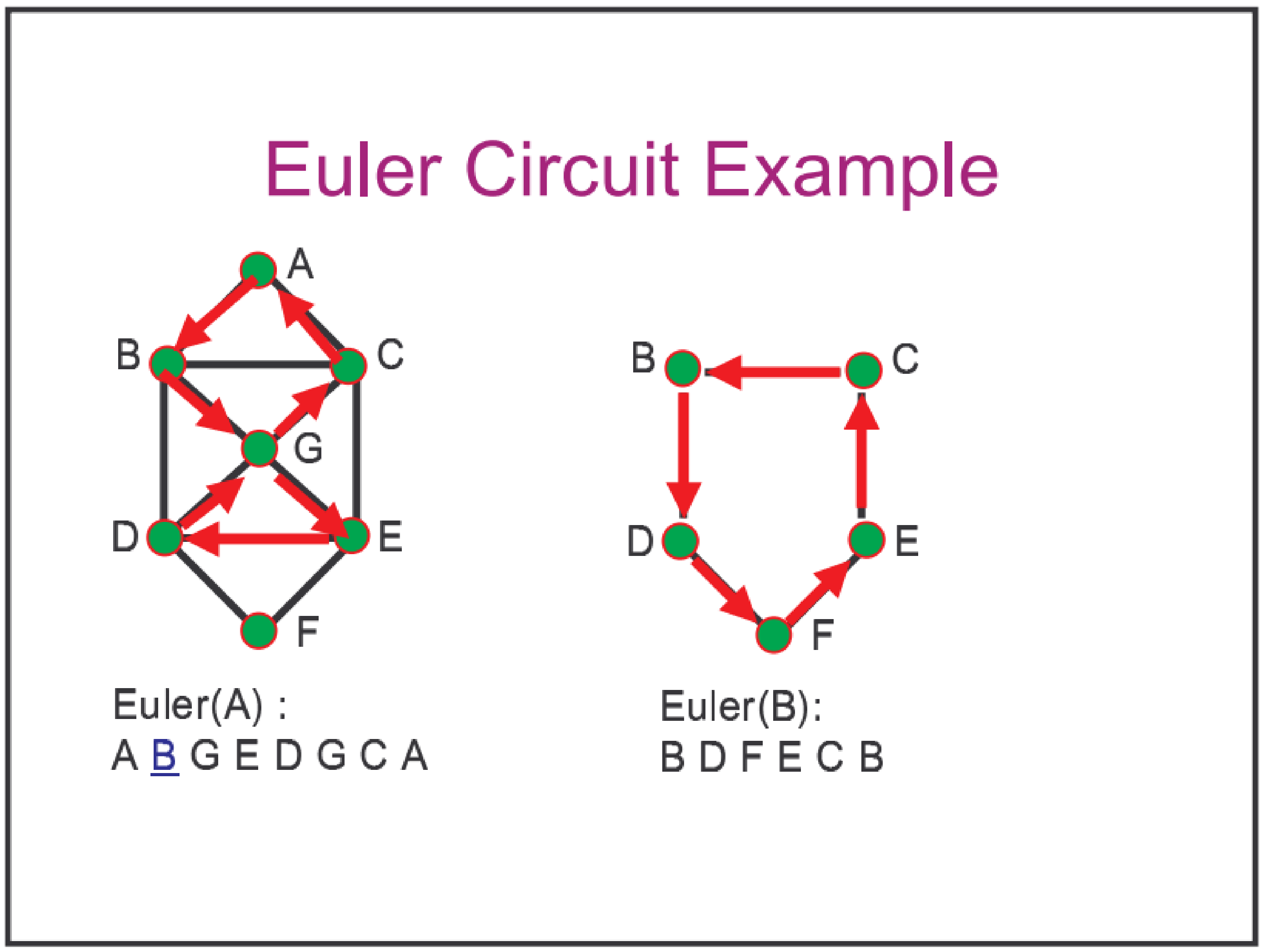
Finding Euler Cycle



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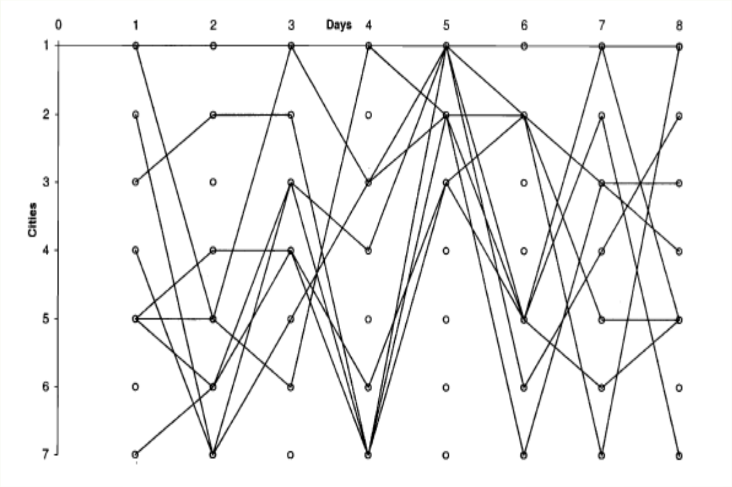
Data and data structures

Start constructing your solution based on randomly generated data from the article



Aircraft	Maintenance Type A cost in						
	City 1	City 2	City 3	City 4	City 5	City 6	City 7
1	2	5	10	10	4	3	1
2	4	6	1	1	4	5	9
3	3	7	3	8	7	9	10
4	7	10	3	7	10	4	8
5	10	7	2	2	5	2	9
6	4	1	6	10	9	6	9
7	7	1	4	4	1	4	4
8	1	6	7	5	4	5	10

cost for maintenance check A for each aircraft in the fleet (Sriram and Haghani 2003)

Result and data structures

The maintenance schedule generated by heuristic (Sriram and Haghani 2003)

Aircraft	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 1
1	1	2	3	4	7	5	3	1
2	2	5	6	5	5	1	3	2
3	1	5	1	5	6	3	4	1
4	2	7	3	3	2	2	7	2
5	1	6	4	2	7	3	7	1
6	2	2	7	1	5	6	1	2
7	3	2	5	5	4	4	7	3
8	3	5	2	7	6	4	6	3

The maintenance schedule generated by heuristic (Sriram and Haghani 2003)

Aircraft	Type Check A		Type Check B
	Day 1	Day 2	
1	1	5	5
2	4	7	3
3	3	6	1
4	3	7	1
5	2	6	1
6	1	4	6
7	1	4	1
8	2	6	6

Algorithm

Step 1: Let $n = 1$.
Step 2: Pick the nth aircraft from the list of aircraft.
Step 3: Let $K = 1$.
Step 4: Pick the Kth node from the list of nodes.
Step 5: If there are no more nodes available for the allocation in the Kth node, let $K = K + 1$ and go to step 4, otherwise go to step 6.
Step 6: Do depth first search to find the best possible cyclic schedule for the nth aircraft. If a feasible cyclic schedule exists go to step 7, otherwise let $K = K + 1$, go to step 5.
Step 7: Add the route to the schedule. Delete the arcs from the network that are assigned to the nth aircraft.
Step 8: If n = number of aircraft, (a) reconstruct the network (in step 7 arcs are removed from the network, for new iteration, these arcs need to be placed back in the network), (b) perturb the aircraft list randomly (construct a list by choosing each aircraft in random from the list of aircraft), (c) perturb the node list randomly (construct a list by choosing each node in random from the list of nodes that belongs to any given day). If a feasible solution was found in the previous iterations, compare the current solution with the existing one and if the current one has a lower objective function value save the current solution and delete the previous solution. Otherwise let $n = n + 1$ and go to step 2.
Step 9: If the number of iterations is less than the maximum number of iterations, increment the number of iterations and go to step 2, otherwise stop.