Airline Operations
Lecture #2

1.206J

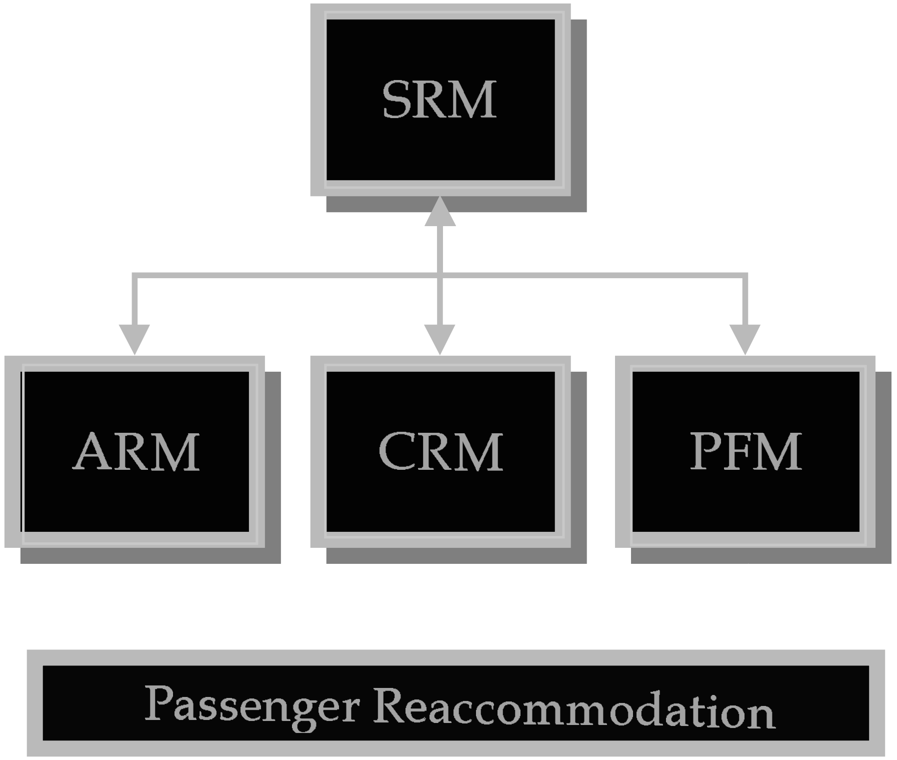
April 27, 2003

Summary Lecture #1

- **Airline schedules (Aircraft, crew, passengers) are optimized leading to:**
  - **Little slacks (idle time)**
  - **Schedule dependencies**
  - **Delay chain effects**
- **Causes of schedule disruptions**
  - **Shortages of airline resources**
  - **Shortages of airport resources**
- **Complex airline resource regulations**
  - **Aircraft maintenance**
  - **Pilots**

Airline Schedules Recovery

- Schedule Recovery Model (SRM)
- Aircraft Recovery Model (ARM)
- Crew Recovery Model (CRM)
- Passenger Flow Model (PFM)
- Journey Management
- Passenger Re-accommodation



Summary Lecture #1 (Cont.)

- **Airline schedules recovery problems**
  - ➢ **Aircraft maintenance module:**
    - **Objective: feasibility only**
  - ➢ **Crew schedule recovery module**
    - **Objective: to minimize disruptions, recover the disrupted with minimum flight schedule disruptions and control Flight Time Count**
    - **Complex rules**
  - ➢ **Passenger schedule recovery module**
    - **Objective: to minimize passenger delays, ill will, gap between expected and delivered service**
    - **Complexity:**
      - – **Priority rules (booked over disrupted, priority among disrupted: network, user, FFP, fare class)**
      - – **Seat availability uncertainty**

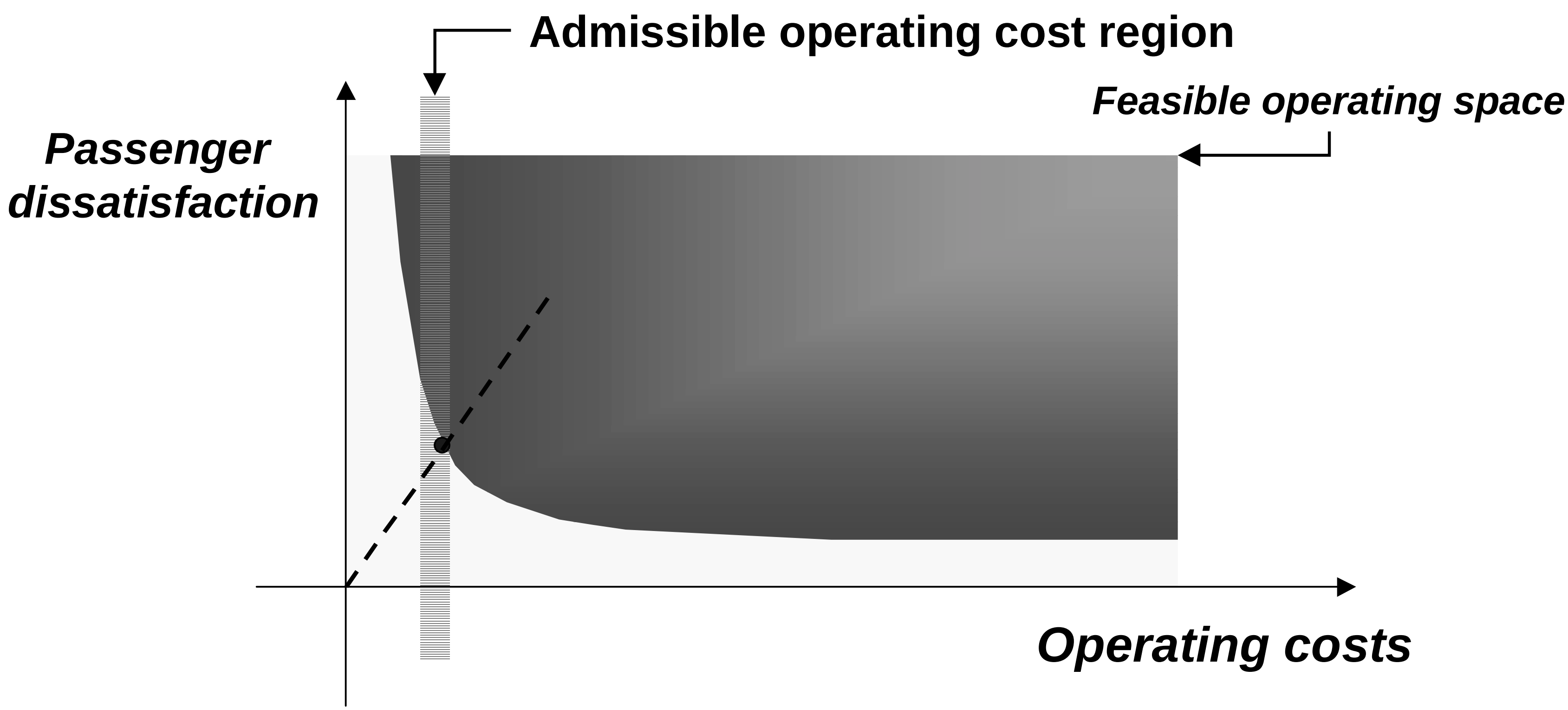
Lecture #2 Outline

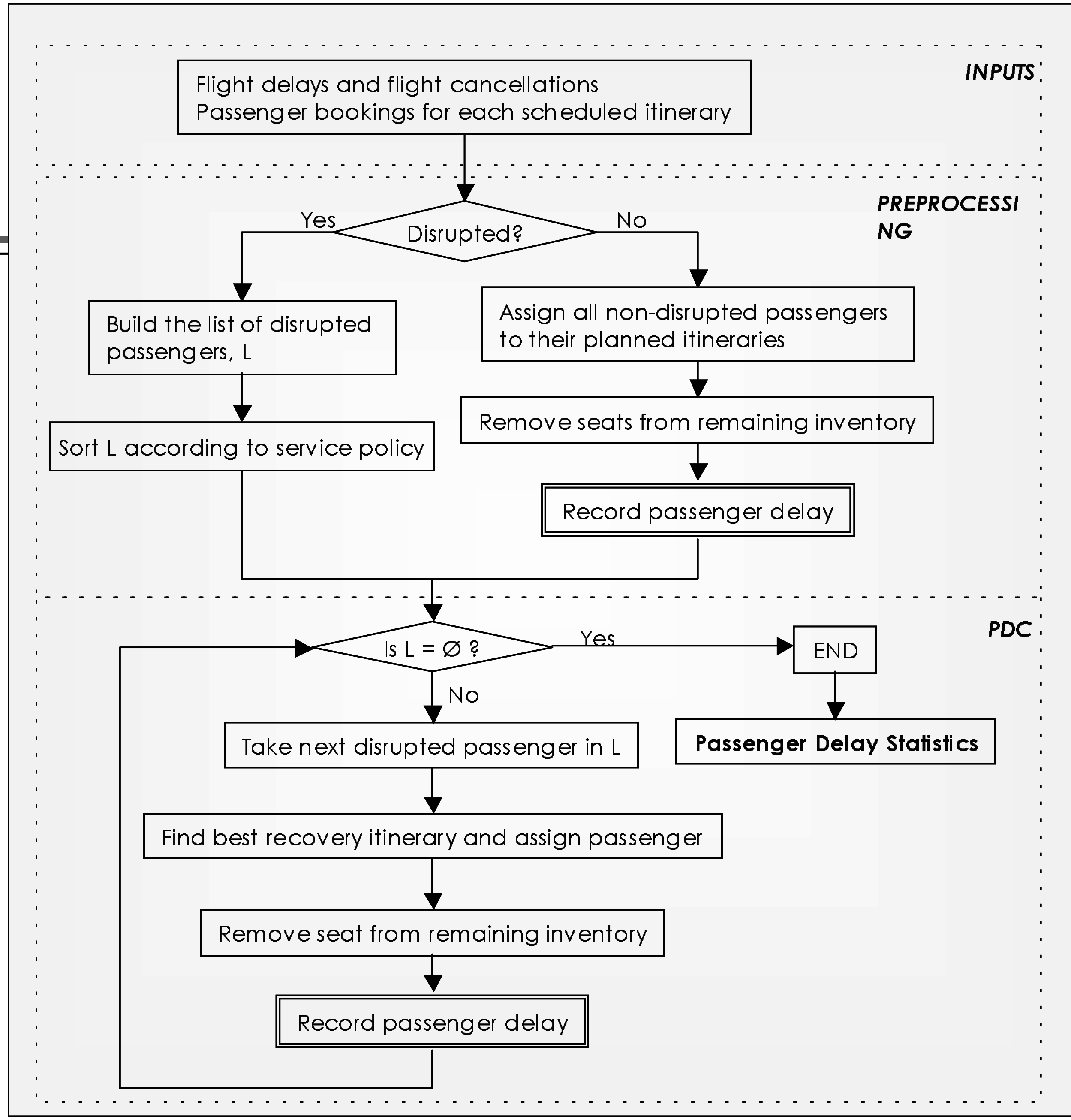
- Passengers are important to satisfy
- Tricks to prevent schedule disruptions and recover schedules
- Traditional ARM; Model shortcomings
- Interdependency of passengers and aircraft operations
- Our approach: Minimizing sum of disrupted passenger
- Flight copy generation and solution feasibility
- Minimizing sum of passenger delays
- Proxy of minimizing sum of passenger delays
- Simulation environment
- Conclusion

Importance of delivering services as expected in airline industry

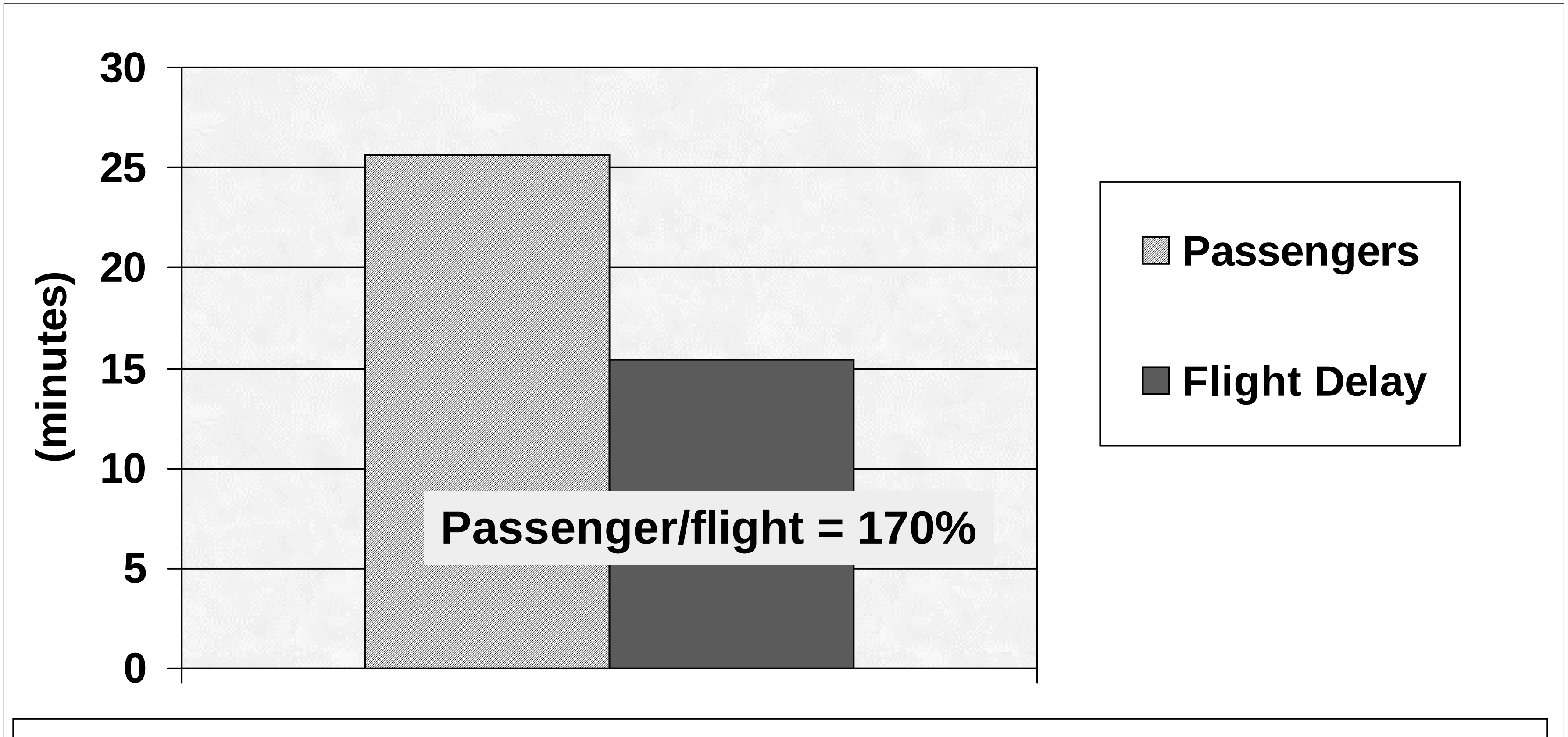
- Very competitive industry
- Low profit margin (5% in 2000, best year)
- Dissatisfied customers might shop next to competitors, jeopardizing your profitability
- On time service is not prime factor to attract customers but it contributes to loyalty
- Passenger delay distribution is not continuous, few passengers suffer high delays
- Passenger dissatisfaction function with respect to delays is not linear
- Clear objective: minimize passenger ill will with same operations costs

Trade off: Passenger service reliability versus operating costs




INPUTS
Flight delays and flight cancellations
Passenger bookings for each scheduled itinerary
PREPROCESSING
Disrupted?
Yes
No
Build the list of disrupted passengers, L
Assign all non-disrupted passengers to their planned itineraries
Sort L according to service policy
Remove seats from remaining inventory
Record passenger delay
PDC
Is L = Ø ?
Yes
END
No
Take next disrupted passenger in L
Passenger Delay Statistics
Find best recovery itinerary and assign passenger
Remove seat from remaining inventory
Record passenger delay

Flight and passenger delays



Flight delays underestimate passenger delays
Key explanation lies in the disrupted passengers

Disrupted passengers versus non disrupted passengers

August 2000	Av. Delay (minutes)	% Passengers	% Delays
Disrupted passengers	320 minutes	3.2%	40%
Non disrupted passengers	16 minutes	96.8%	60%

- **Disrupted passengers experience long delays in general because 20% of them are stranded overnight (delay propagation results in more disruptions later during the day)**
- **Although a small percentage, disrupted passengers account for 40% of the total passenger delay and most of the severely delayed passengers (80% of passengers delayed by more than 4 hours)**

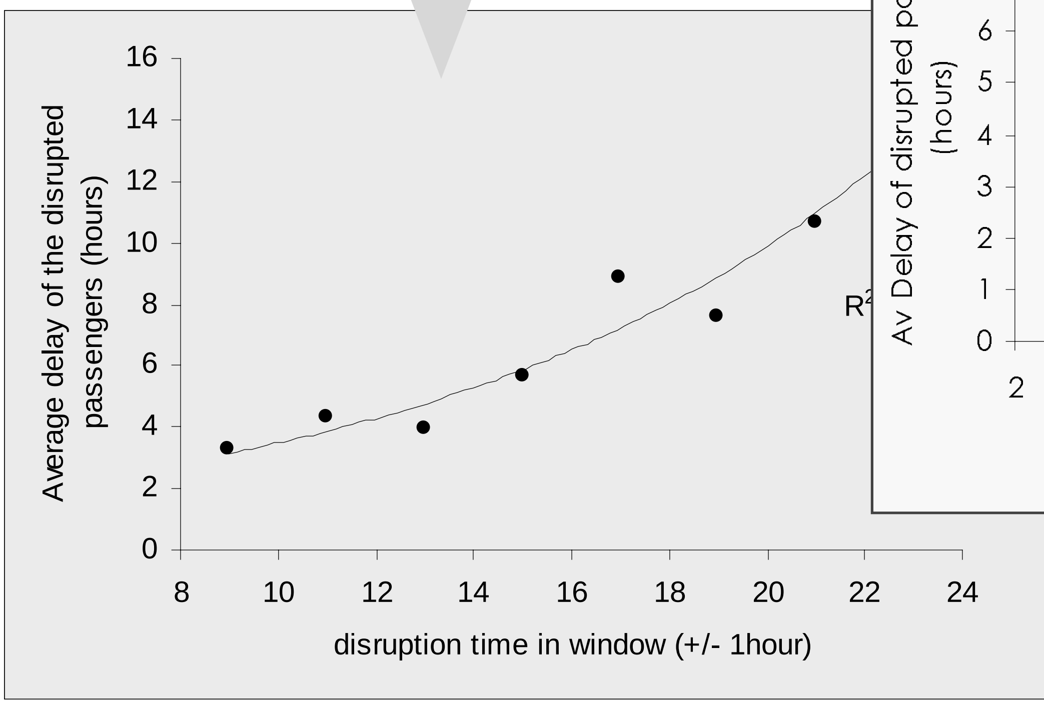
Risk of being disrupted

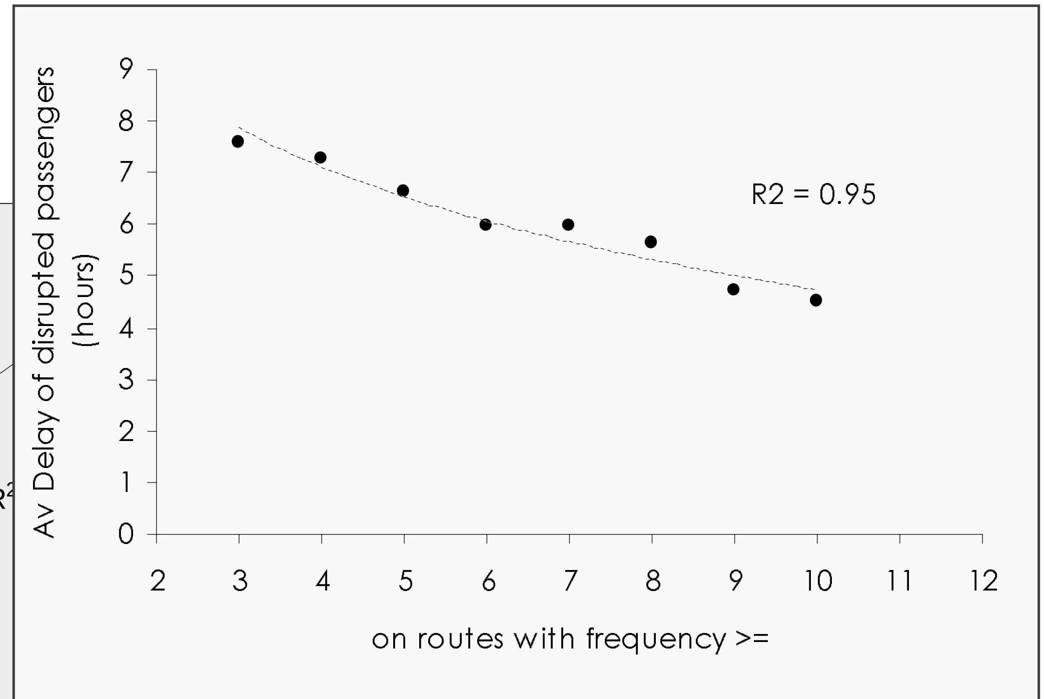
Passenger type	Connecting	Local
Scheduled passenger mix	35%	65%
Disrupted passenger mix	60%	40%
Caused by flight cancellations	52%	100%
Caused by missed connections	48%	

- **Although fewer planned connecting passengers, higher number are disrupted**
- **The risk of a passenger to be disrupted is 2.75 times greater for connecting (5.5%) than for local (2%)**
- **Does not bode well for hub-and-spoke with banks**

Passenger disruption: important factors

- **Disruption time & Route frequency**

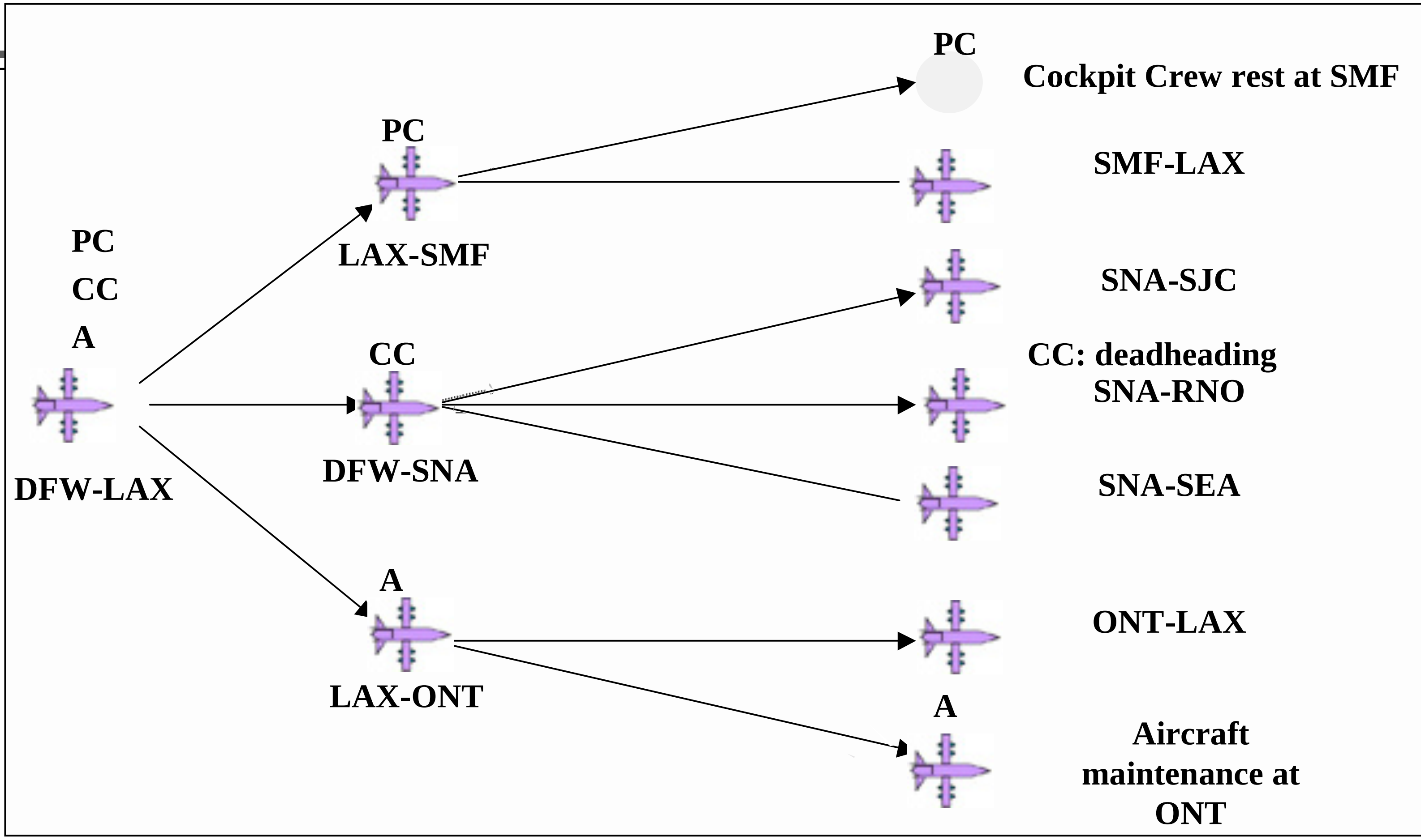




Passenger service reliability study: Conclusions

- **Disrupted passengers are important: 80% of the passengers delayed by more than 4 hours are disrupted**
- **Minimizing the sum of disrupted passengers while recovering the schedule might be a good idea…**

Resource Dependability: Ripple effects



PC: Pilot Crew; CC: Cabin Crew; A: Aircraft

Source: Sabre, 1998

Disruption Impacts; Solutions and Constraints

Disruption Impacts

- Flight delays
- Broken crew pairings
- Resource shortage
- Crew unavailability
- Disrupted maintenance
- Gate problems
- Baggage handling problems
- others

Solutions

- Hold flights
- Cancel flights
- Aggregate flights
- Divert aircraft
- Swap resources
- Use spare aircraft
- Use reserve crews
- Deadhead crews
- Layover crews

Constraints

- Aircraft balance
- Market protection
- Fleet/crew compatibility
- Resource positioning
- Maintenance requirements
- Crew legalities
- Union contracts
- Others

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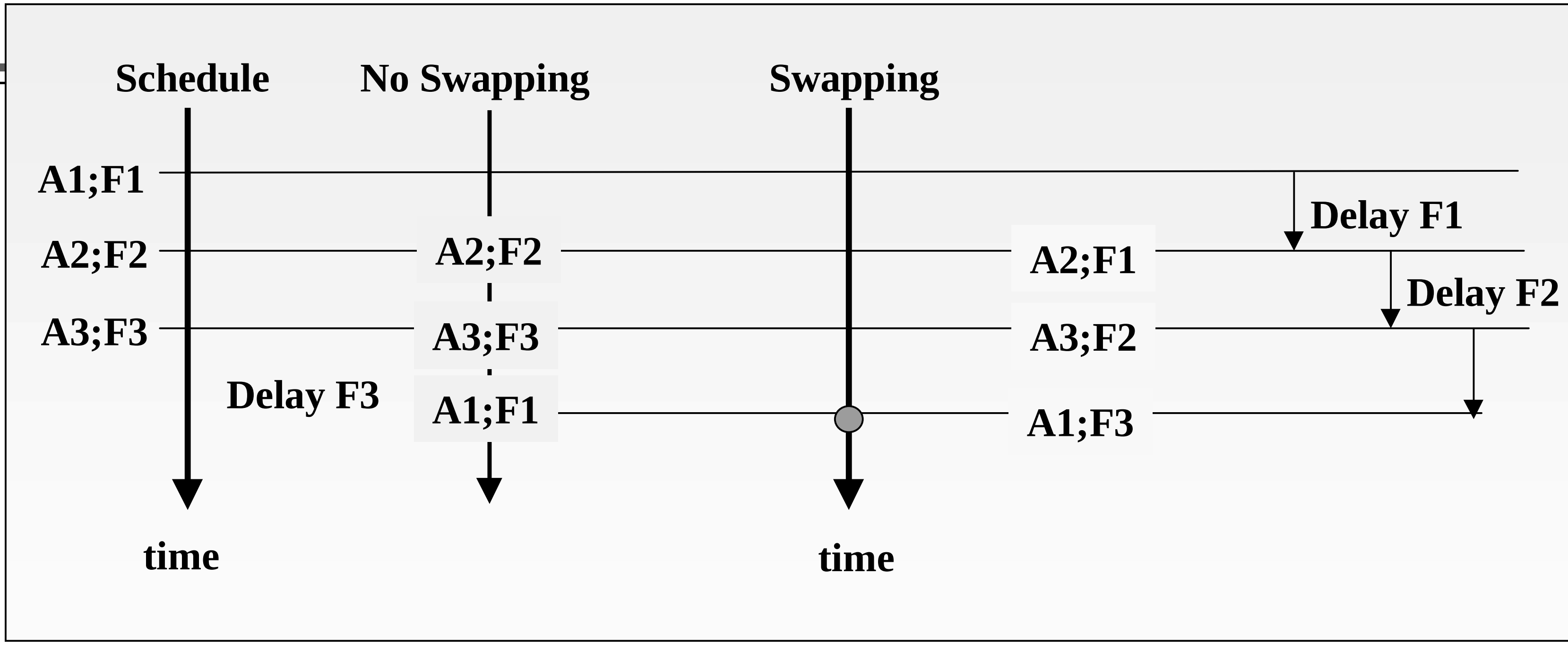
Aircraft route swaps

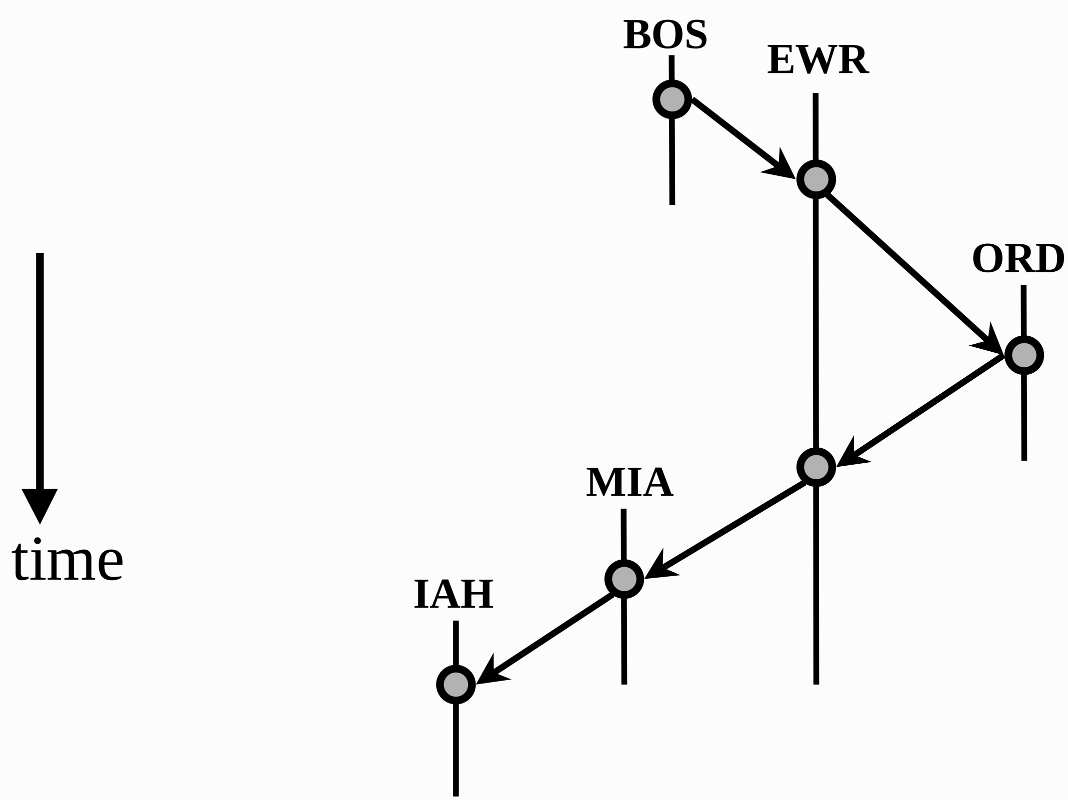


Swapping useful to:

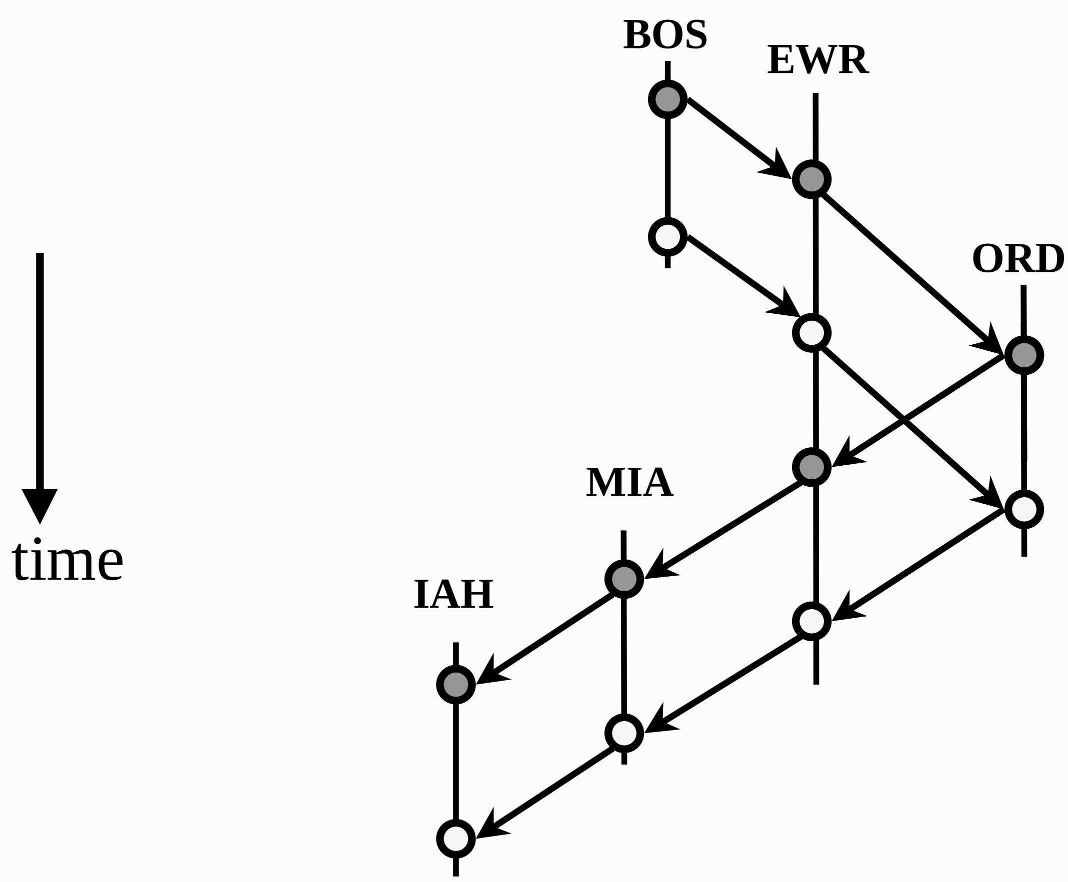
+ Spread the delays informally, converge toward bank integrity
+ Postpone the shortage problem
+ Recover from irregularities

Constraints: Crew compatibility and legalities

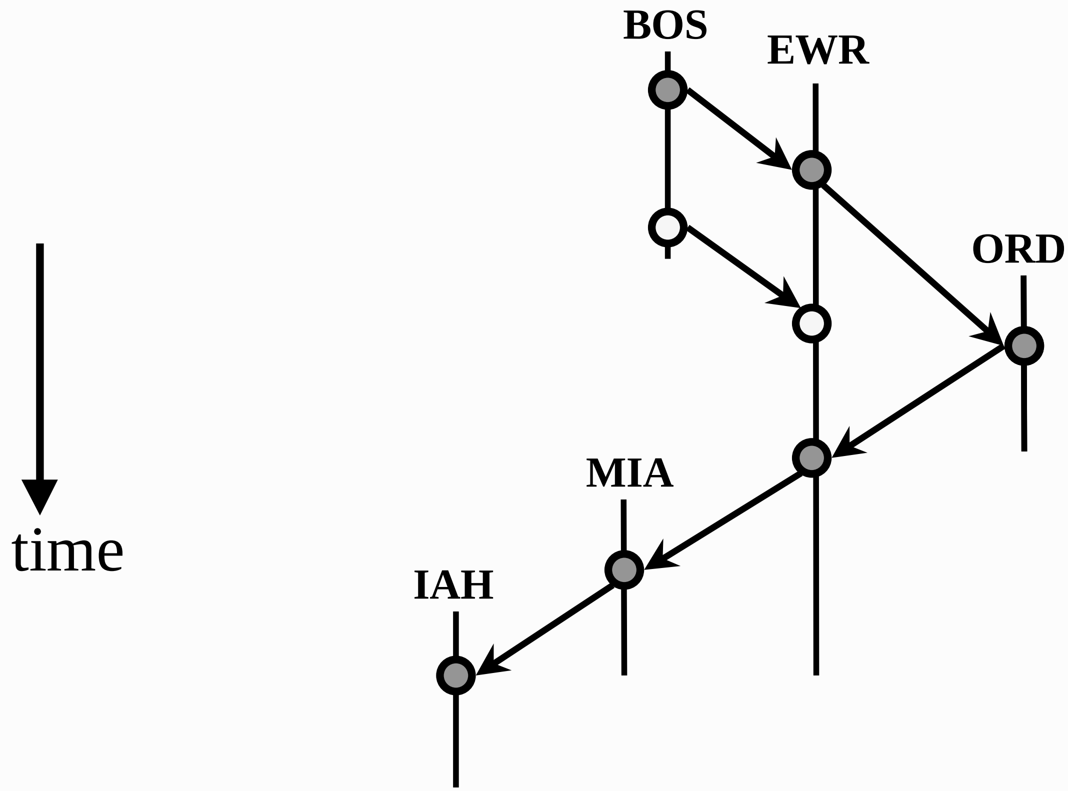
SCHEDULE



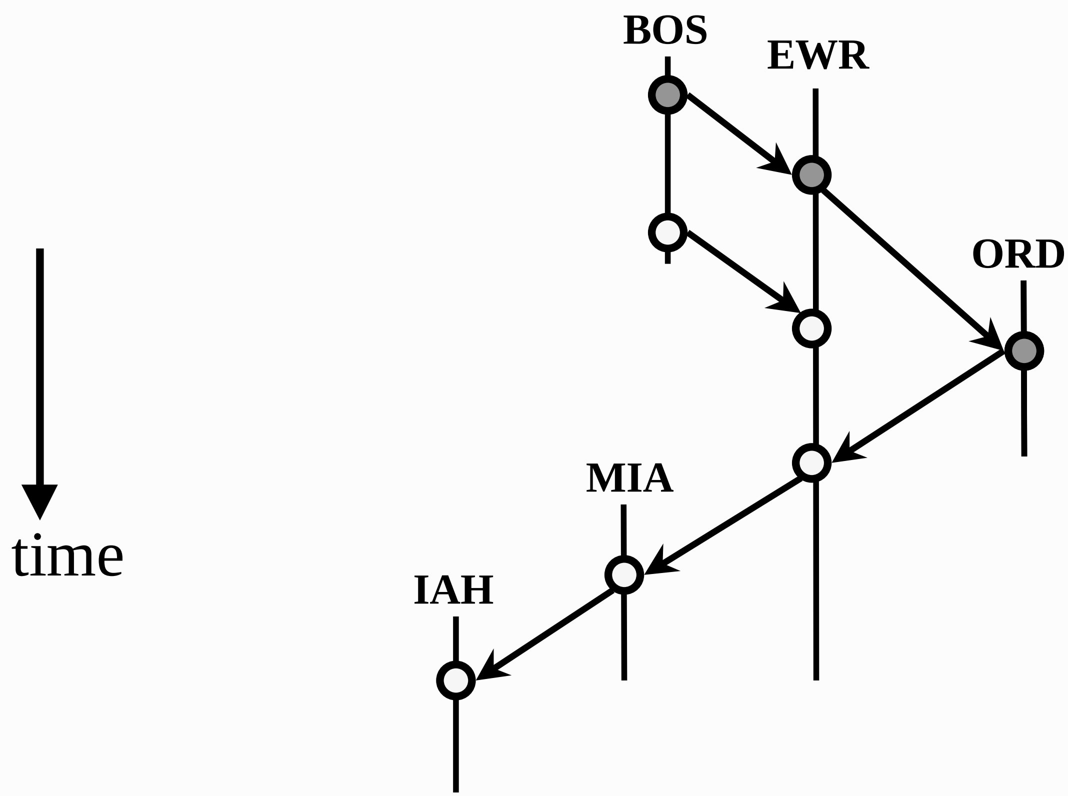
HYPOTHETICAL CASE: Flights not canceled (NC)



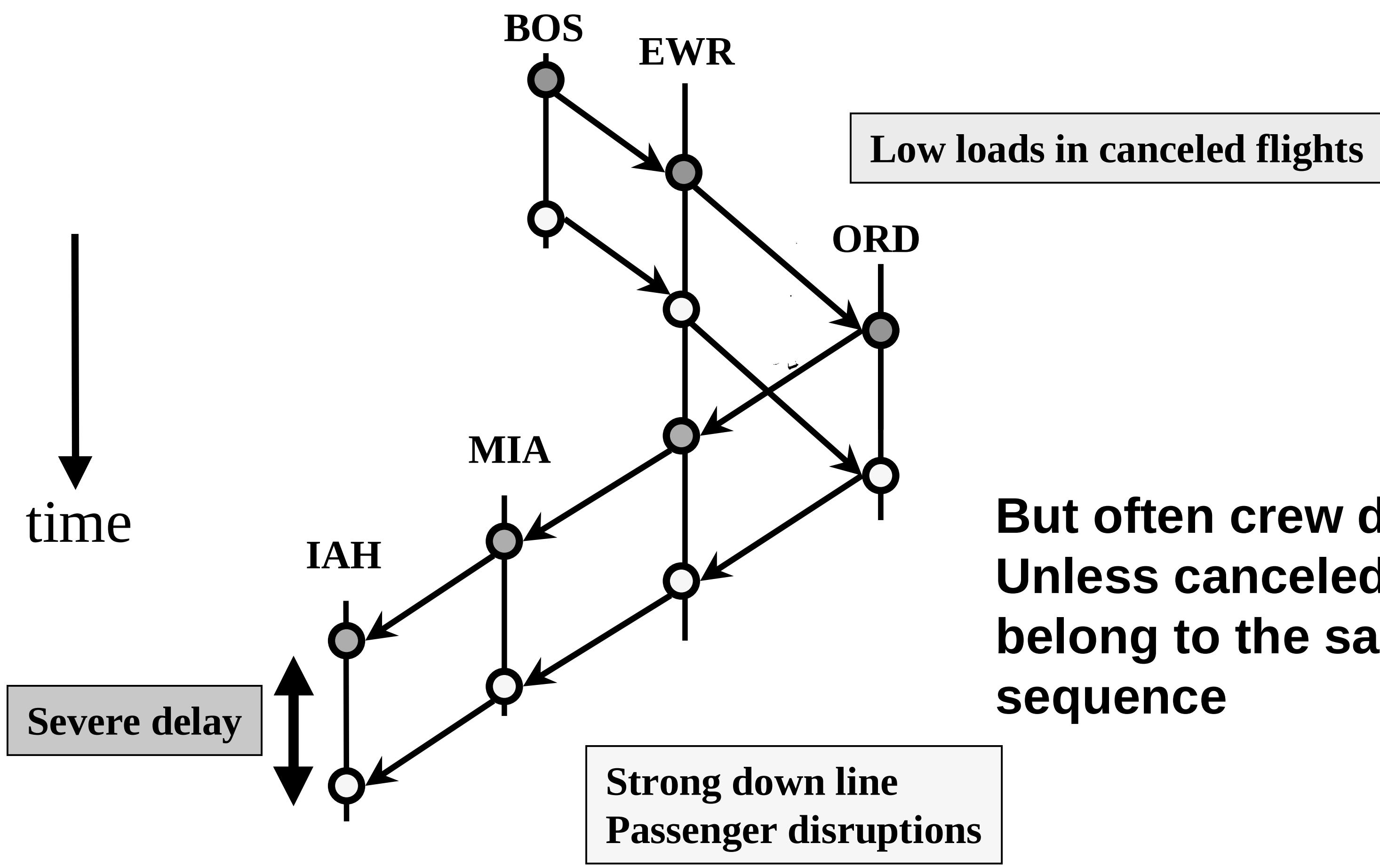
ACTUAL OPERATIONS



ACTUAL OPERATIONS: Flights canceled (C)



Flight cancellation benefits passengers when…



But often crew disruptions…
Unless canceled flights belong to the same crew duty sequence

Airline Schedule Recovery Problem: Assumptions

- **At a given time of the day, we assume that airline controllers know the state of the system:**
  - **Locations and availability of resources**
    - **Aircraft**
    - **Pilot and flight attendant crews**
  - **Passenger states (i,e., disrupted or not) and locations/destinations**

Airline Recovery Model, ARM (G. Yu et al.)

$$\min\left(\sum_{f\in F}\sum_{t\in T_f} d_f^t \times x_f^t + \sum_{f\in F} c_f \times z_f\right)$$

Ops cost + Cancellation cost

st :

$$\sum_{t\in T_f} x_f^t + z_f = 1 \qquad \textbf{Flight coverage}$$

$$\sum_{f\in F_{dj}^t} x_f^t + y_f^{t-} = \sum_{f\in F_{oj}^t} x_f^t + y_f^{t+} \qquad \textbf{Aircraft balance}$$

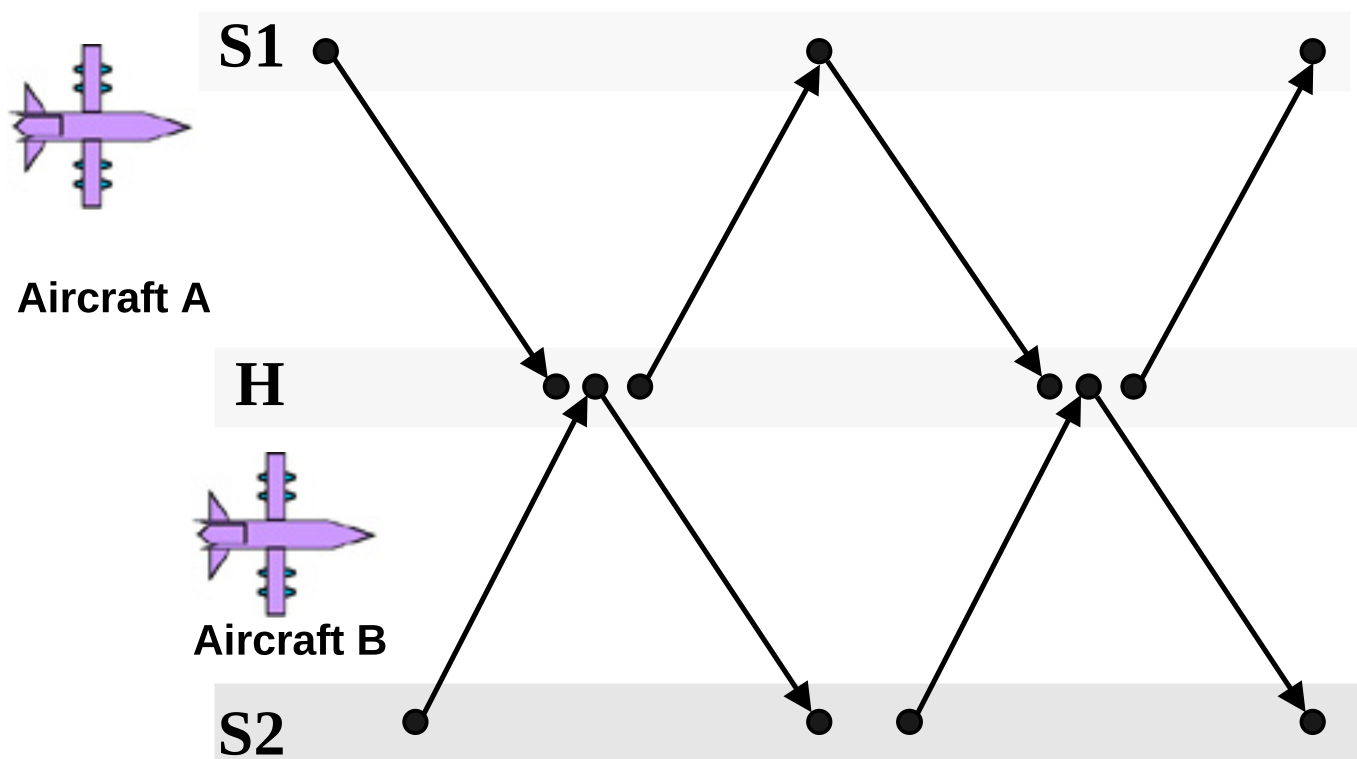
$$\sum_{f\in F_{oj}^0} x_f^0 + y_f^{0+} = j_0 \qquad \textbf{Initial resource at airports}$$

$$\sum_{f\in F_{\bar{dj}}^{-}} x_{\bar{f}}^{-} + y_{\bar{f}}^{-\,-} = j_{-} \qquad \textbf{End of the day resource at airports}$$

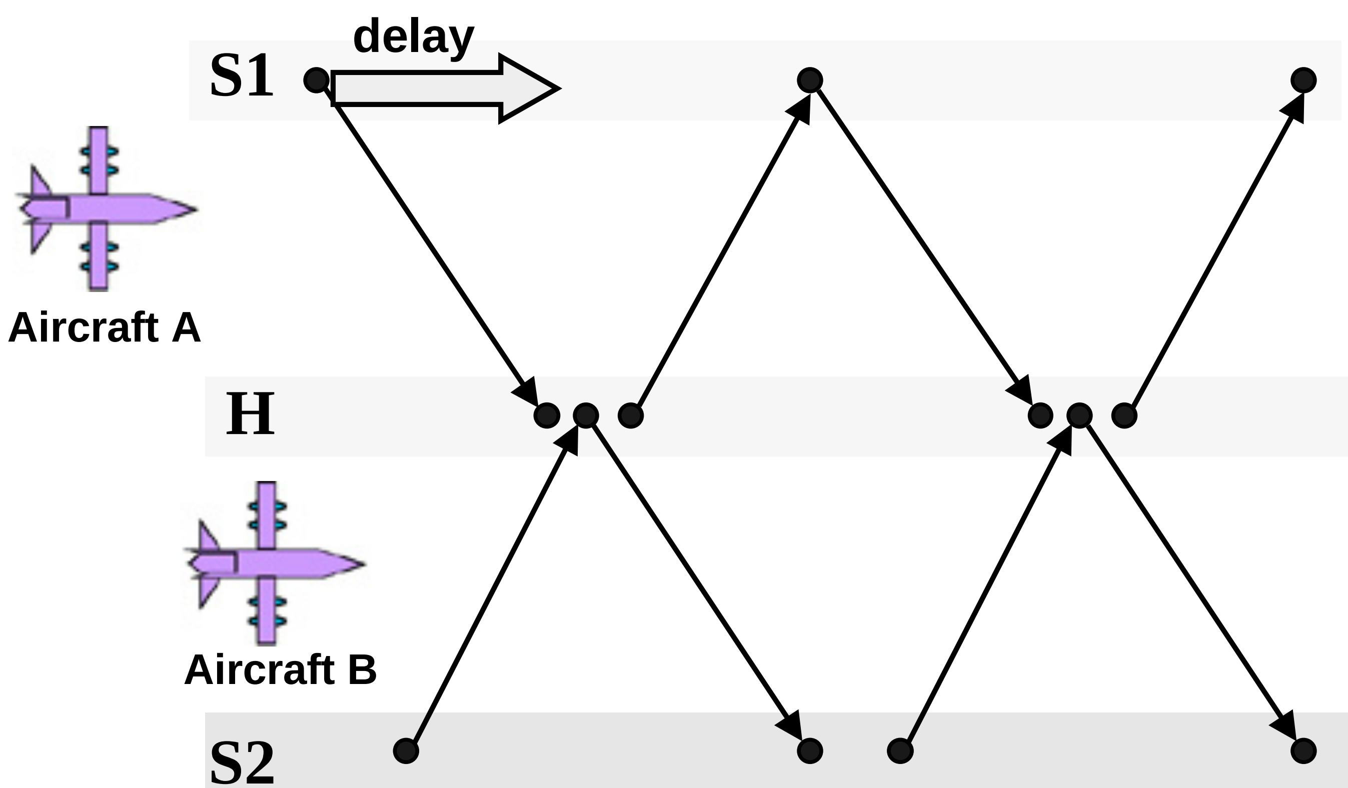
$$x_f^t \in \{0,1\};\ y_f^t \geq 0$$

- **Objective is to minimize operating cost (flight delay and cancellation costs)**

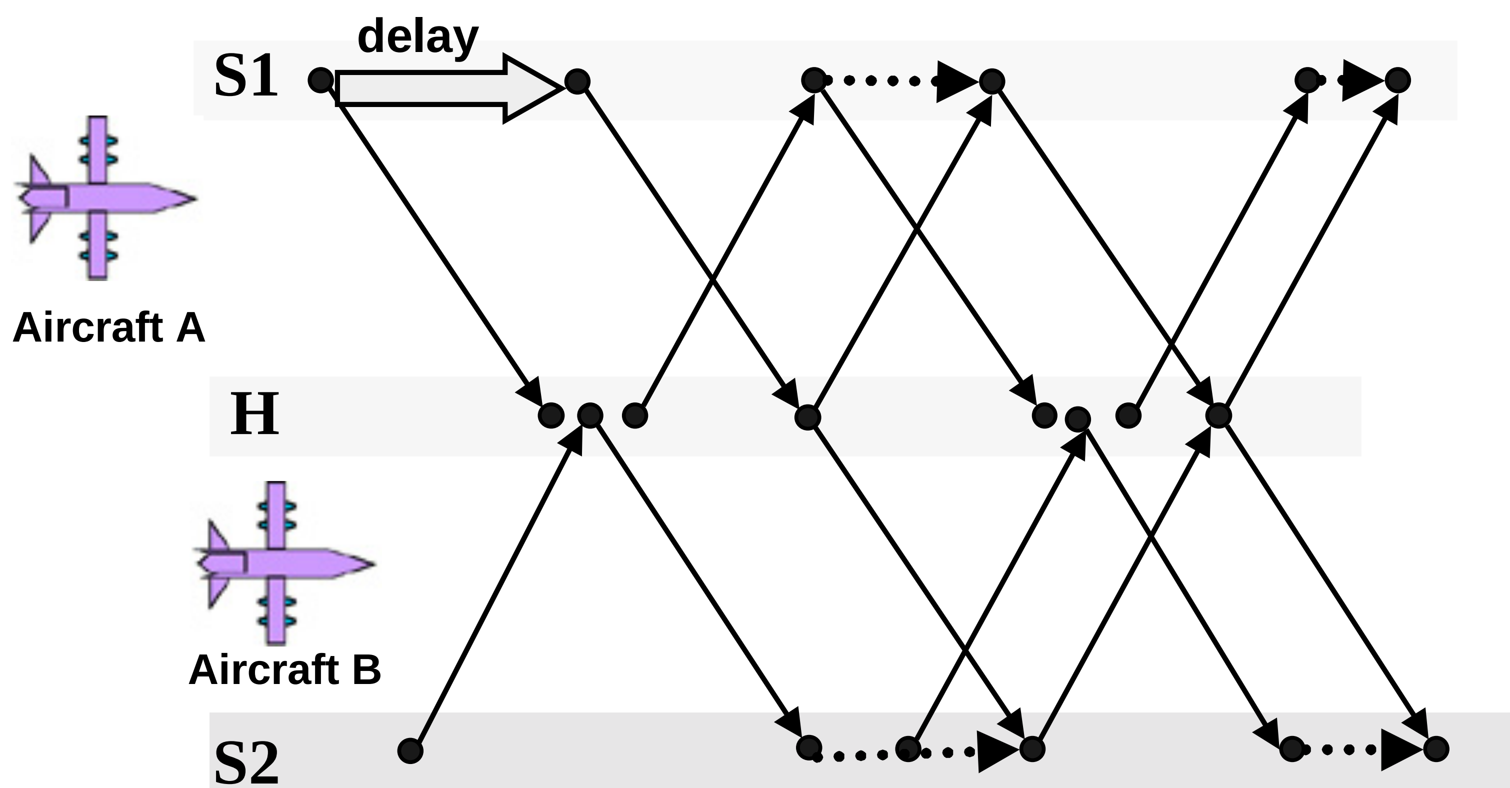
Aircraft route schedule



Aircraft actual operations: unexpected delay (e.g., aircraft technical problem)



Passenger actual itineraries Operations decision #3: don't cancel & postpone aircraft B



Flight copy generations

- **We have developed a technique to minimize the number of flight copies**

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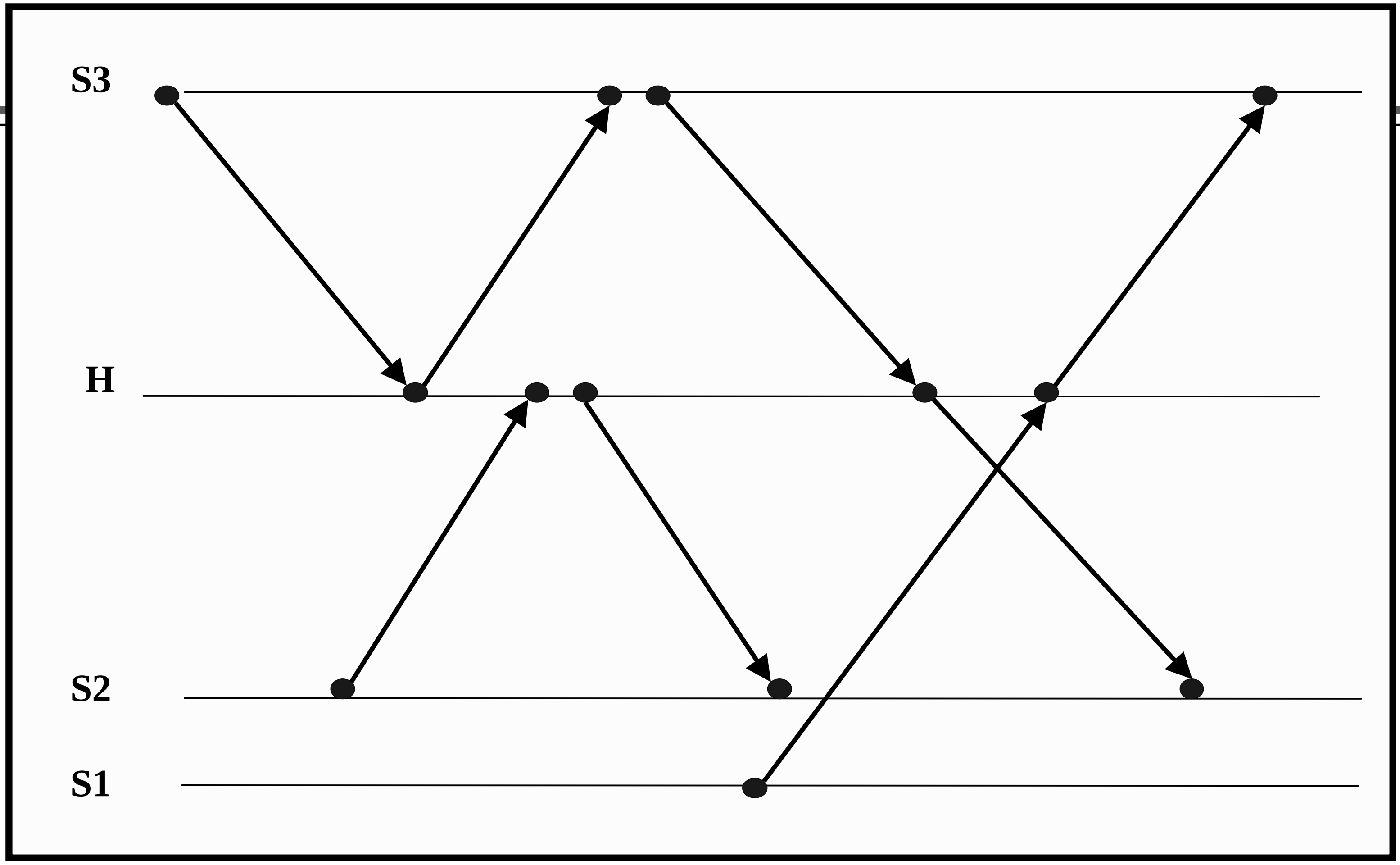
- Four types of flight copies are generated:
  - Aircraft ready times


S3
H
S2
S1

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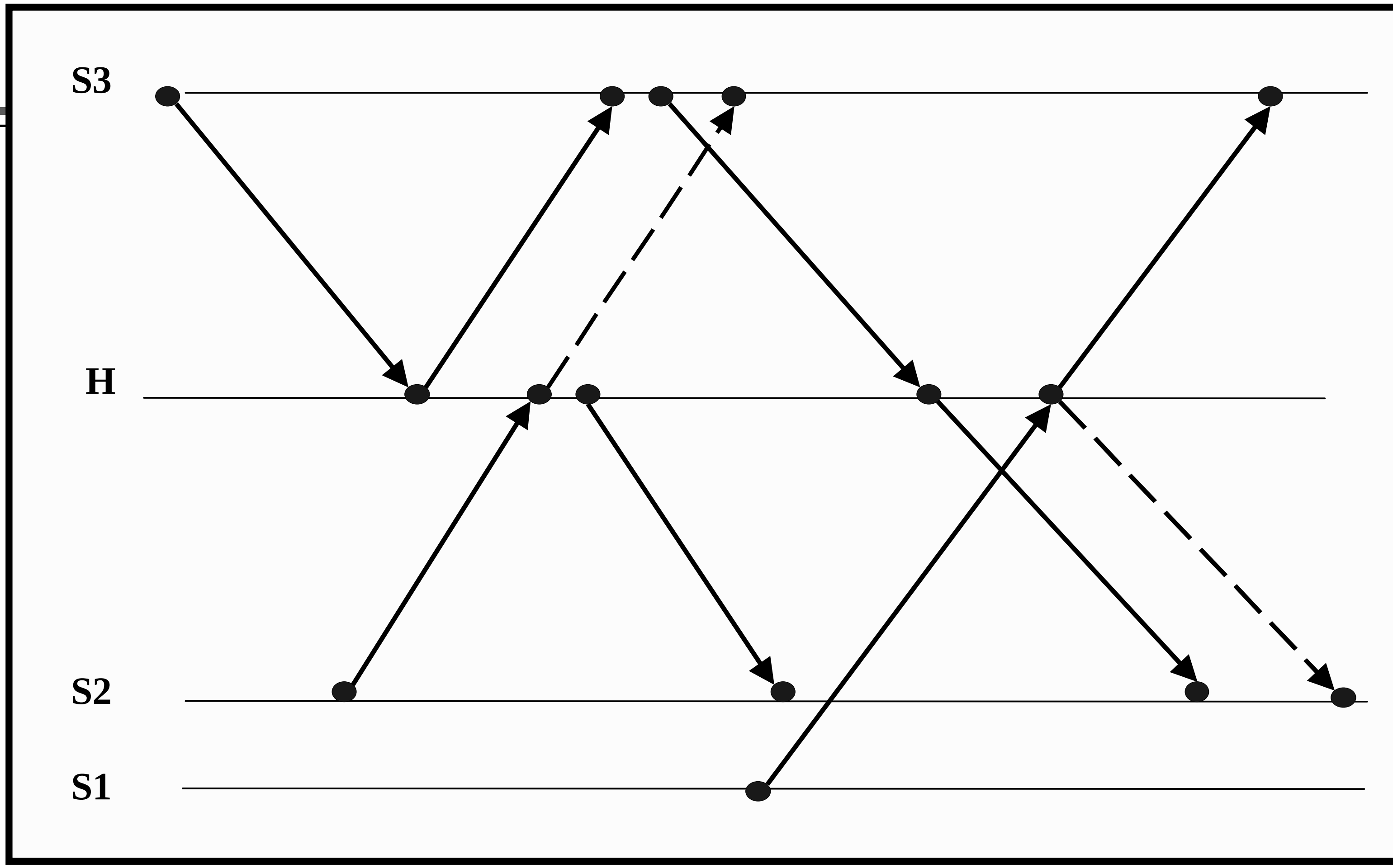
S3
H
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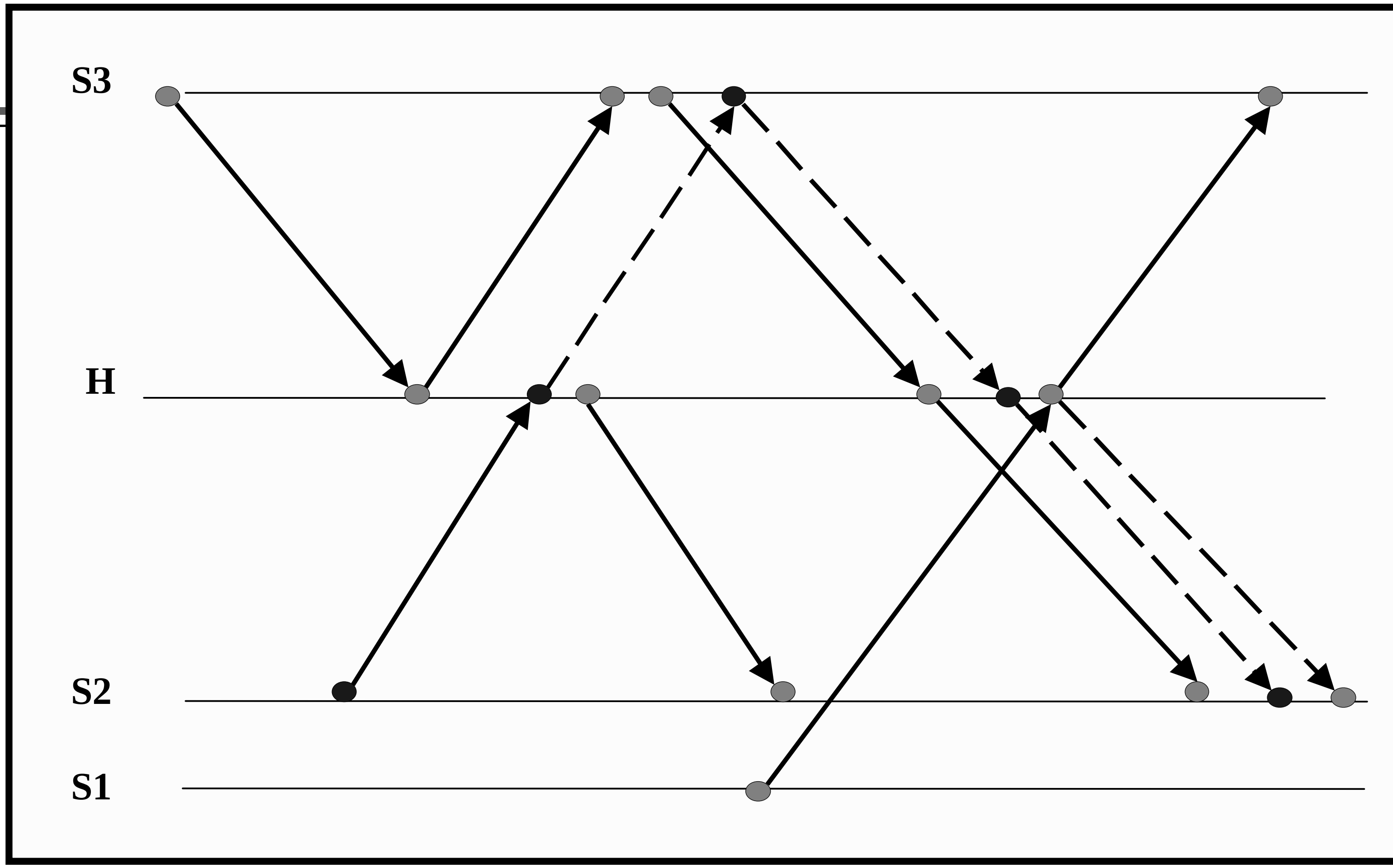
  - Consequence of type 2, aircraft postponement propagation



S3
H
S2
S1

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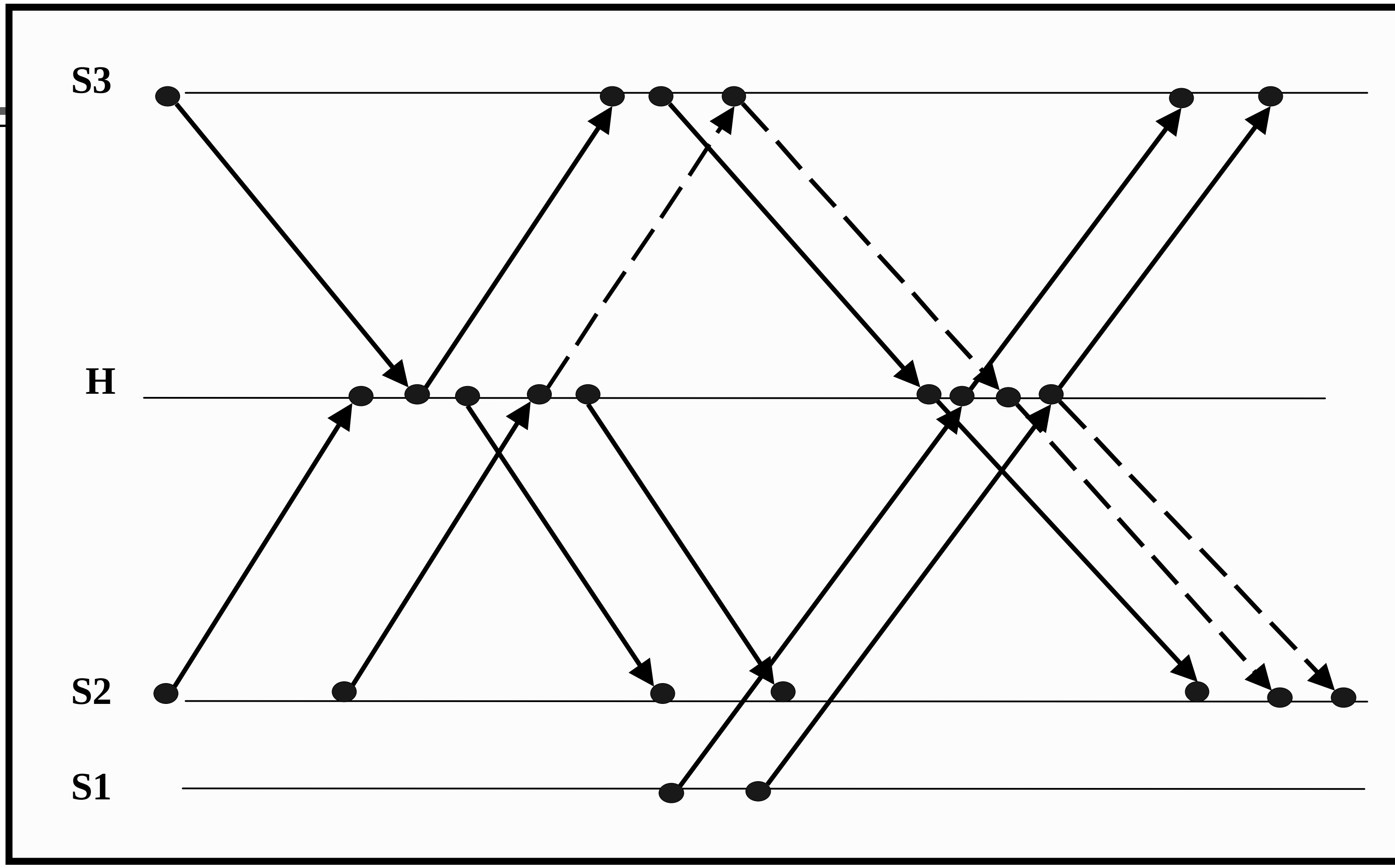
  - Schedule (for cancellations)


S3
H
S2
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Flight copy generations

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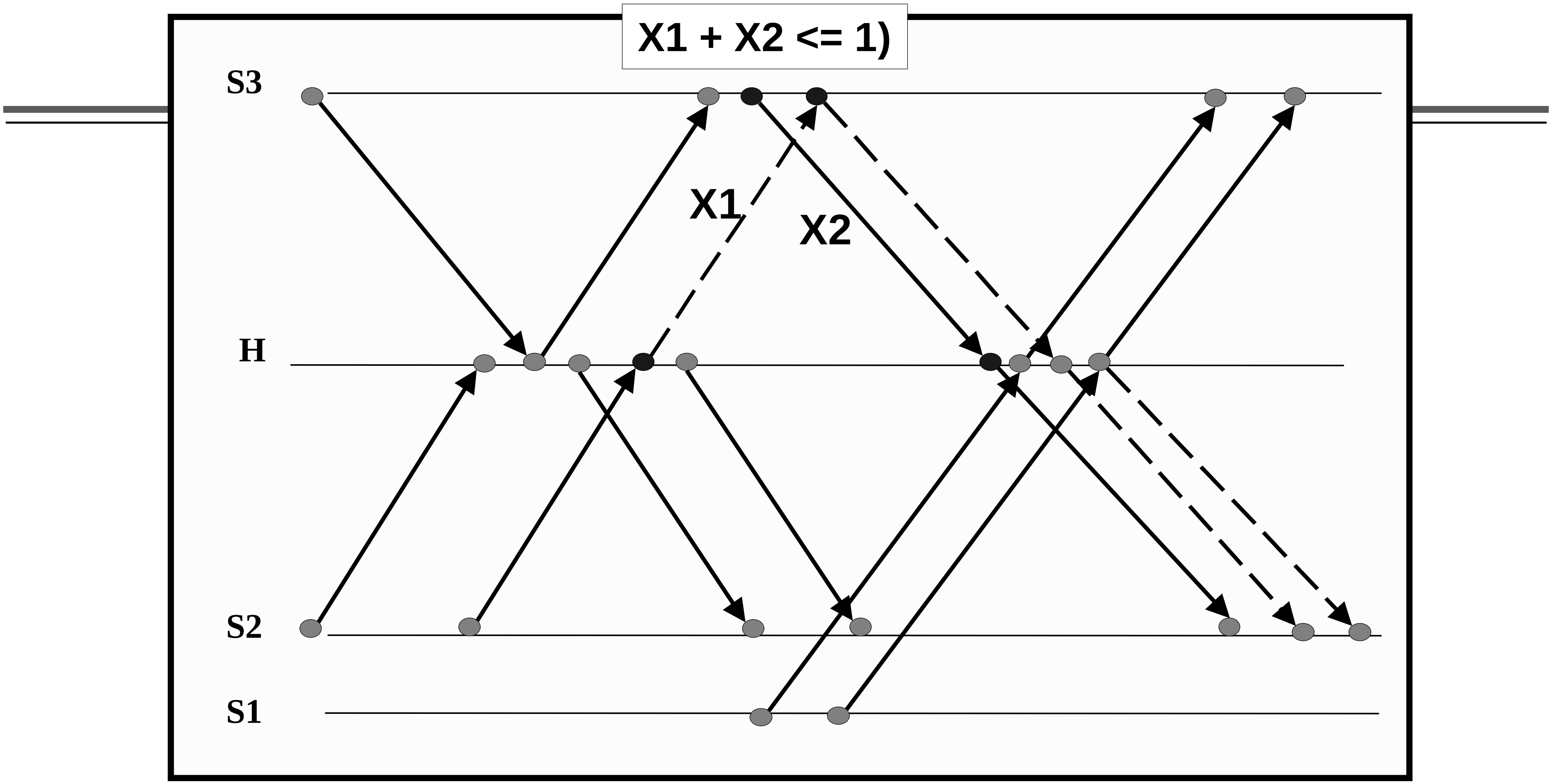
- Four types of flight copies are generated:
  - Aircraft ready times
  - Copies to prevent passengers from missing connections
  - Consequence of type 2, aircraft postponement propagation
  - Schedule (for cancellations)
- Claim: We generate the minimum set of copies to capture one optimal solution
- Had we generated copies every minute (as proposed in literature), we would typically have to generate between 5 and 10 times as many flight copies (10,000 to 20,000 per day of operations), which would greatly increase running time and may jeopardize solution feasibility because of running time

Maintaining crew feasibility

- Respect planned duty period (constraints)
  - Given a sequence of flights assigned to a crew (duty), add feasibility constraints
  - Not always needed because either the flight terminates the crew duty assignment or some reserve crews can be used (typically at hubs); up to the user to define these constraints (shadow prices indicates the benefit for the passengers of relaxing the constraint)


X1 + X2 <= 1)
S3
H
S2
S1
X1
X2

Maintaining crew feasibility

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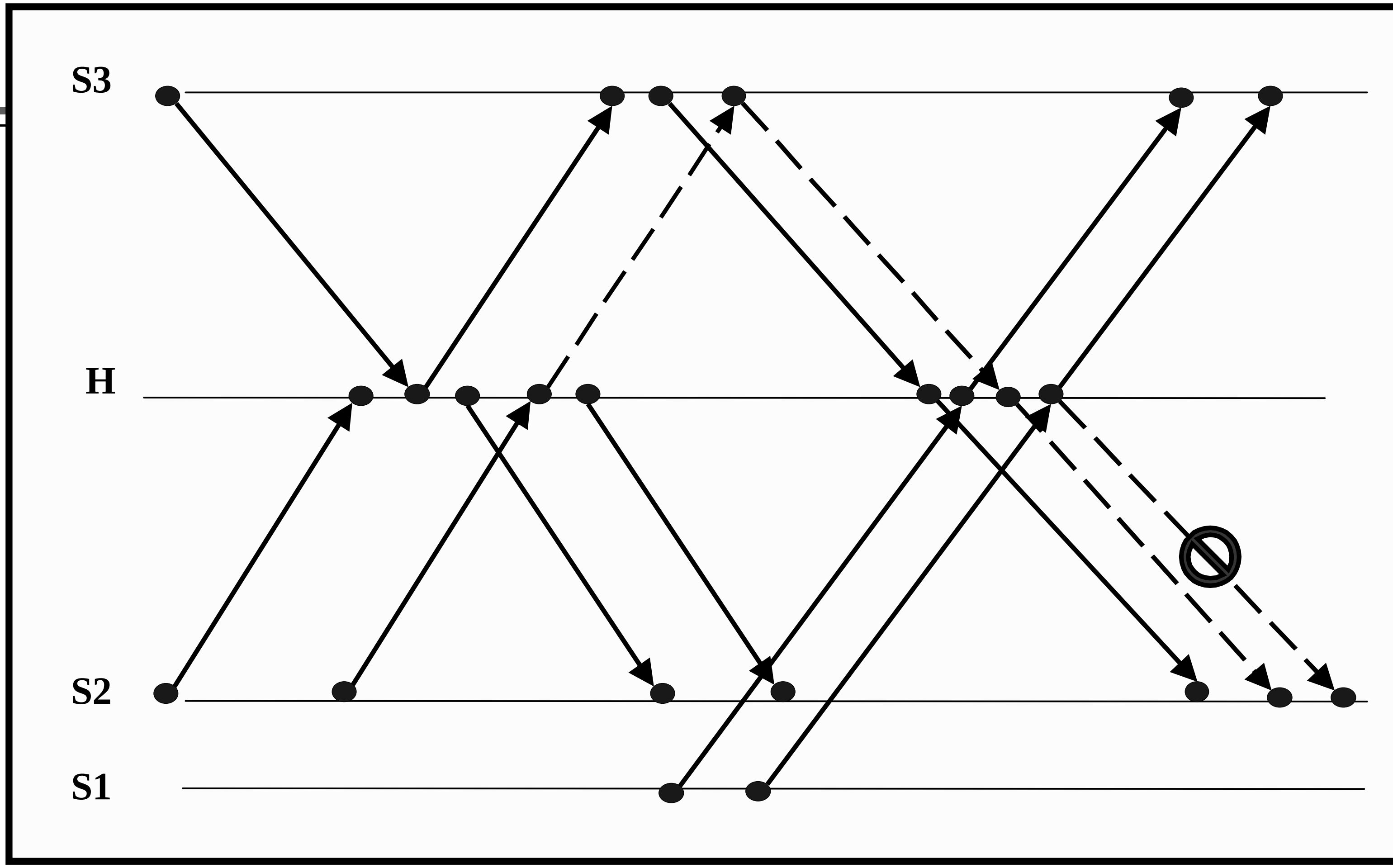
- **Satisfy regulatory constraints (Flight copies)**
  - **Maximum total flying time (not affected)**
  - **Maximum total elapsed time (MTET); iterative algorithm: if by adding a flight copy, the associated crew's elapsed time exceeds MTET, don't generate copy, otherwise do**


S3
H
S2
S1

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  - **Maximum total elapsed time (MTET); iterative algorithm: if by adding a flight copy, the associated crew's elapsed time exceeds MTET, don't generate copy, otherwise do**
- **Model solutions do not result in any additional crew disruptions due to postponement decisions; keep control on overhead operating costs**
- **Several models to minimize the crew disruption impact and minimize the cost of crew disruptions, but these models assume the flight operations are given. They can be used as complement to our models (Desrosier et al. (optimal); Yu et al. (heuristic))**

Minimizing Sum of Disrupted Passengers

$$\text{Minimize}\left(\sum_{p\in P} n_p \times \rho_p\right)$$

$$\text{st}: \quad \sum_{t\in T_f} x_f^t + z_f = 1$$

$$\sum_{(f,t)\in In(j)} x_f^t + y_f^{t-} = \sum_{(f,t)\in Out(j)} x_f^t + y_f^{t+}$$

$$\sum x_f^\bullet + y_f^\bullet = Res(a, ft, \bullet)$$

$$\rho_p \geq z_f$$

$$x_f^t + \sum_{g\in C(u) | d(g)<a(f)} x_g^u - \rho_p \leq 1$$

$$\rho_p \in [0;1]; \; x_{f,a}^t \in \{0,1\}; \; y_f^t \geq 0$$

- **Objective: Minimize sum of disrupted passengers**
- **Flight coverage constraints**
- **Aircraft balance for each sub fleet type**
- **Initial and end of the day aircraft resource constraints**
- **Passenger cancellation constraints**
- **Missed connected passengers constraints**
- **Only flight copy variables, x, have to be binary**

Minimizing passenger delay

- Need to consider all potential recovery itineraries for each passenger
- Large scale problem: 500,000 integer variables; 12 hours CPU using B&B deep first search methodology

Investigated approximate approaches that meet the time constraint requirements

$$\text{Min} \quad \sum_{p \in P} \sum_{i \in I_p} b_p^i q_p^i$$

$$\sum_{t \in T_f} x_f^t + z_f = 1 \quad \forall f \in F$$

$$\sum_{(f,t) \in In(j)} x_f^t + y_f^{t-} = \sum_{(f,t) \in Out(j)} x_f^t + y_f^{t+}$$

$$\sum x_f^0 + y_f^{0+} = j_\bullet$$

$$\sum_{i \in I_p} q_p^i = n_p$$

$$\sum_{p \in P} \sum_{i \in I_p} \delta_{fi}^t q_p^i \le C_f \times x_f^t$$

$$q_p^i \ge 0; x_f^t \in \{0,1\}; y_f^t \ge 0$$

$$\text{Minimize}\left(\sum_{p\in P} n_p \times \rho_p\right)$$

$$\text{st}: \quad \sum_{t\in T_f}\sum_{a\in A_f} x_{f,a}^{t} + z_f = 1$$

$$\sum_{f\in F_{dj}^{t}} x_{f,a}^{t} + y_f^{t-} = \sum_{f\in F_{oj}^{t}} x_{f,a}^{t} + y_f^{t+}$$

$$\sum_{f\in F_{oj}^{0}} x_{f,a}^{0} + y_f^{0+} = j_{0,a}$$

$$\rho_p \geq z_f$$

$$x_f^t + \sum_{g\in C(u) | d(g)<a(f)} x_g^u - \rho_p \leq 1$$

$$\rho_p \in [0;1];\ x_{f,a}^t \in \{0,1\};\ y_f^t \geq 0$$

$$\text{Total delay} = \sum D(DP)\times N(DP) + \sum D(NDP)\times N(NDP)$$

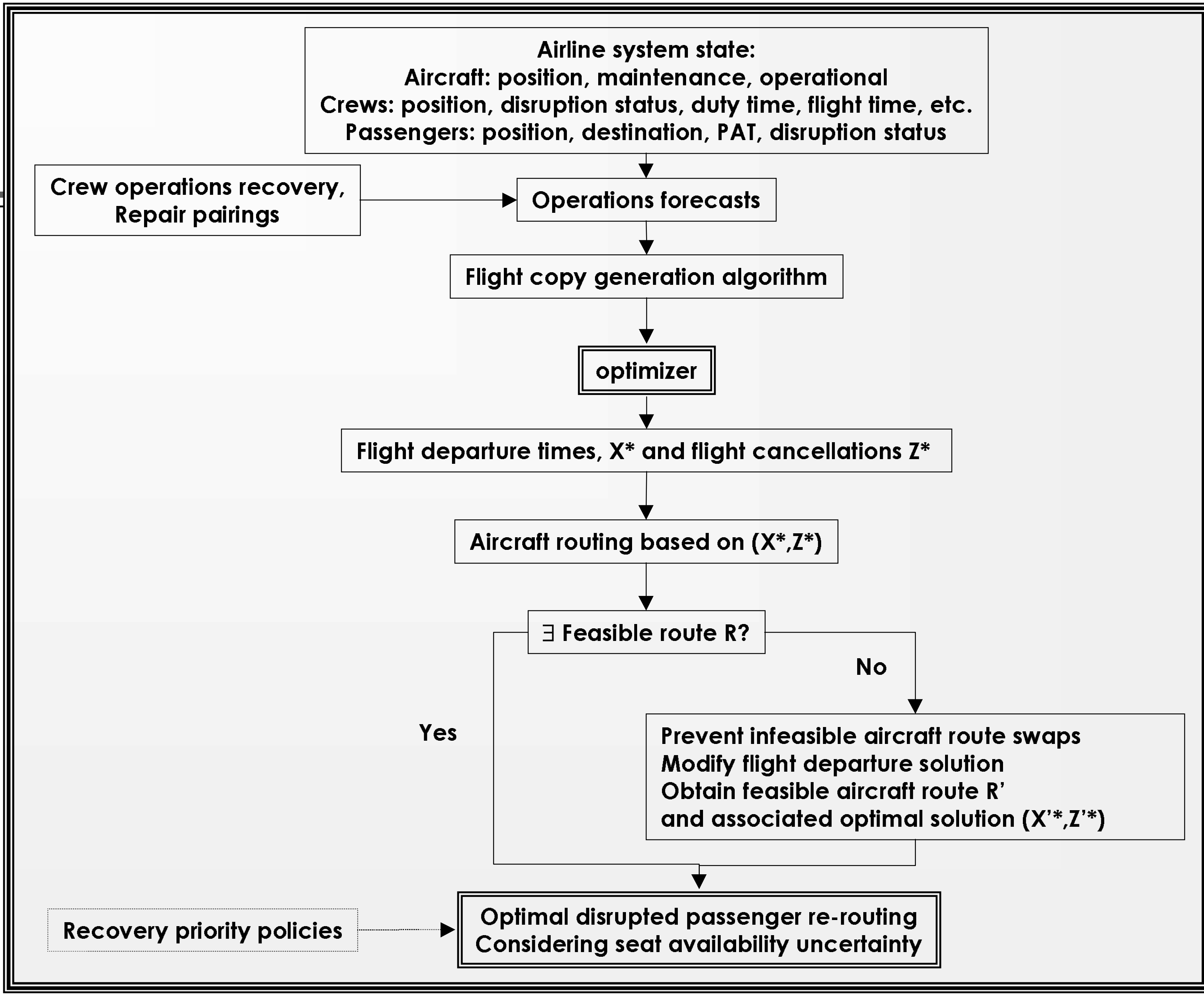
$$NDP = TP - DP$$

$$\text{Minimize}(\sum \tilde{D}(DP)\times N(DP) + \sum D(TP-DP)\times N(TP-DP)$$

Estimate delay of disrupted passenger using PDC

Objective function

- **Objective function:**
  - **Fine grained to Passenger Name Record**
  - **Estimate each passenger dissatisfaction: assign a cost (expected future revenue loss of delay d for PNR p)**
  - **Let the model chose flight decisions**
- **Enforcing feasibility:**
  - **Minimizing crew disruptions**
  - **Preventing maintenance routing infeasibility**


Airline system state:
Aircraft: position, maintenance, operational
Crews: position, disruption status, duty time, flight time, etc.
Passengers: position, destination, PAT, disruption status
Crew operations recovery,
Repair pairings
Operations forecasts
Flight copy generation algorithm
optimizer
Flight departure times, X* and flight cancellations Z*
Aircraft routing based on (X*,Z*)
∃ Feasible route R?
No
Yes
Prevent infeasible aircraft route swaps
Modify flight departure solution
Obtain feasible aircraft route R'
and associated optimal solution (X'*,Z'*)
Recovery priority policies
Optimal disrupted passenger re-routing
Considering seat availability uncertainty

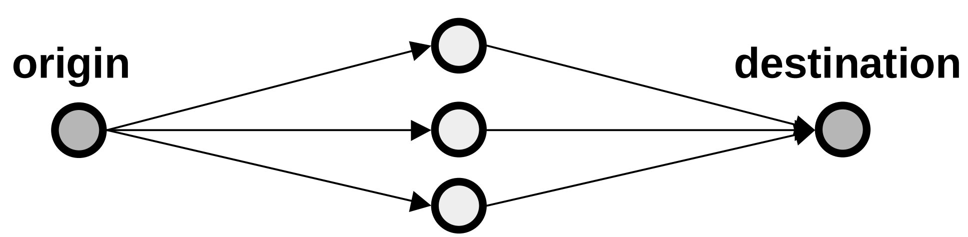
Routing passengers

Several optimizations models that route passengers to their destinations are used depending on the service priority rules

Passenger service priority rule		**Routing algorithm**
Priority given to booked passengers over disrupted	***Recovery priority among disrupted passengers***	
Yes	**FDFS for disrupted; local first when same disruption time**	**The Passenger Delay Calculator (PDC)**
No	**Optimal passenger recovery**	**The Passenger Mix model (PMIX)**
Yes	**Optimal passenger recovery**	**Combination of PDC+PMIX**
Yes	**FDFS for disrupted; local first when same disruption time**	**Stochastic PDC; Don't know exact seat capacity before boarding ends due to potential no shows**

Passenger routing algorithm performance

- PMIX provides the optimal passenger routings; We found that PDC is close to optimality (PMIX) to route the passengers
- When passengers are disrupted at the hub (flight cancellation or missed connection), PDC provides the optimal recovery most of the time because only one route typically goes from the hub to destination airport (hub and spoke topology); Only when passengers are disrupted at the origin spoke (first flight canceled), does PDC might provide sub-optimal solution



Conclusion and future research

- **Propose new airline operations recovery models that reduce passenger disruptions and:**
  - **Does not disrupt additional crew duties**
  - **Recover aircraft plan**
  - **Maintain overhead costs**
  - **Found 10% to 20% reduction in passenger disruptions for bad days of operations, using a sophisticated simulation environment**
  - **Run fast and meet real time AOCC needs**
- **Airline long term profitability: higher service reliability improves customer retention and long term revenues**
- **Future research:**
  - **Estimate the impact of different disrupted passenger's priority strategies (e.g. *Passenger routing*: recovery priority given to business passengers over leisure passengers; *Optimization*: minimize the revenue of disrupted passengers) on overall passenger population**