Operational Resilience of the Airport Network

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Airport network

Abstract form of air transport system

It consists of airports and flights scheduled between them.
Resilience

• Collins dictionary
  – The property of an object return to its original shape after it has been stretched, pressed or bent
• System
  – Static: the ability of a system to maintain operational when it comes to disruptive event.
  – Dynamic: the speed of system to recover to the desired state after disturbance.
Severe weather (heavy rain, snow storm, dense fog, tornados etc.), nature disasters, equipment failures, and human errors
Recent research

- What will system behave when the disruptive event occur?

Existing research

- **Robustness**
  - Regard attacked airports as failure nodes
  - Remove nodes and edges

- **Complex network perspective**
  - Topology structure characteristics
  - Measure connectivity
  - Degree
  - Betweenness

Essential question

- **Resilience**
  - Airports barely shut down
  - Operation with capacity decreased

- **Operational characteristics**
  - Flow
  - Delay
  - Supply and demand
Objectives

- Investigating operational resilience of air transport system from network perspective.
  - Focus on operational characteristics
  - Simulate airports failure as the capacity decreased
  - Resilience indicators
  - Identify critical airports effect operation
Simulation

- Data:
  - One day historical flight data recorded on 28th February 2011, with a total of 139 airports and 5374 flights involved.
  - Flight scheduled information → calculate actual departure/arrival time

Algorithm

1. Antecedent flight arrived?
2. Ground turnaround procedure finished?
3. Add into departure queue.

Actual departure time

1. Flight time:
   - Based on historical data
     - OD pair
     - Type of aircraft

Estimate arrival time

1. Add into arrival queue

Actual arrival time
Scenarios

• Attack strategies:
  ① random attack  
  - select a certain number of airports at the same time  
  ② selective attack  
  - select one airport for attack each time

• Attack time periods:
  ① 08:00 — 10:00（The peak hours of departure traffic）
  ② 14:00 — 16:00（The peak hours of total traffic）

• Attack form: disruptive event → decrease the runway capacity  
  attacked interval constraint（runway separation）
Scenarios

- Attack strategies:
  ① random attack
    - select a certain number of airports at the same time
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Scenarios

- **Attack time periods:**
  1. 08:00 — 10:00 (The peak hours of departure traffic)
  2. 14:00 — 16:00 (The peak hours of total traffic)
Scenarios

- Attack form: disruptive event $\rightarrow$ decrease the runway capacity
  Change the runway separation (during attack time period)
Indicators

- How to evaluate performance of system and measure resilience?
  - Punctuality

- Queuing diagram delay

\[ \text{Punctuality} = \frac{\text{Number of flights (delay less than 15min)}}{\text{Total number of flights}} \]

Delay: unbalance of demand and supply

- Scheduled cumulative departure curve
- Actual cumulative departure curve

Queuing diagram delay:
(qquantify the damage caused by attack)
Random attack

- Random simulation based on Monte Carlo method: 100 times simulation → average value

- Attack Scenarios:
  - Attack strategy: random attack
  - Time period: 08:00—10:00
  - Indicator: Punctuality

(Number of attacked airports = 60)
(Number of attacked airports = 60)
Random attack

- How the punctuality behave if we change the attack time period?

- Attack Scenarios:
  - Attack strategy: random attack
  - Time period: 14:00—16:00
  - Indicator: Punctuality

- Short recovery phase

(Number of attacked airports = 60)
Topography vs. Operation

The study of robustness is based on topology structure.
Most important indicators: degree, betweenness centrality (BC)

**Degree:**

The number of edges a node share with others.

**Interactivity opportunity**

**Betweenness centrality:**

$$BC = \frac{\text{shortest paths passing through the node}}{\text{total number of shortest paths}}$$

Transitivity, contribution to the efficiency

**Operational Characteristics**
Selective attack

Select an airport for attack

Operational importance of the nodes.

Calculate the queuing diagram delay of whole network

Topography importance of the nodes.

Degree: 35 < 27 < 10 < 18

Queuing diagram delay
Selective attack

- Attack time periods: 08:00 — 10:00

“Jump nodes”: when we consider the operational characteristics, the importance of these airports are underestimated by degree.
Selective attack

- Attack time periods: 08:00 — 10:00

Degree, betweenness centrality: influential indicators for structure robustness
Considering the actual operation: not the best choice.
 Contributions
- Indexes to measure the network operational characteristics.
- Resilience process: ”deteriorate - recover - stabilize”
- Identify some critical nodes that structure indicators cannot find.

 Further studies
- More research efforts are needed to improve resilience evaluation system and discover the specific characteristics of those critical nodes.
Thank you for your attention