SARDA Surface Schedulers

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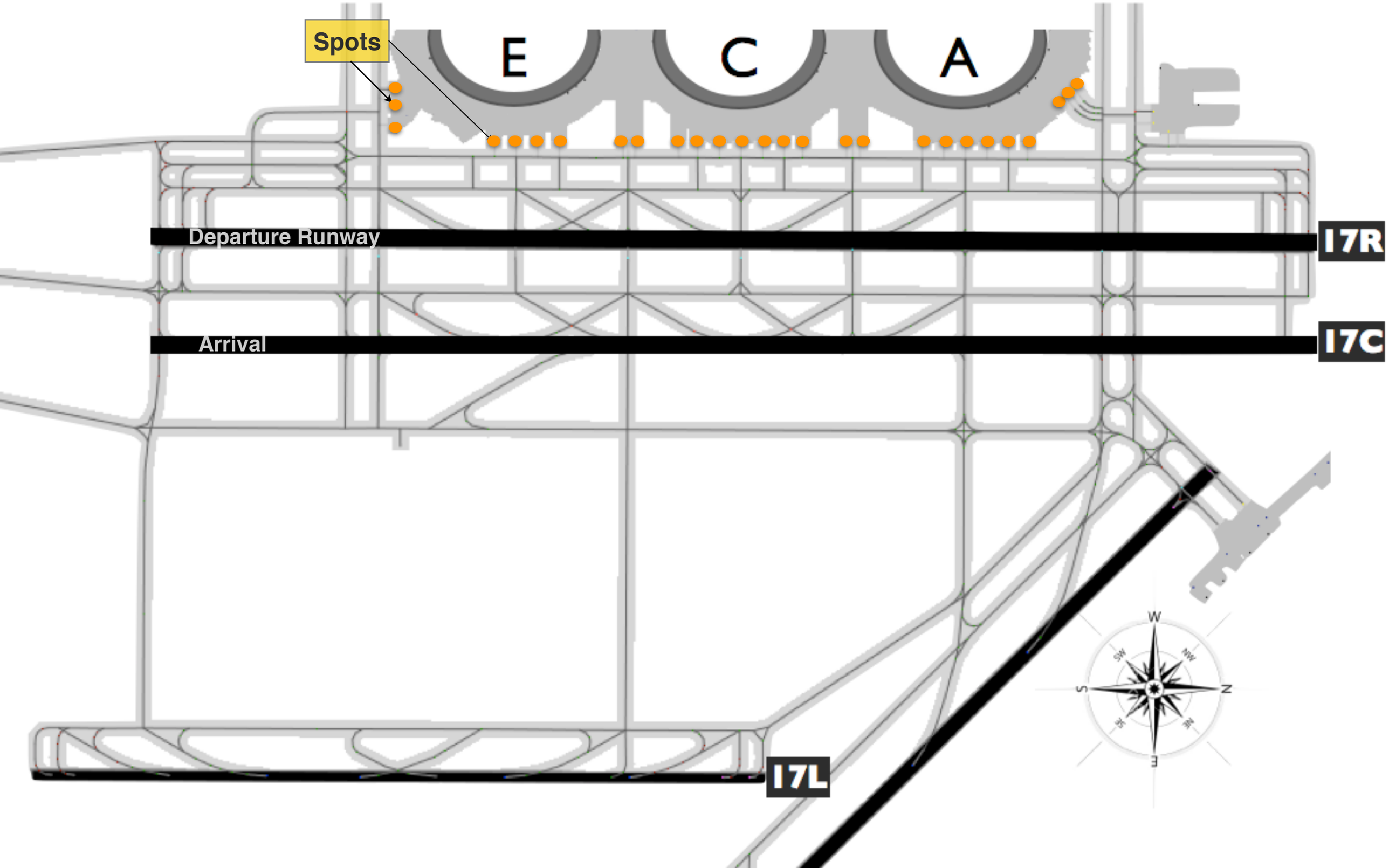
Universities Space Research Association

3rd Joint Workshop for
KAIA/KARI - NASA ATM Research Collaboration
October 24-26, 2016

Outline

- Overview of airport surface management
- Single runway scheduling
  - One exact algorithm
  - Two heuristics-based algorithms
  - Simulation setup and results
- Multiple runway scheduling
  - CLT airport layout
  - Mixed Integer Linear Program Formulation
  - Simulation setup and results

Current Operations



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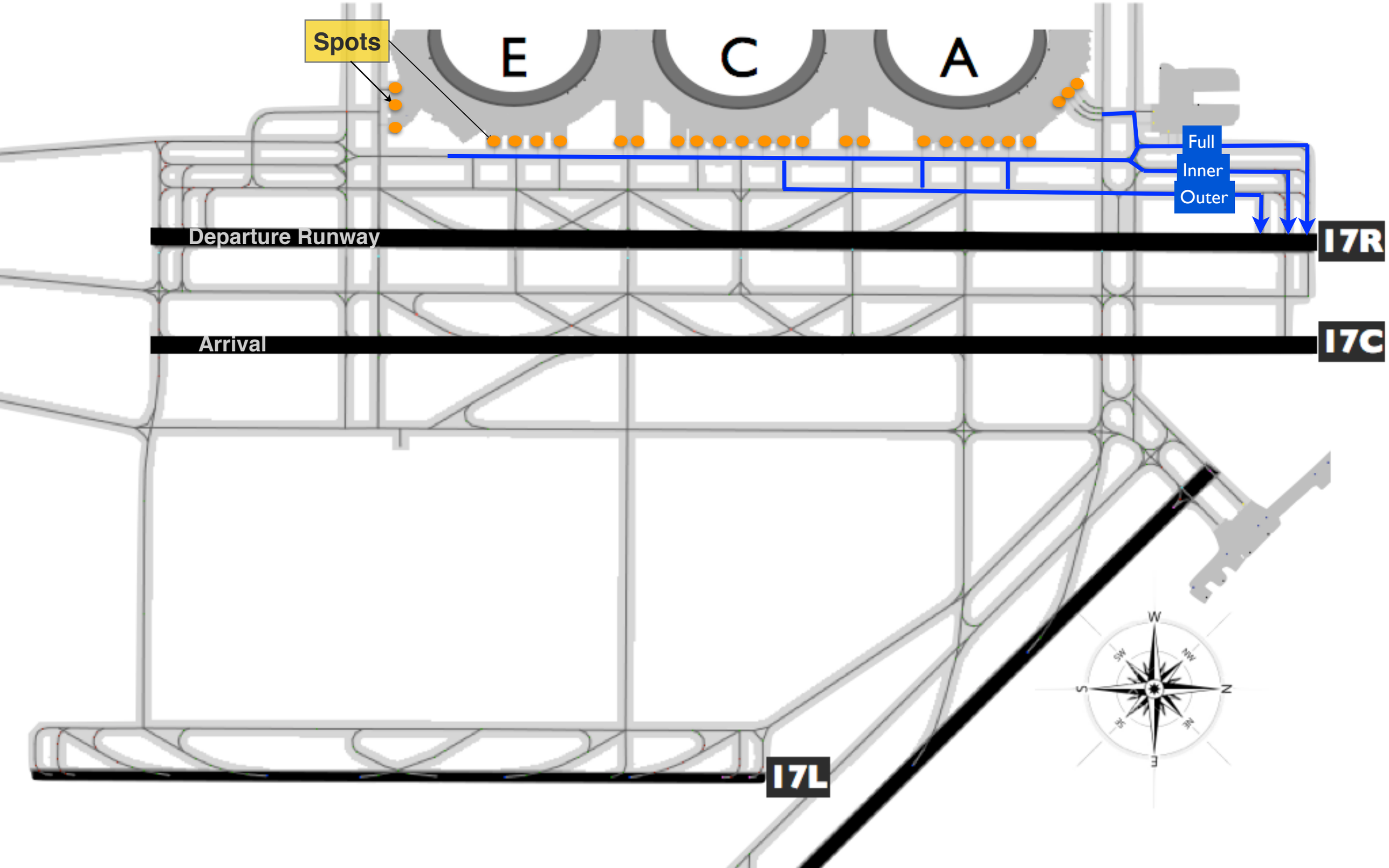

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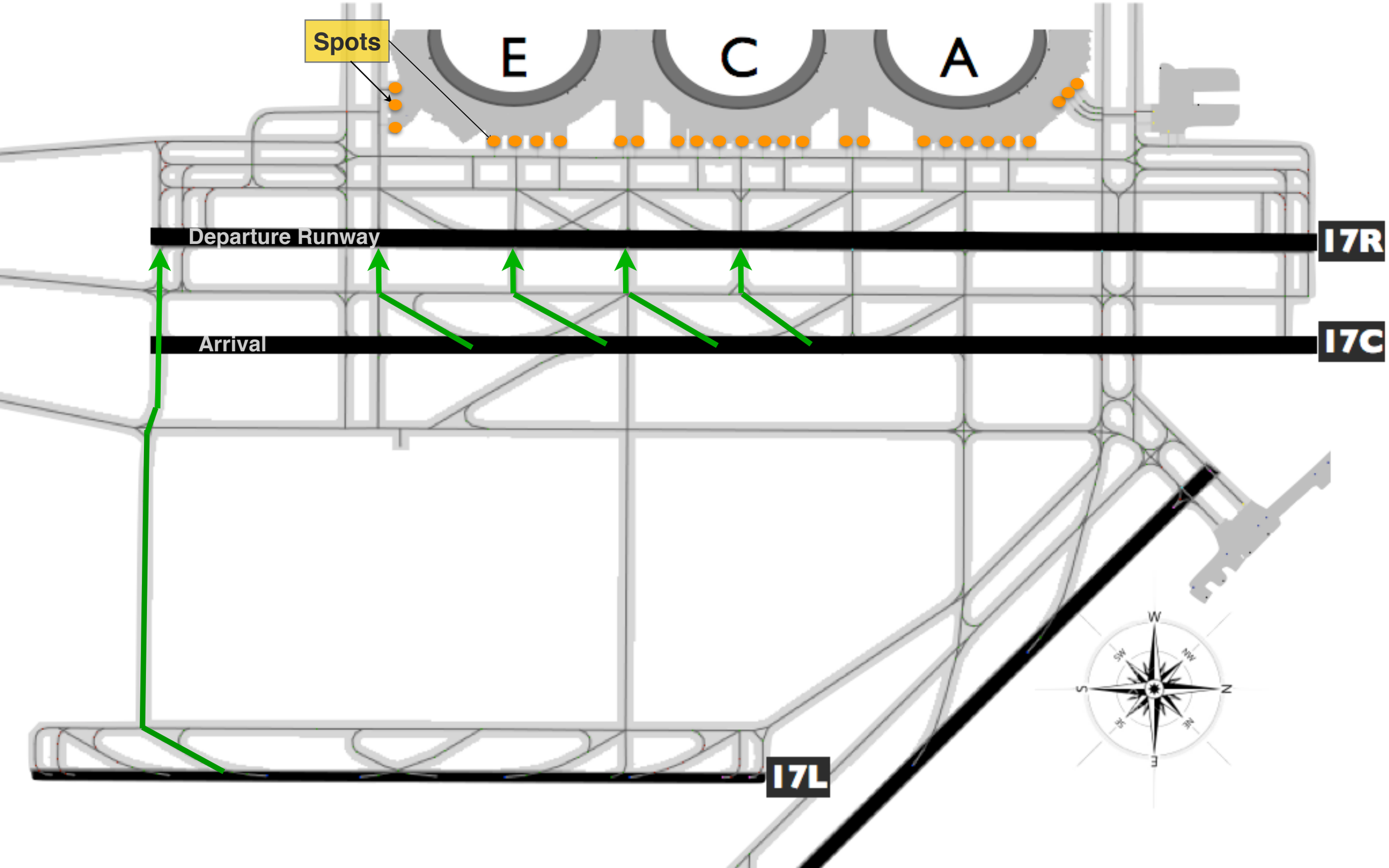

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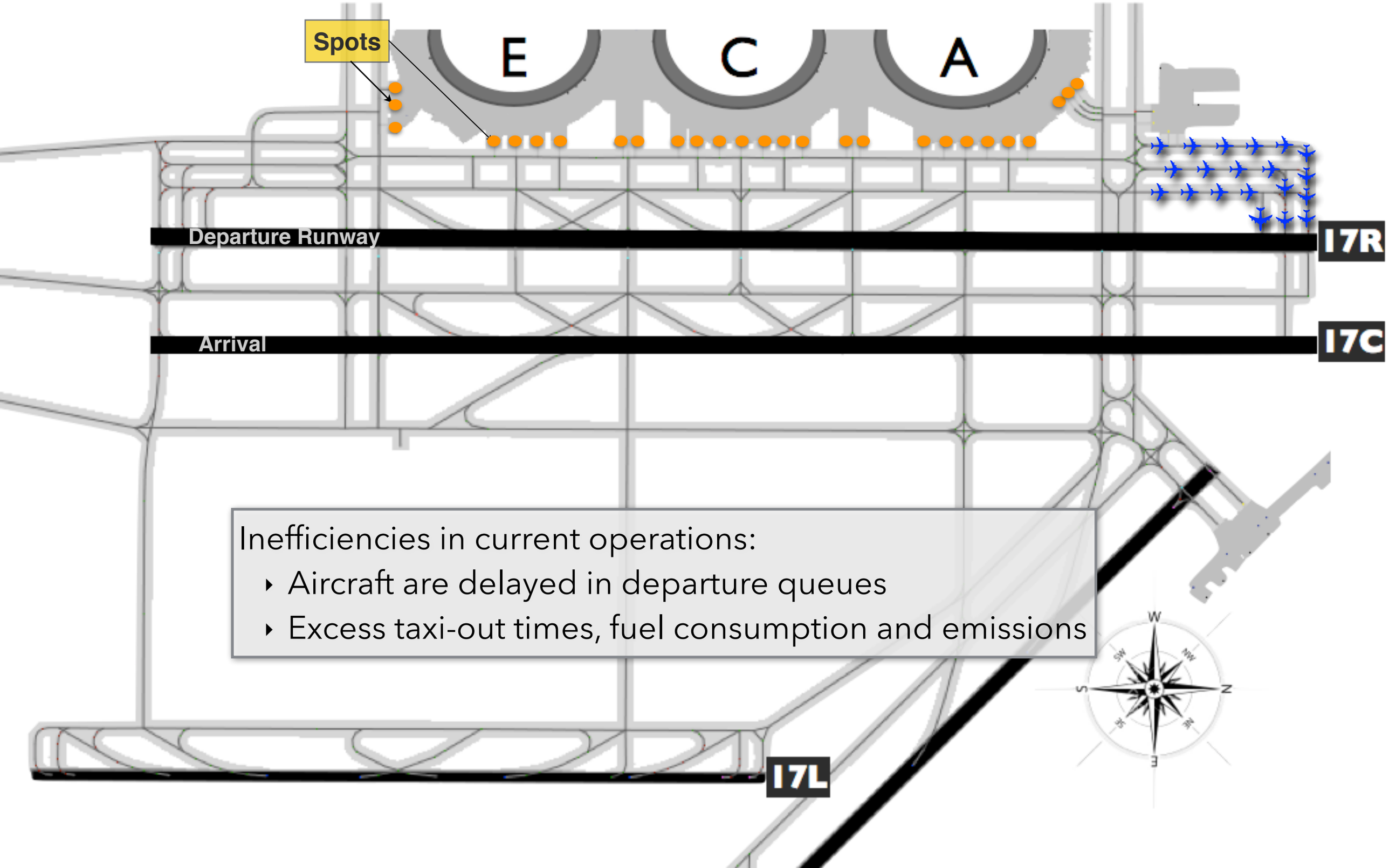


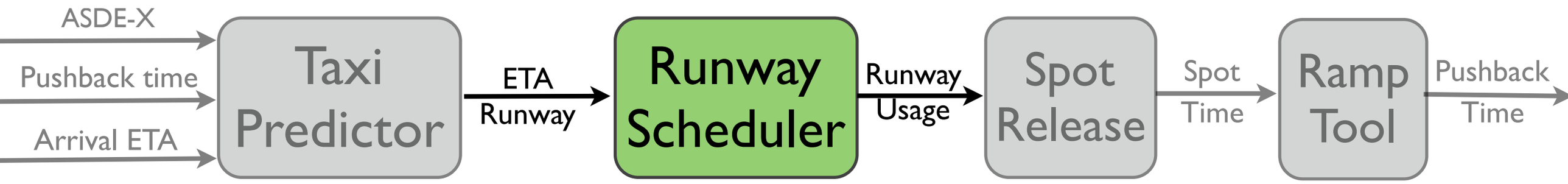
Inefficiencies in current operations:

- Aircraft are delayed in departure queues
- Excess taxi-out times, fuel consumption and emissions

Surface Optimization at NASA

- Spot and Runway Departure Advisor (SARDA) provides a departure metering capability by efficiently scheduling aircraft on airport surface
- Human-in-the-loop simulations (2010, 2012)
  - Dallas/Fort Worth Airport (DFW), East Tower
  - Advisories provided to tower controllers
- Human-in-the-loop simulations (2014)
  - Charlotte Douglas International Airport (CLT)
  - Advisories provided to ramp controllers

SARDA Concept



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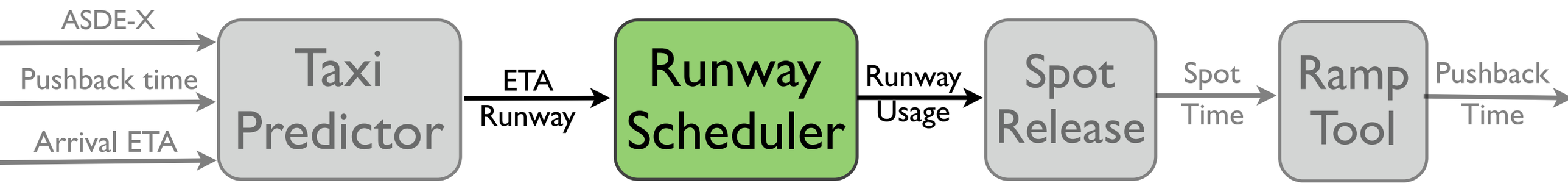

- A collaborative decision support tool for airlines and tower controllers to enhance the efficiency of surface traffic

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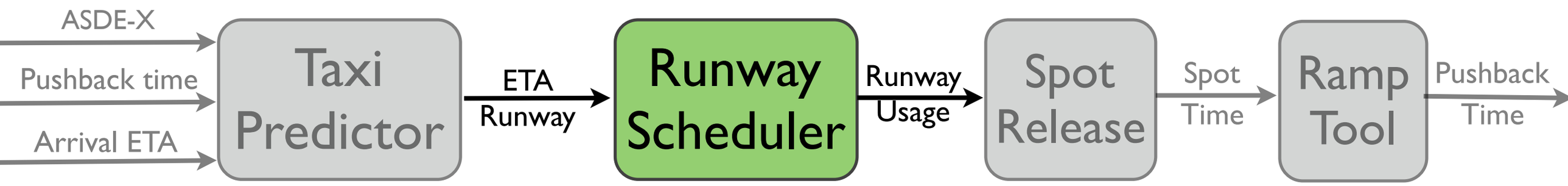

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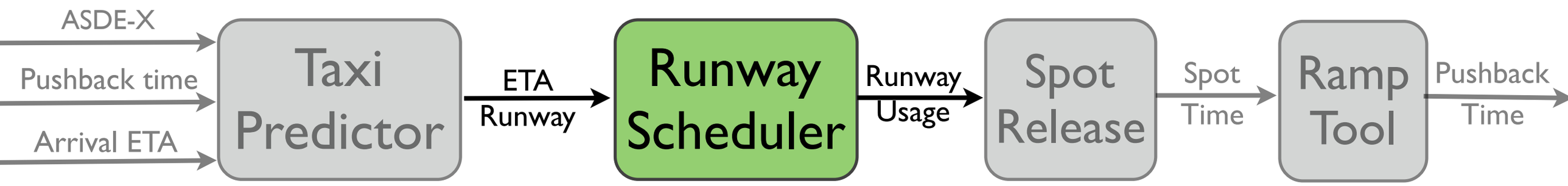

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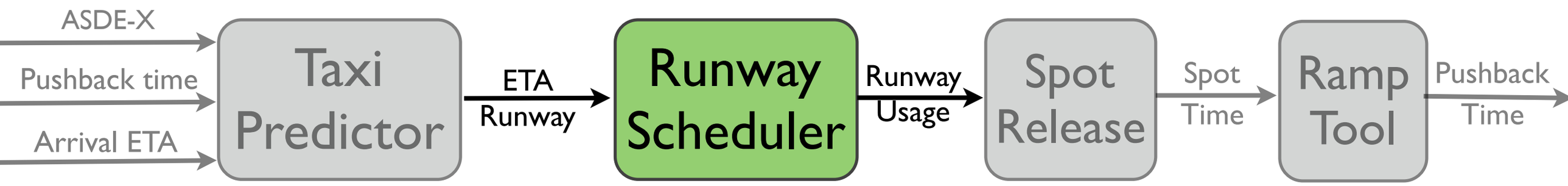

- A collaborative decision support tool for airlines and tower controllers to enhance the efficiency of surface traffic
- Provides advisories to Air Traffic Control Tower controllers and airline operators
- Efficient Runway Scheduler that incorporates aircraft specific constraints, as well as arrivals
- Both computation time and solution quality are critical factors in deciding a solution technique for Runway Scheduler

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- Overview of airport surface management
- **Single runway scheduling**
  - One exact algorithm
  - Two heuristics-based algorithms
  - Simulation setup and results
- Multiple runway scheduling
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  - Mixed Integer Linear Program Formulation
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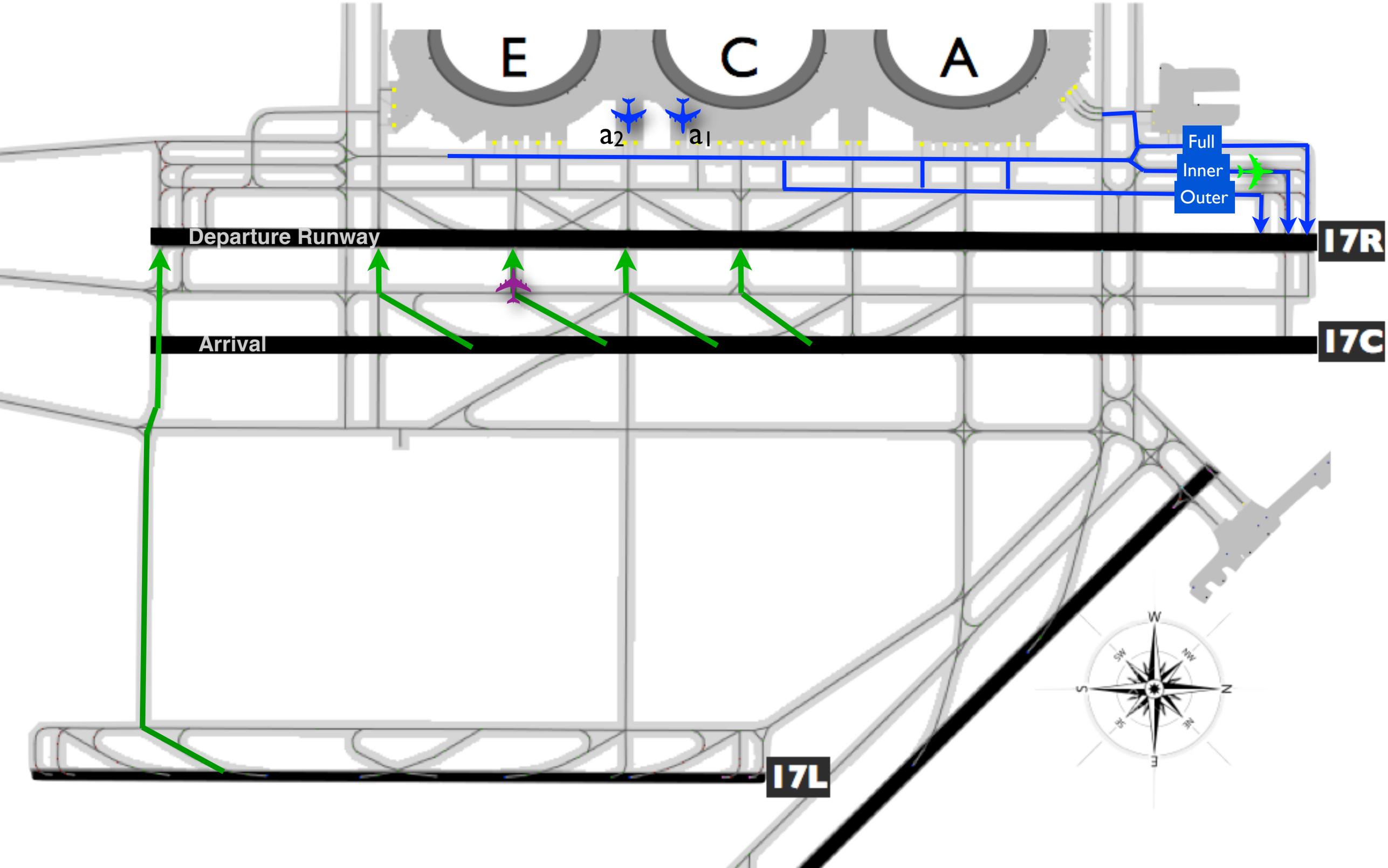
Single Runway Scheduling



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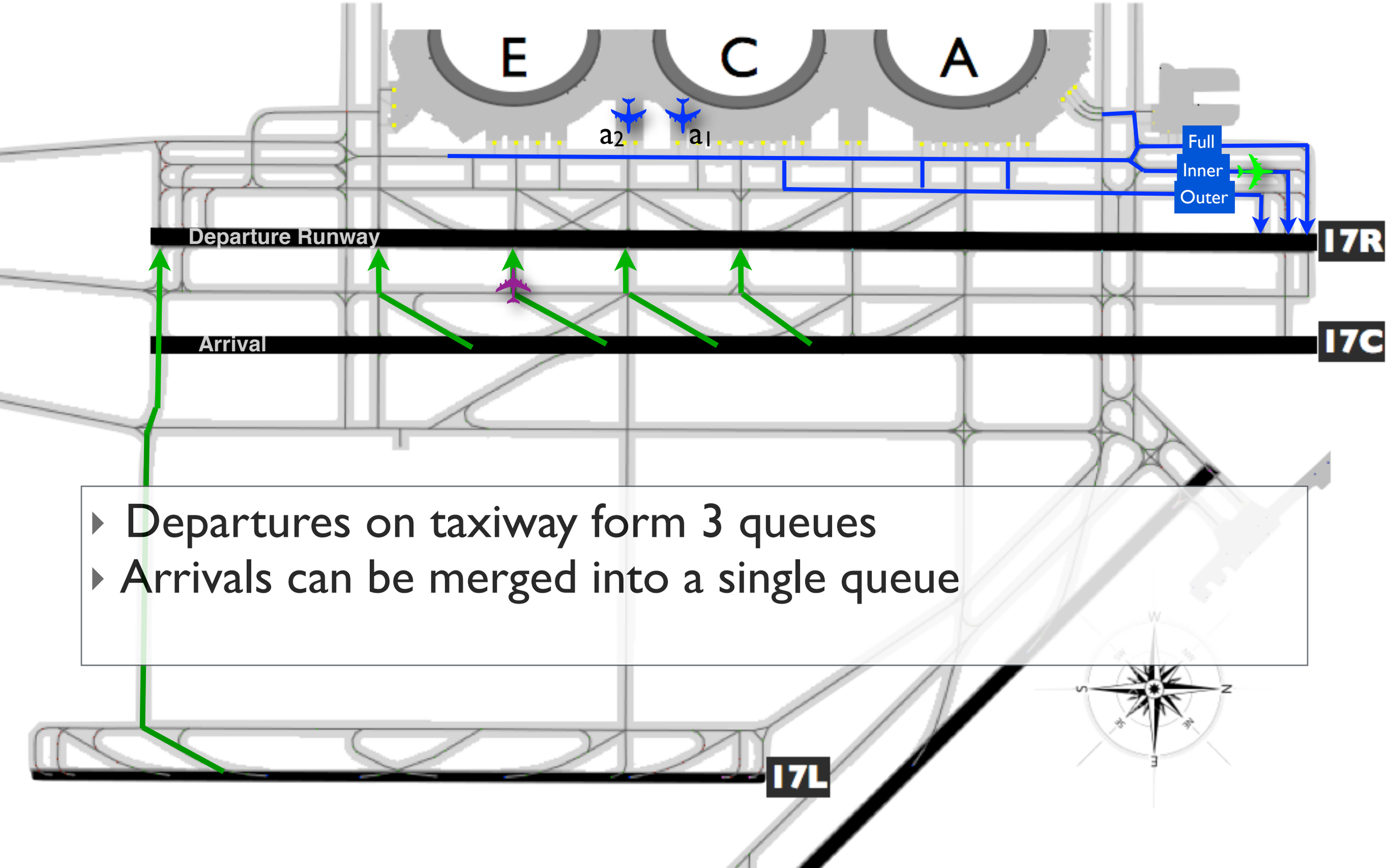
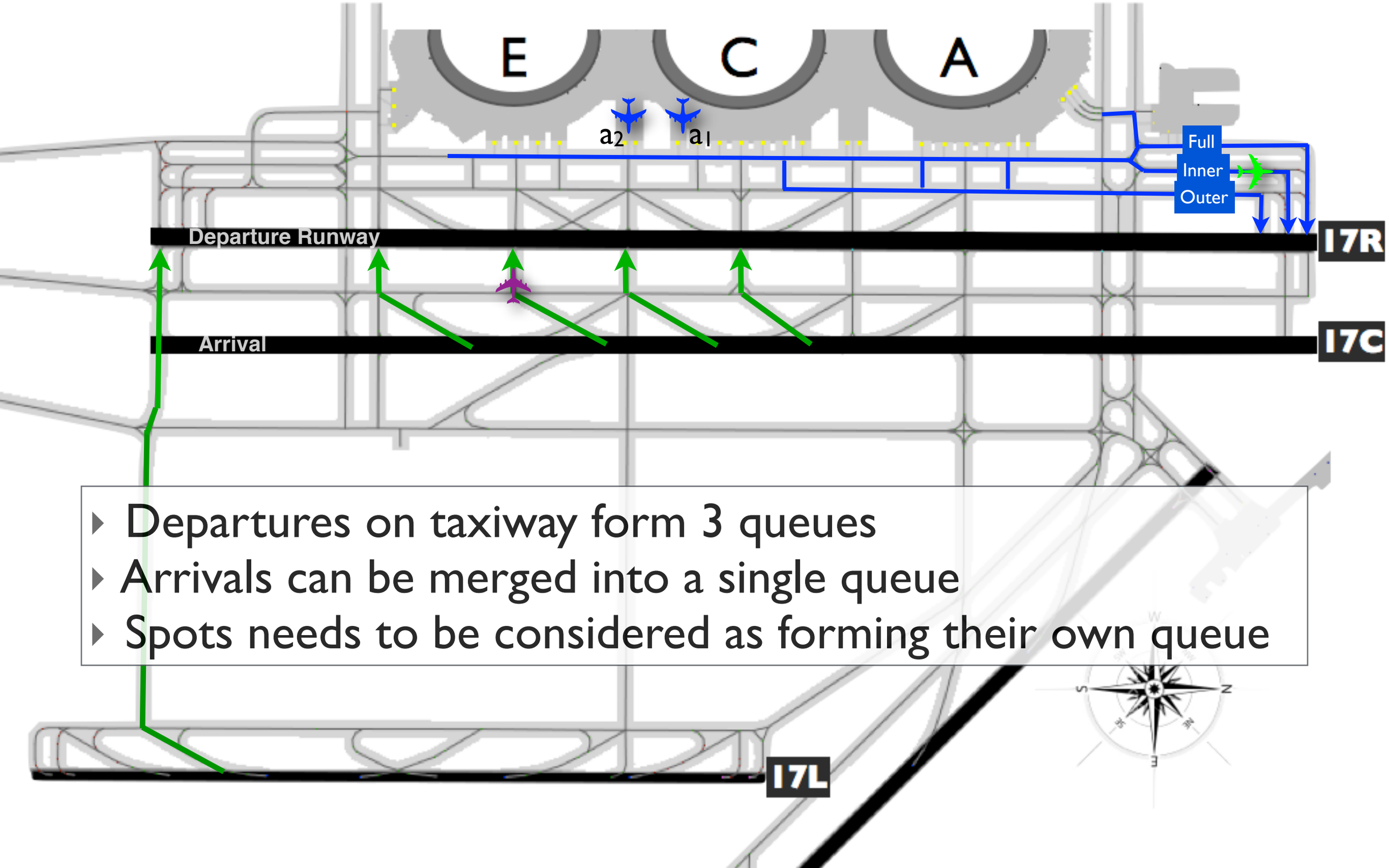


- Departures on taxiway form 3 queues
- Arrivals can be merged into a single queue

Single Runway Scheduling



- Departures on taxiway form 3 queues
- Arrivals can be merged into a single queue
- Spots needs to be considered as forming their own queue

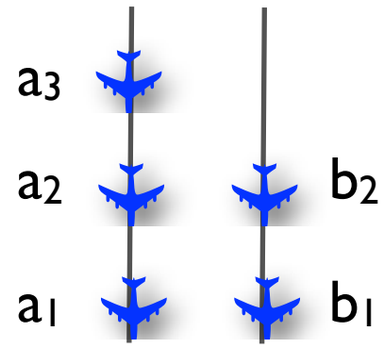
Single Runway Scheduling

- Exact Dynamic Program (EDP)
- Restricted Dynamic Program (RDP)
- Insertion and Local Search (ILS)

Runway Scheduler: Inputs

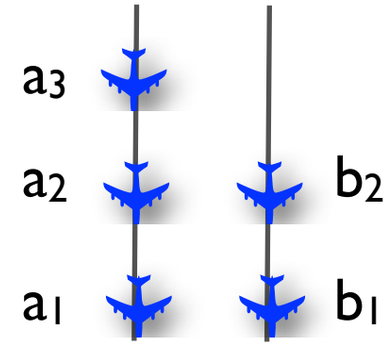
- For each aircraft:
  - Earliest available time
  - Spot, surface route, position, and fix/exit
  - Weight class and operation type
- Wake-vortex separation criteria and RNAV separation
- Separation between arrivals and departures for mixed use runway
- Separation between arrivals and departures for runway crossings
- Individual time-windows of intended take-off times for departing aircraft — Expect Departure Clearance Time (EDCT) and Call For Release (CFR)

Exact Dynamic Program



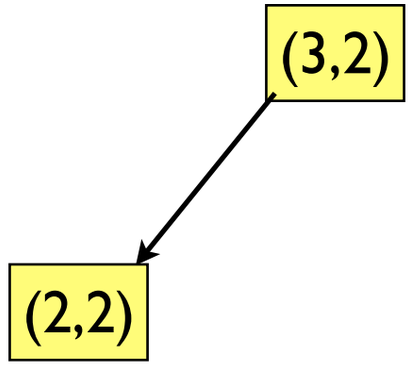
Exact Dynamic Program

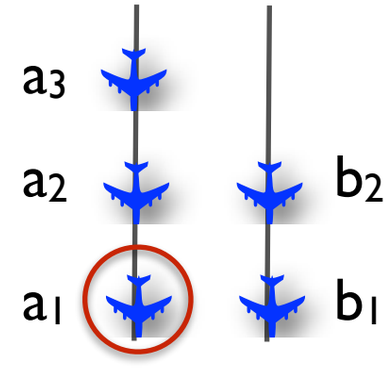
(3,2)



Partial solution:

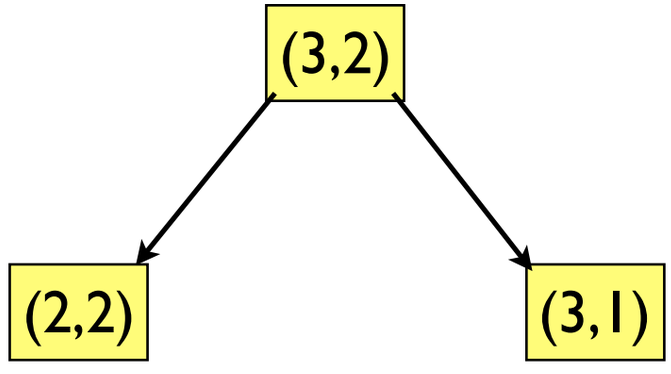
Exact Dynamic Program

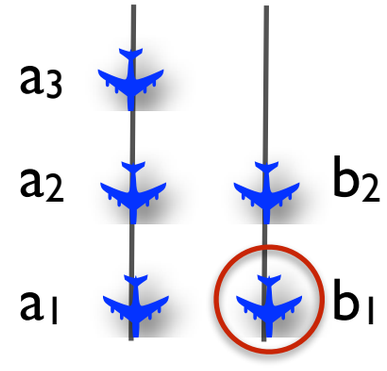




Partial solution: $\{a_1\}$

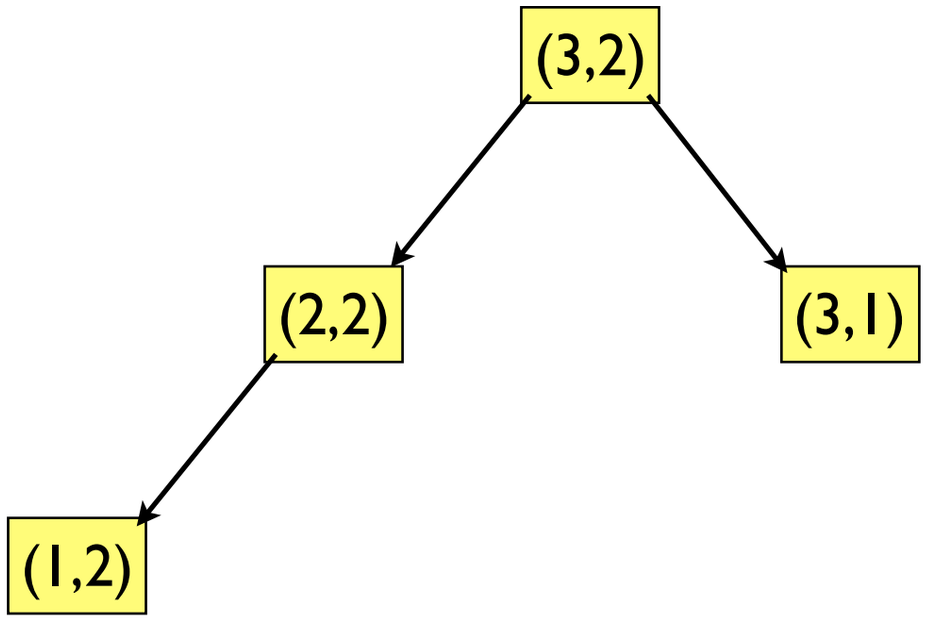
Exact Dynamic Program

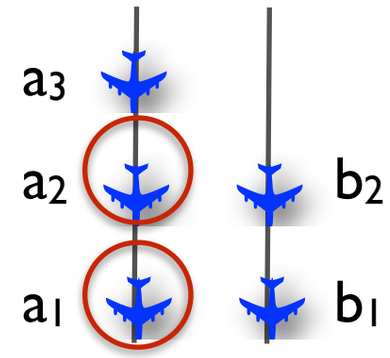




Partial solution: $\{b_1\}$

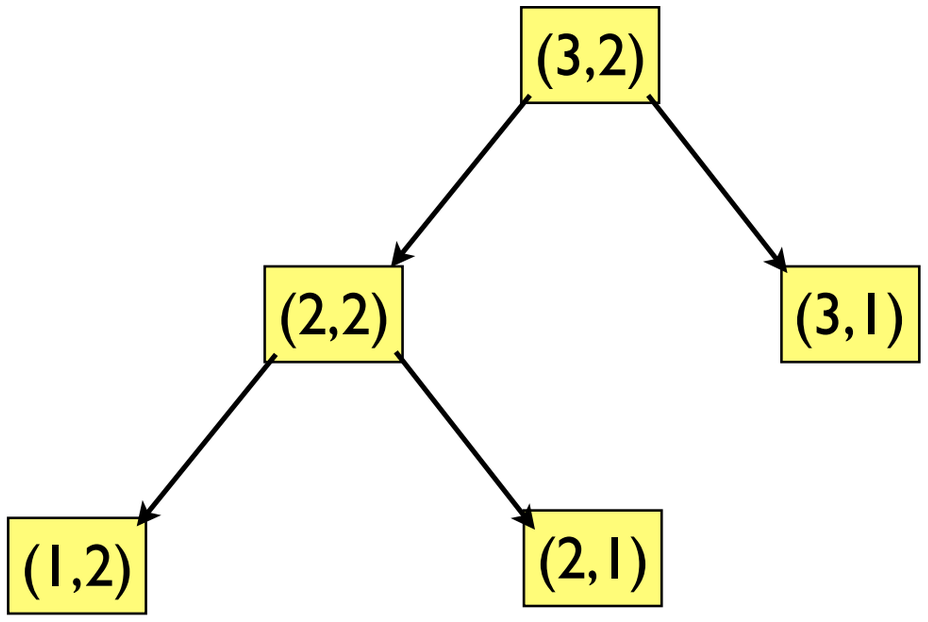
Exact Dynamic Program

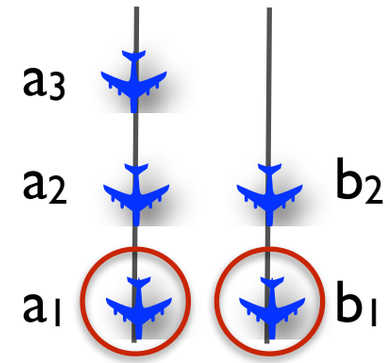




Partial solution: $\{a_1, a_2\}$

Exact Dynamic Program





Partial solution: $\{a_1, b_1\}$

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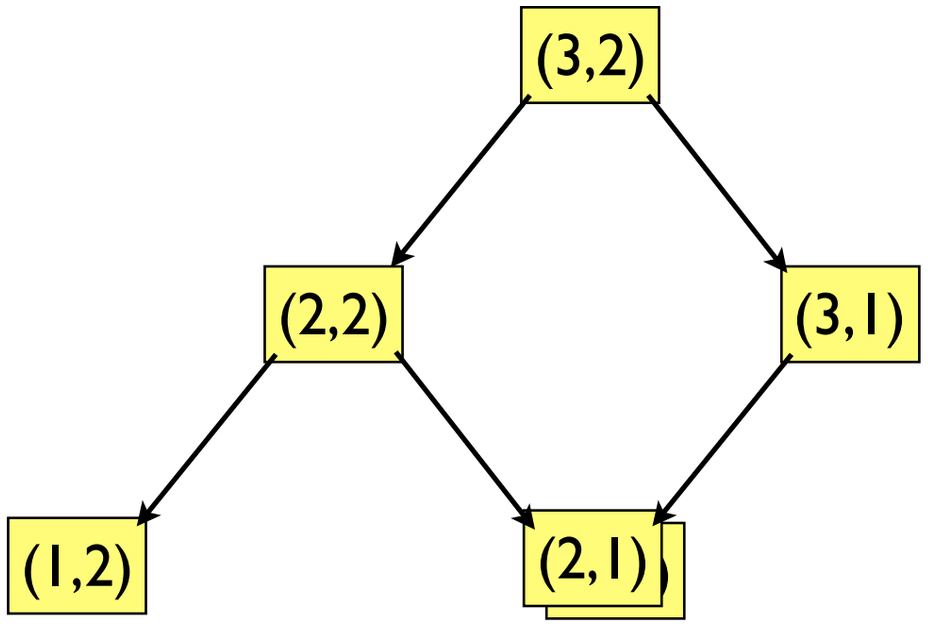
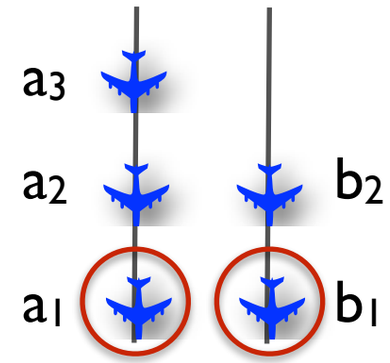
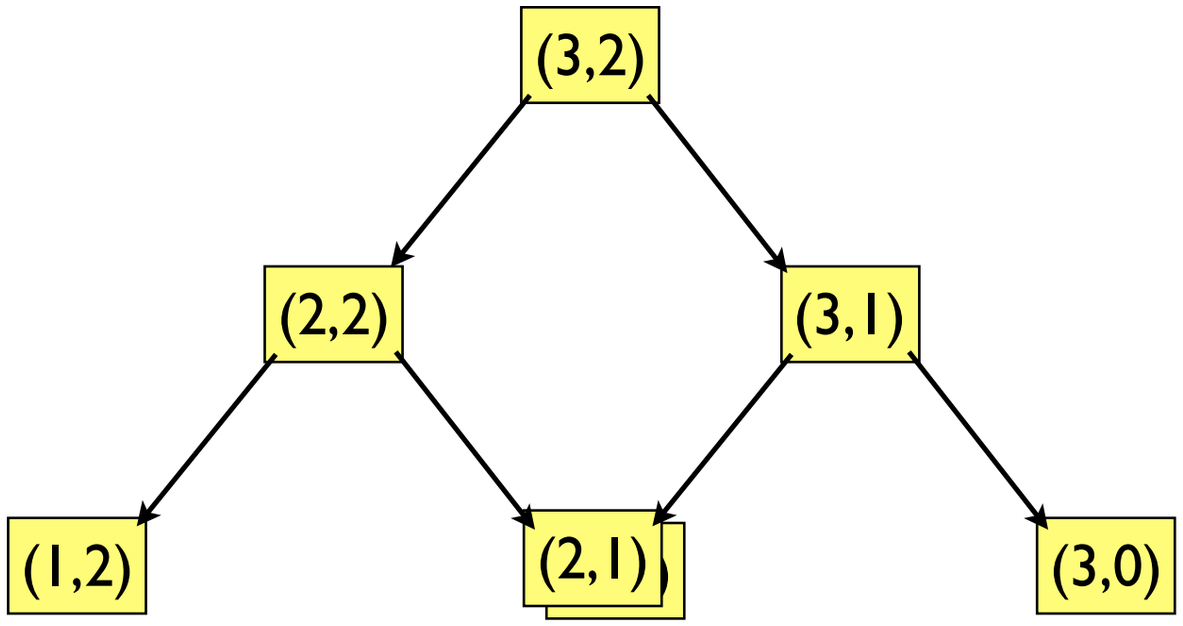
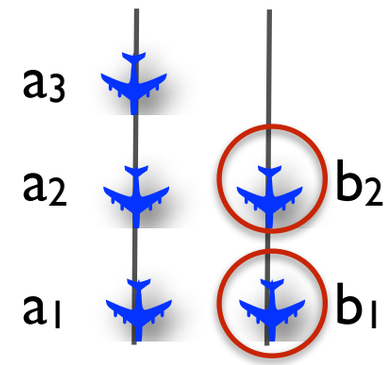




Partial solution: $\{a_1, b_1\}, \{b_1, a_1\}$

Exact Dynamic Program





Partial solution: $\{b_1, b_2\}$

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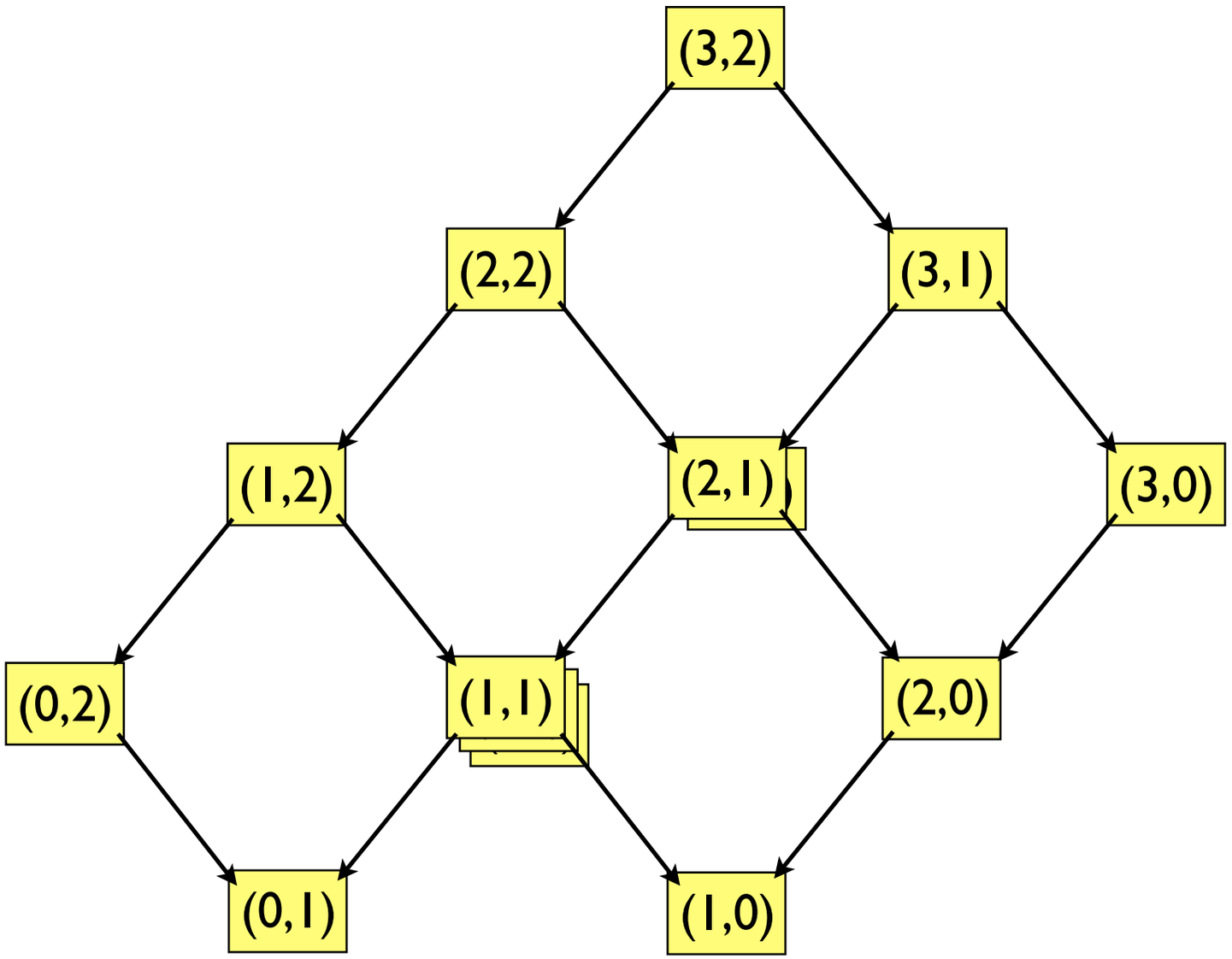

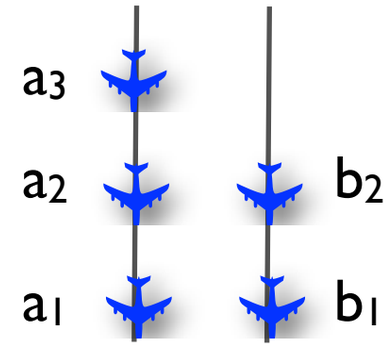

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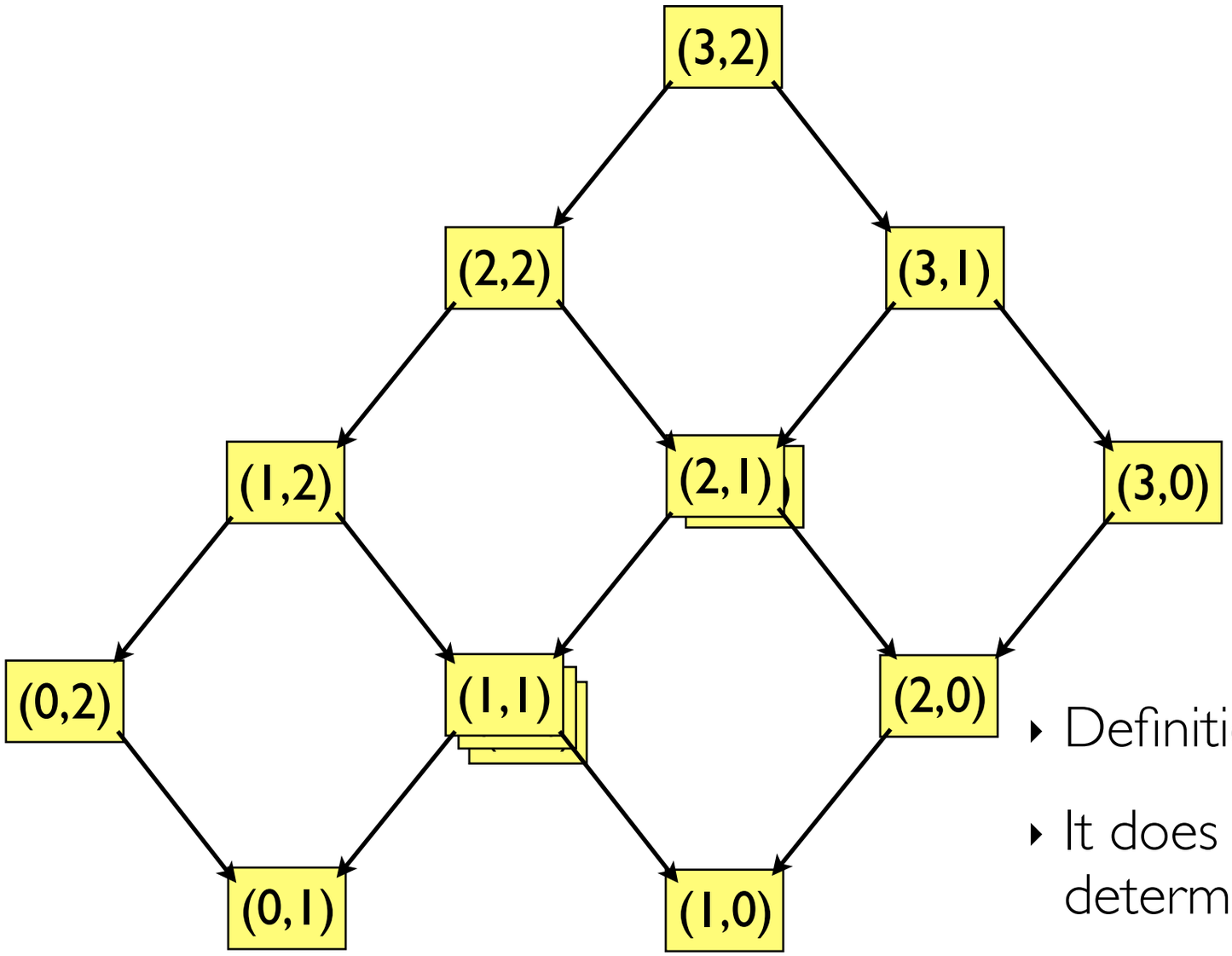

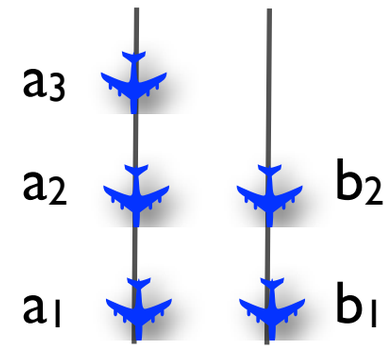

- Definition of state may not be rich enough
- It does not carry enough process history to determine optimality of remaining decisions
- Enhance state definition or consider multiple objectives

Exact Dynamic Program

- State Definition:
  - heading of last departure
  - weight-class of last departure
  - last operation type
  - #aircraft in queue 1
  - #aircraft in queue 2
  - .
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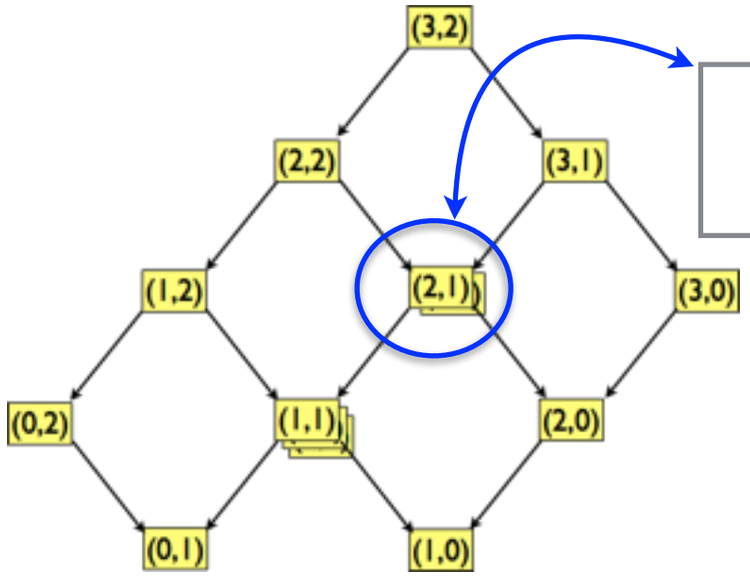

Pareto dominance can be applied

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Restricted Dynamic Program

- Number of nodes in DP is proportional to product of number of aircraft in each queue
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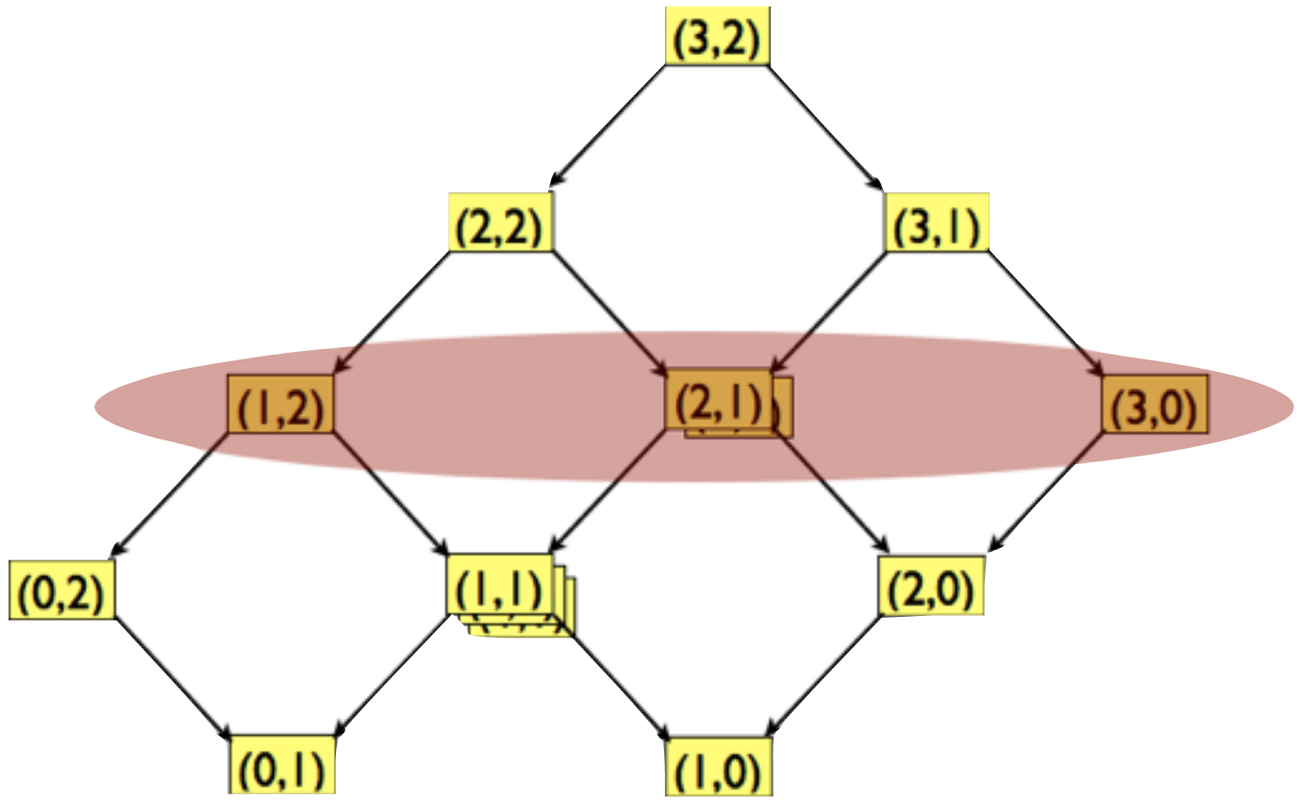
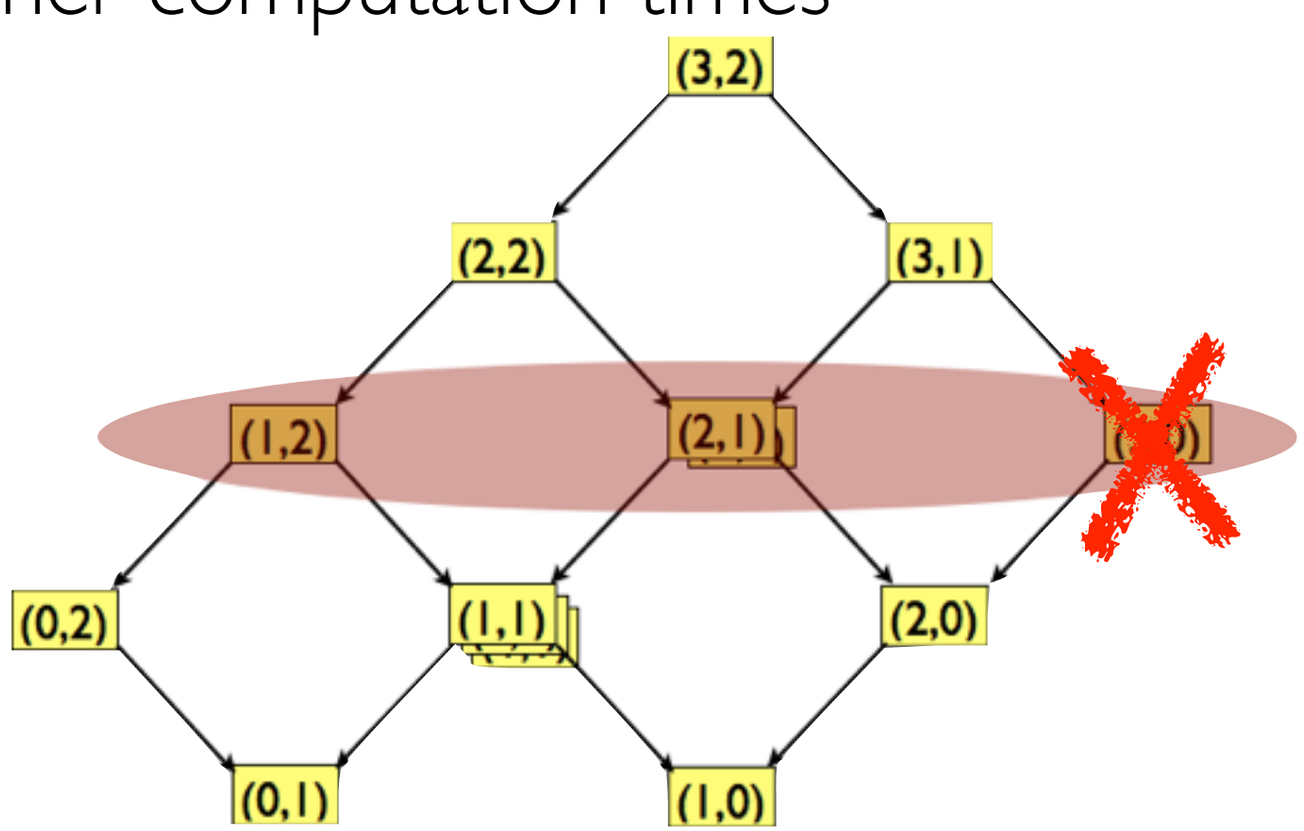


Restricted Dynamic Program

- In each stage, only a restricted subset of H states with the smallest delay is kept
- Increasing the value of H should yield better solutions, but will also result in higher computation times

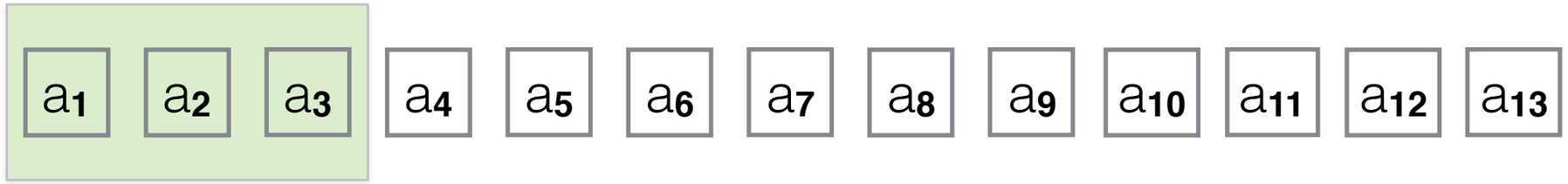


Insertion and Local Search

- Start with a First-Come-First-Served (FCFS) initial solution

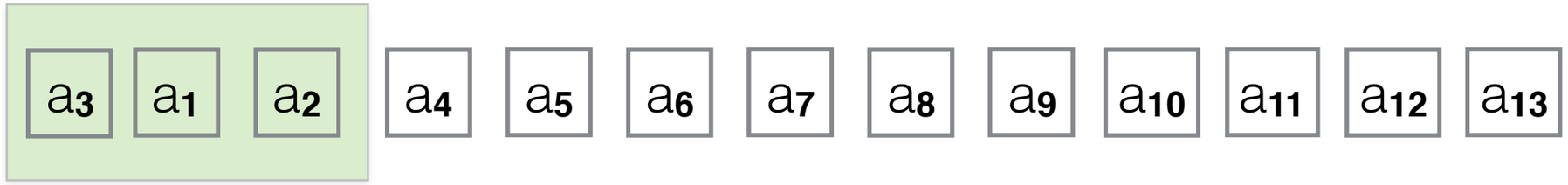
Insertion and Local Search

- Find all permutations of ‘k’ free aircraft



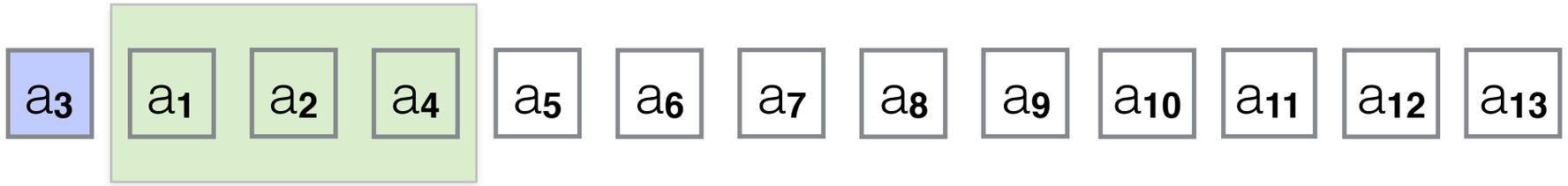
Insertion and Local Search

- Find all permutations of ‘k’ free aircraft
- Select sequence which gives best objective value



Insertion and Local Search

- Fix first free aircraft



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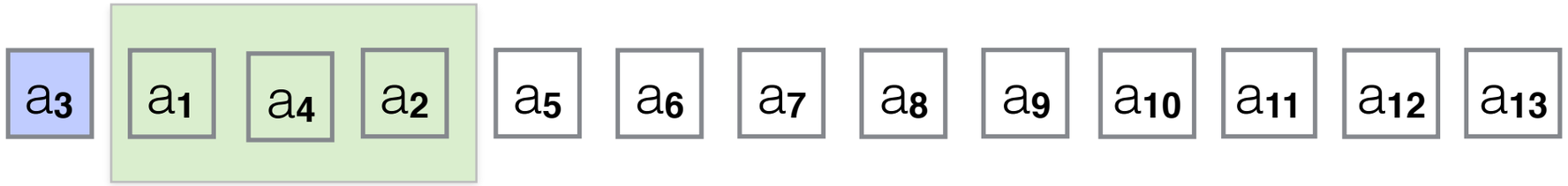

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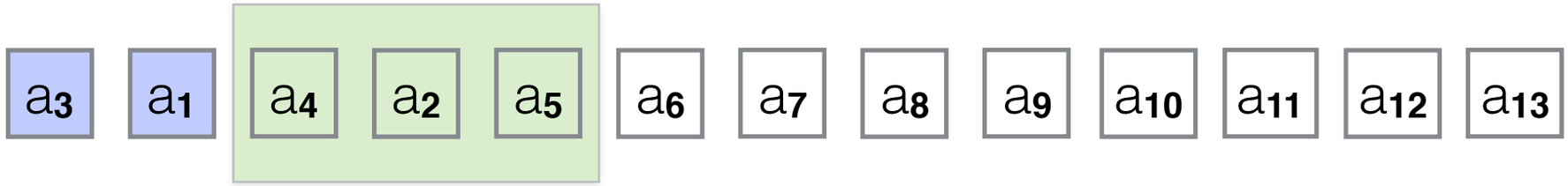

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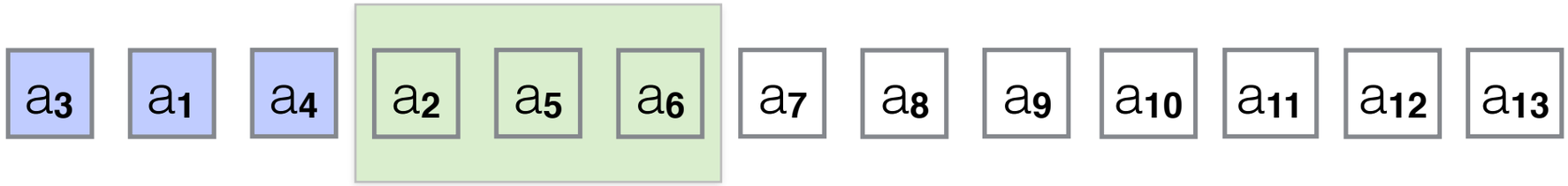

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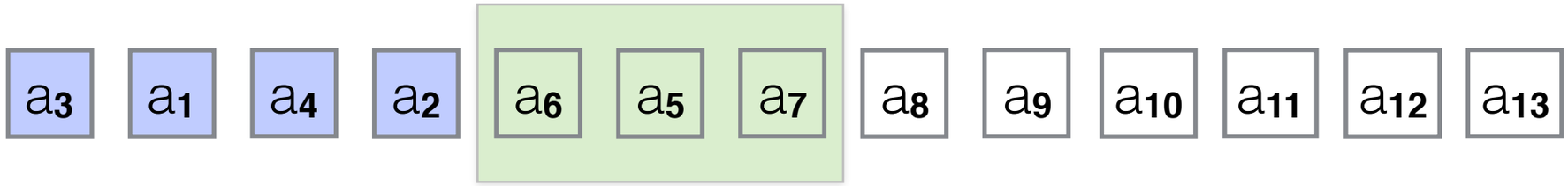

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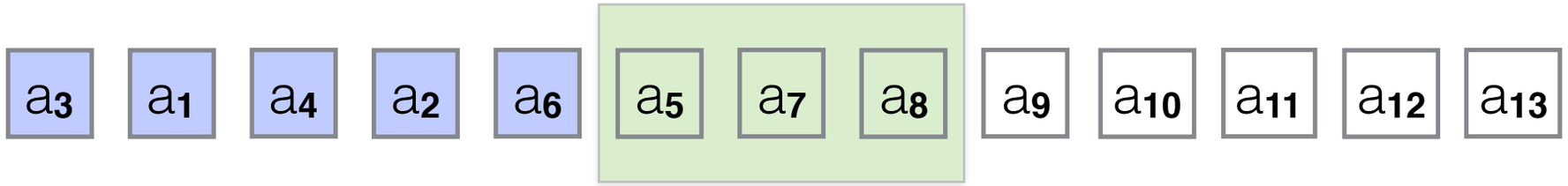

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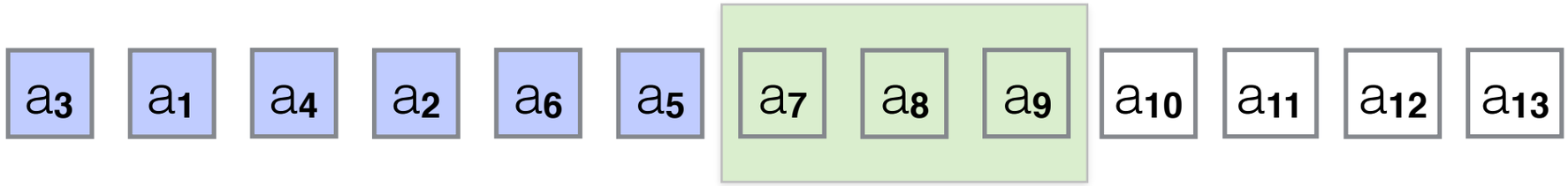

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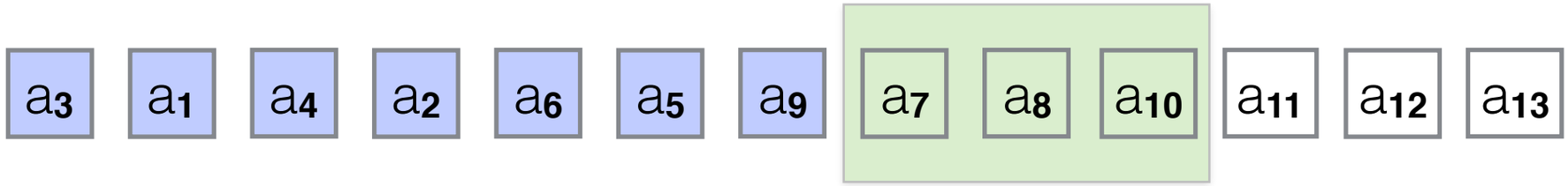

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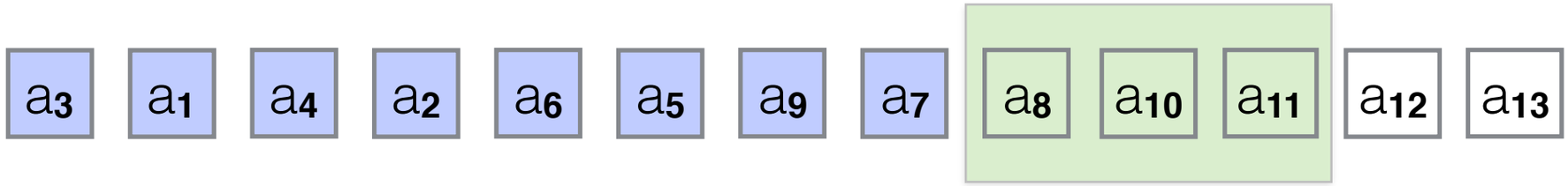

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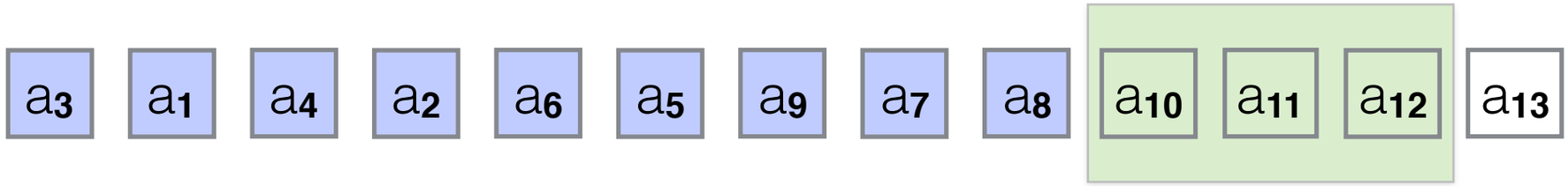

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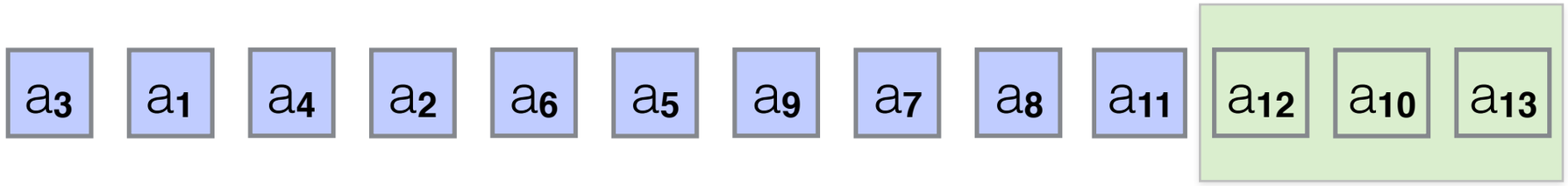

Insertion and Local Search

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Insertion and Local Search

- If final sequence is different from starting sequence, repeat whole procedure (descent search)

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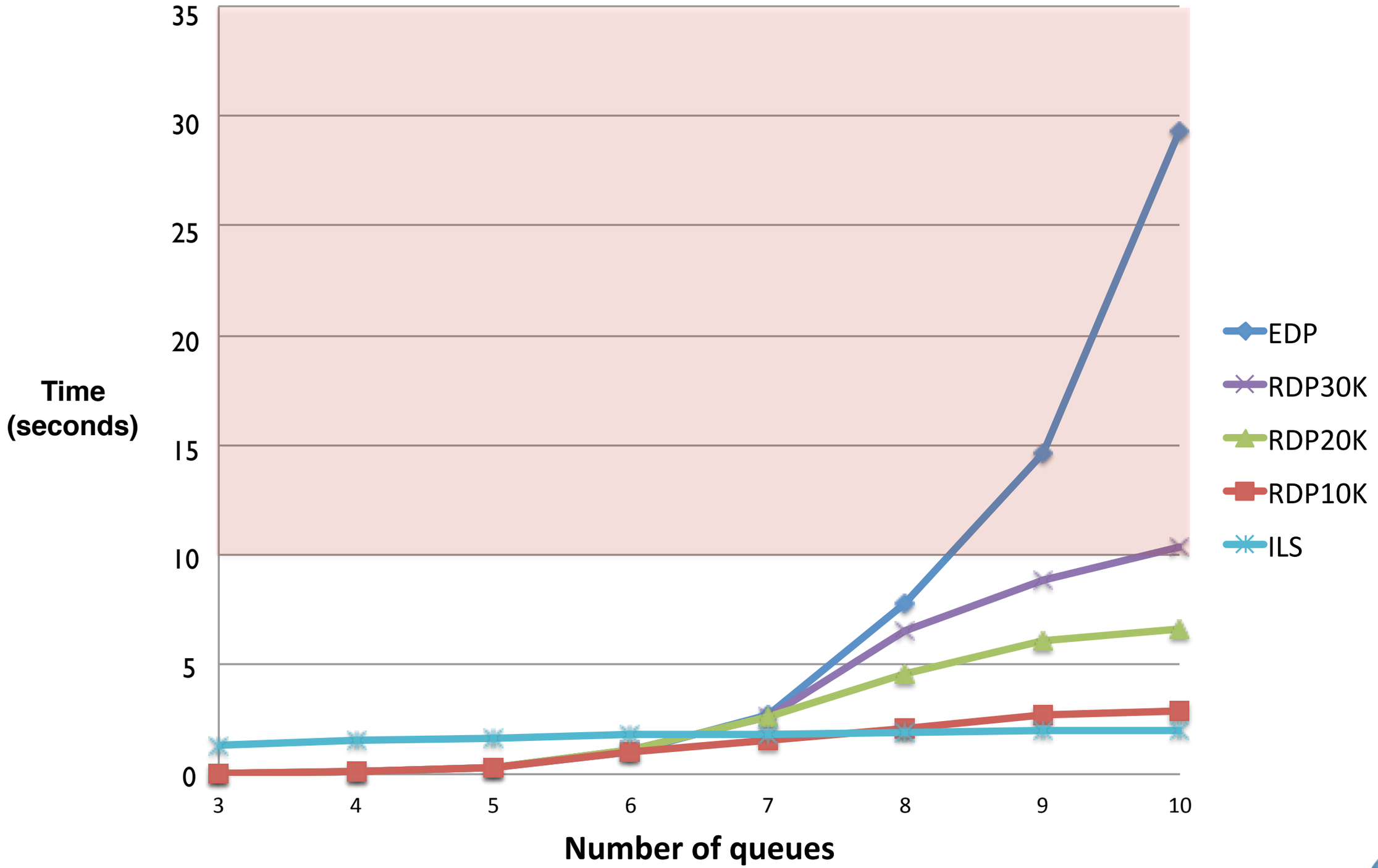
Simulation Setup

- DFW East-side in South-flow configuration
- 20 Departures and 15 runway crossings considered.
- Planning window of 15 minutes
- Earliest available times were uniformly distributed within 0-900 seconds
- 80% of type Large, 10% of type Heavy, 10% B75x
- Heading were randomly assigned to 0 or 1

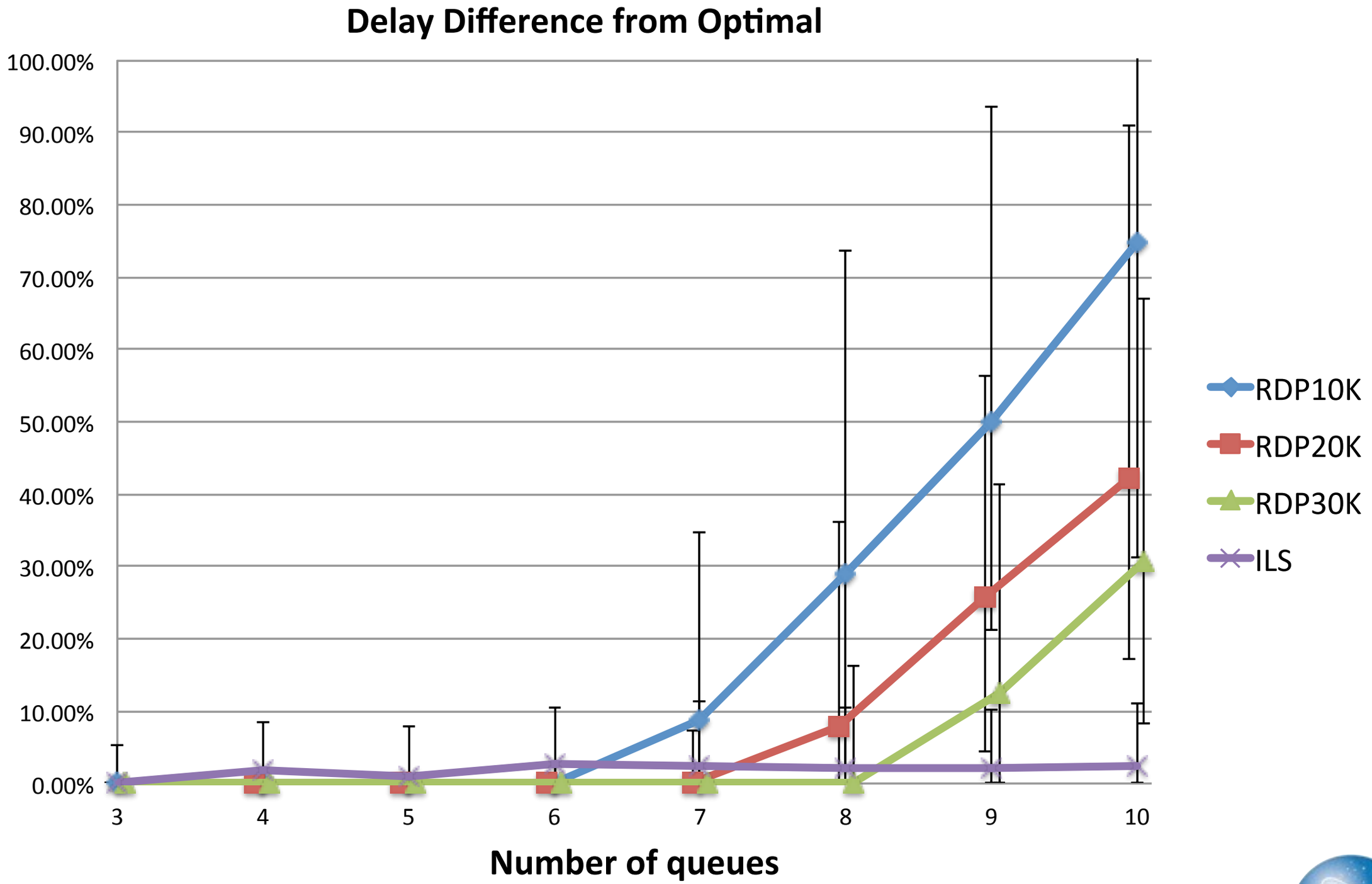
Simulation Setup

- Scenarios were generated with varying numbers of queues (from 3 to 10)
- Hundred different scenarios generated for each queue number
- Three variants of RDP algorithm: RDP10K (H=10,000), RDP20K (H=20,000), RDP30K (H=30,000)
- ILS algorithm used a value of 7 for the neighborhood parameter k

Computation times



Solution Quality



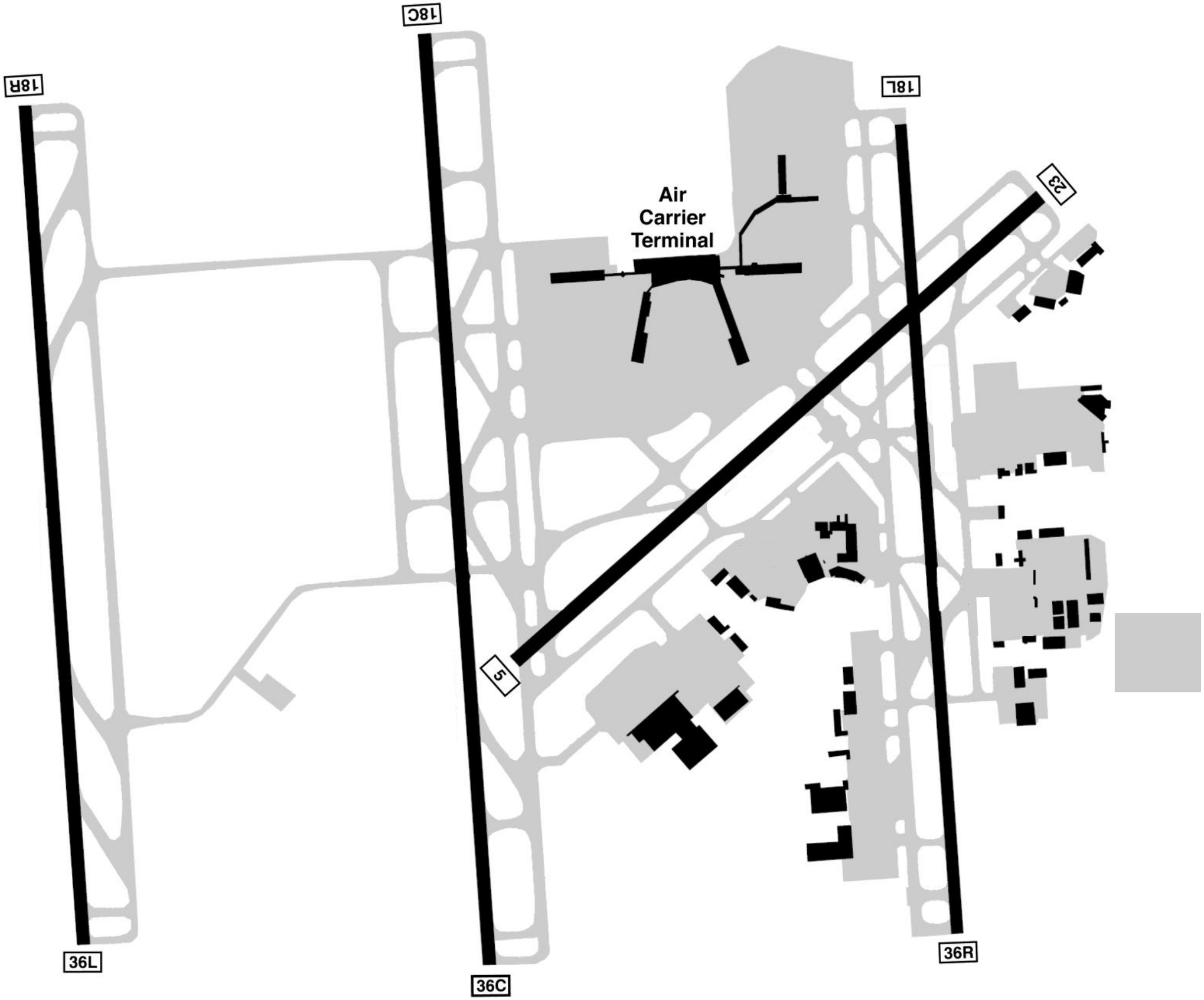
Summary: Single Runway Scheduling

- Comparative study of three algorithms:
  - Exact Dynamic Programming (EDP)
  - Restricted Dynamic Programming (RDP)
  - Insertion and Local Search (ILS)
- Simulations conducted for the east side of the Dallas/Fort Worth International Airport (DFW)
- ILS heuristics is the most suitable candidate for application in tactical surface decision support tools

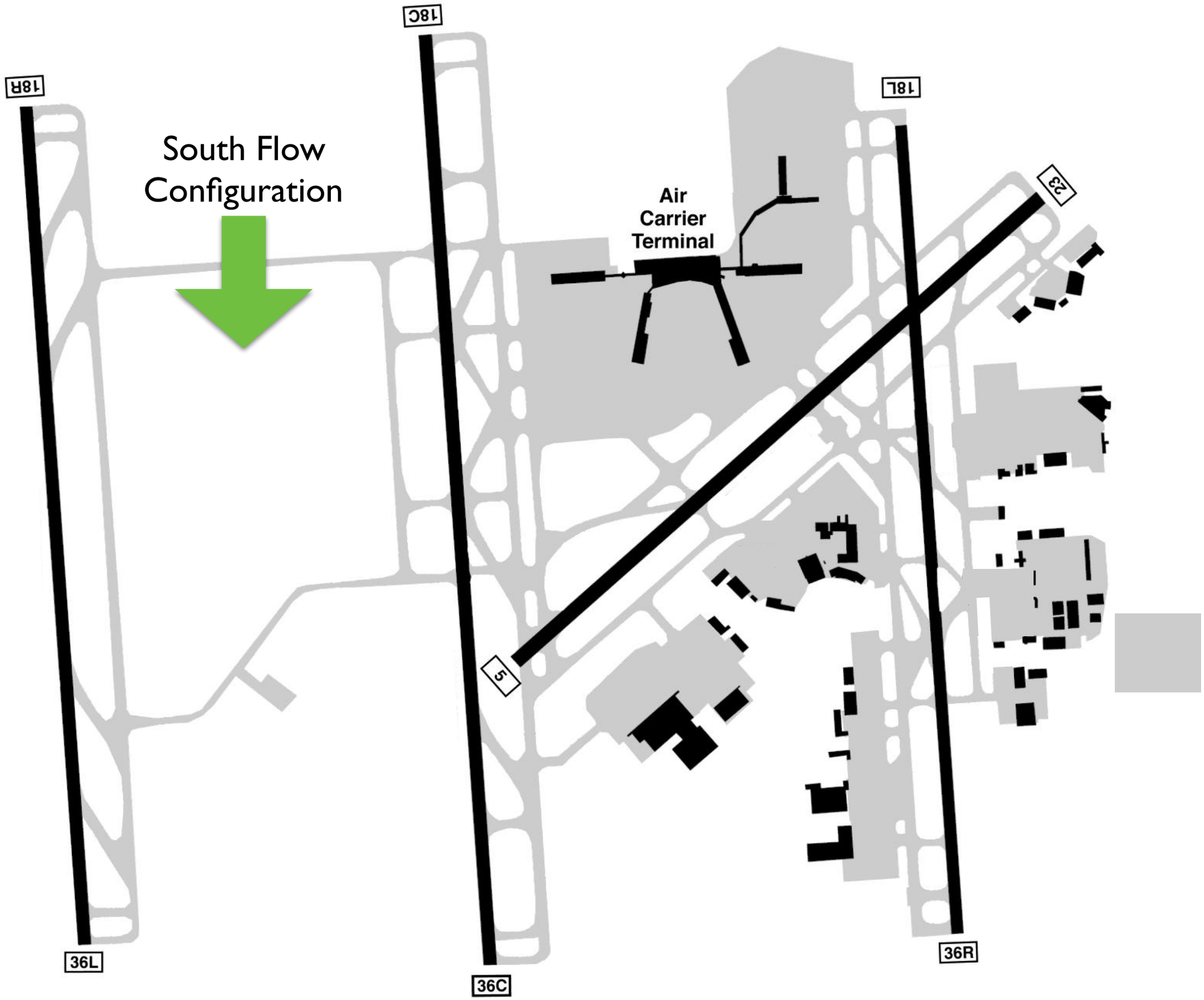
Outline

- Overview of airport surface management
- Single runway scheduling
  - One exact algorithm
  - Two heuristics-based algorithms
  - Simulation setup and results
- **Multiple runway scheduling**
  - CLT airport layout
  - Mixed Integer Linear Program Formulation
  - Simulation setup and results

Airport Layout



Airport Layout



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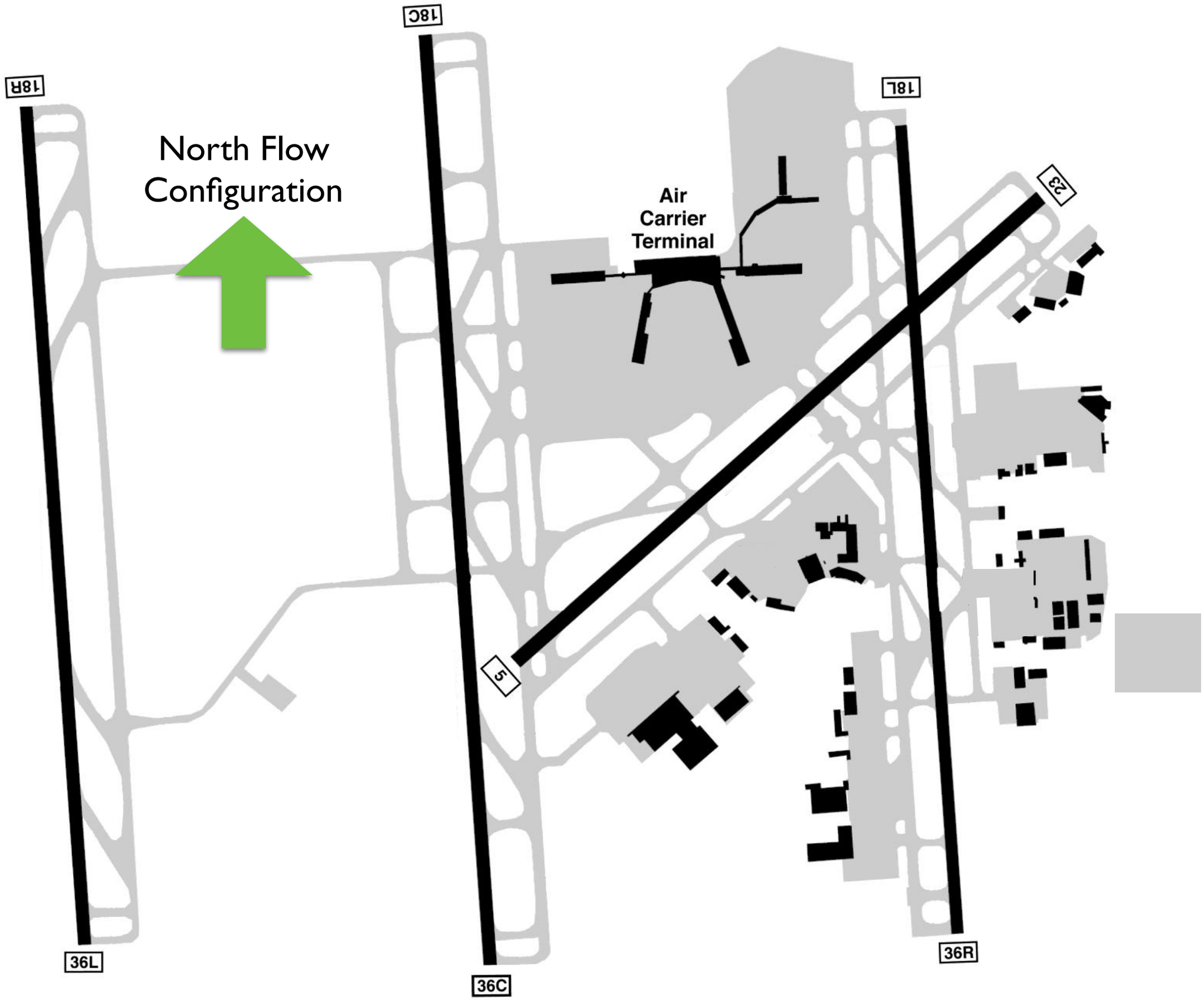

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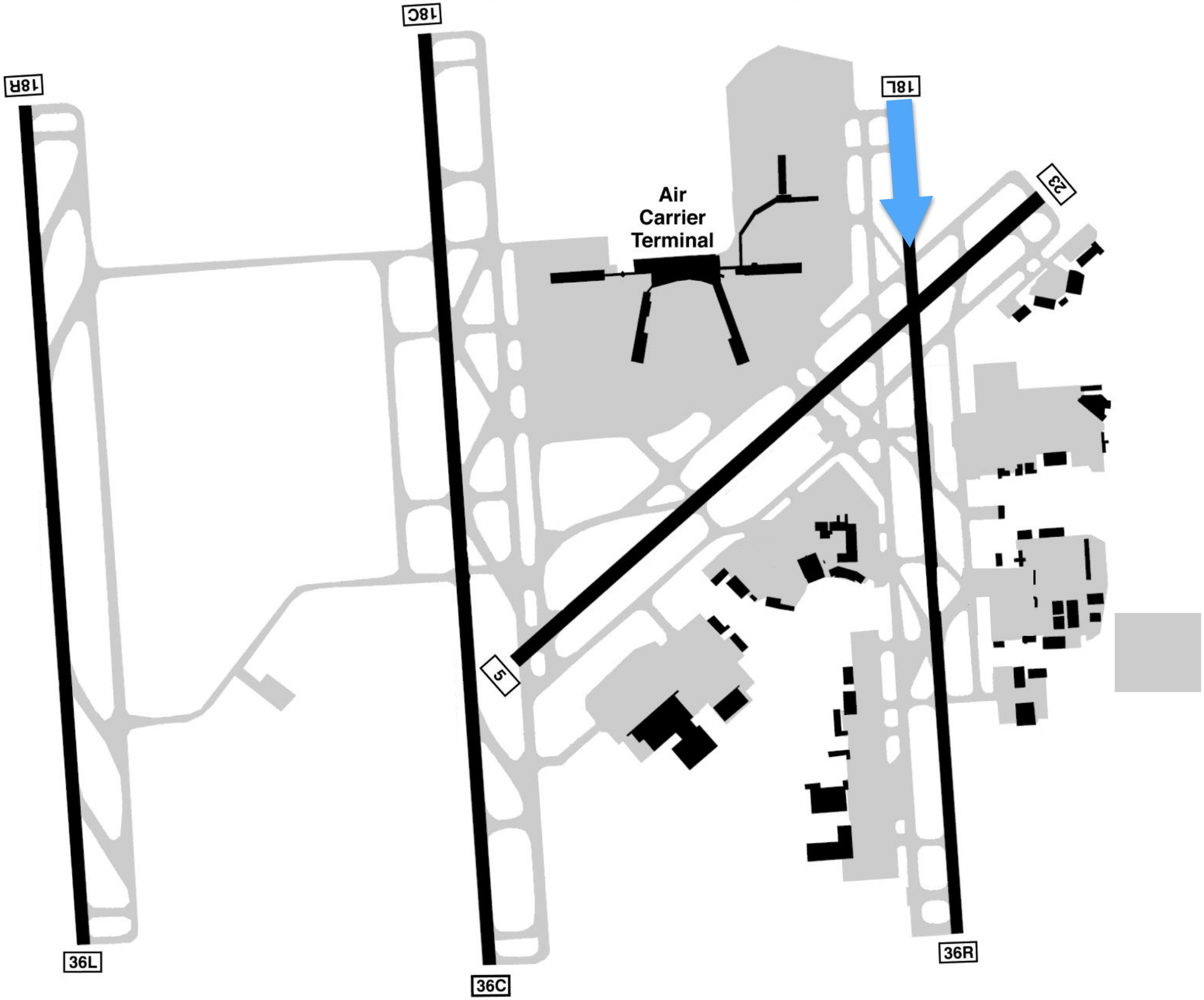

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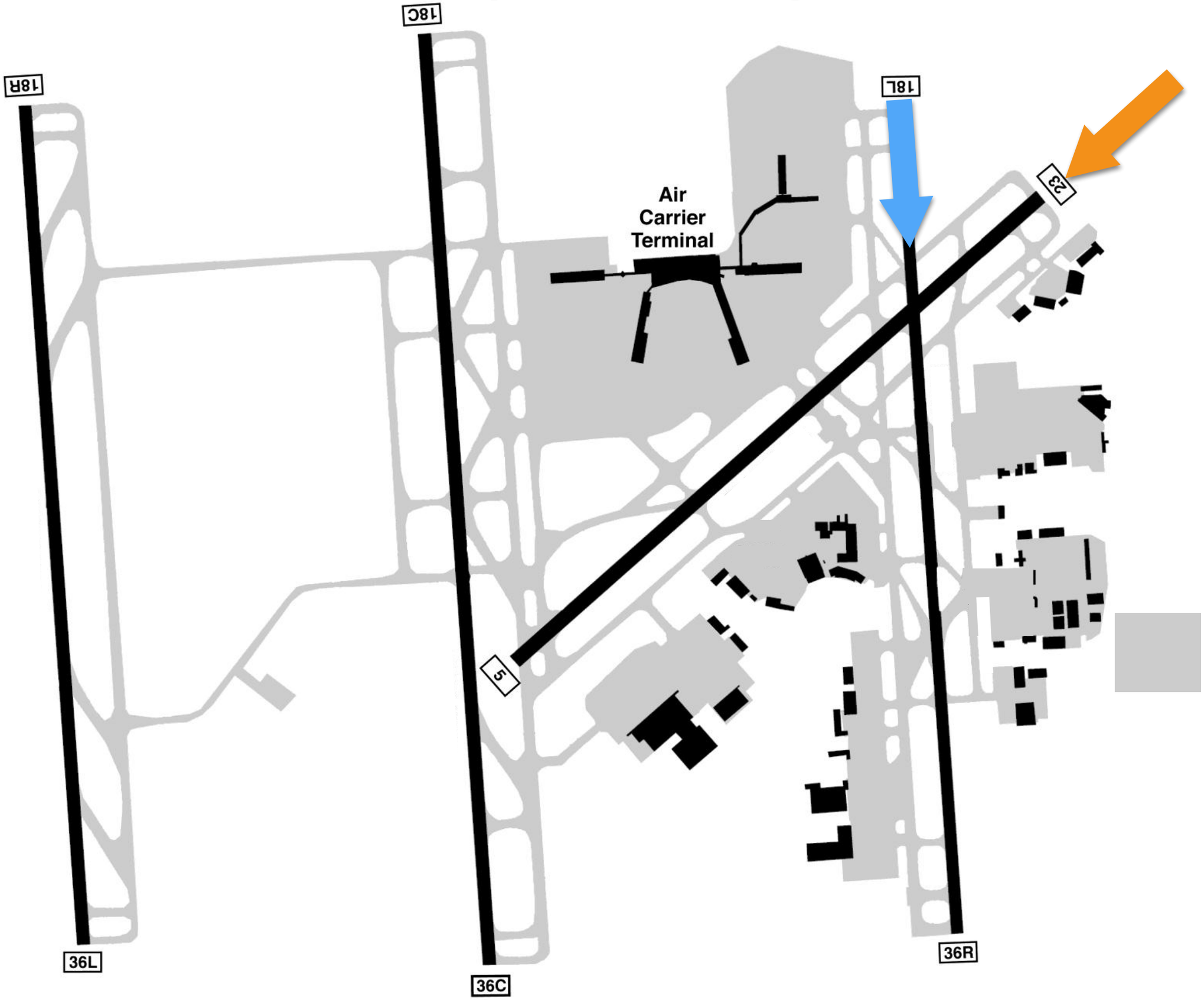

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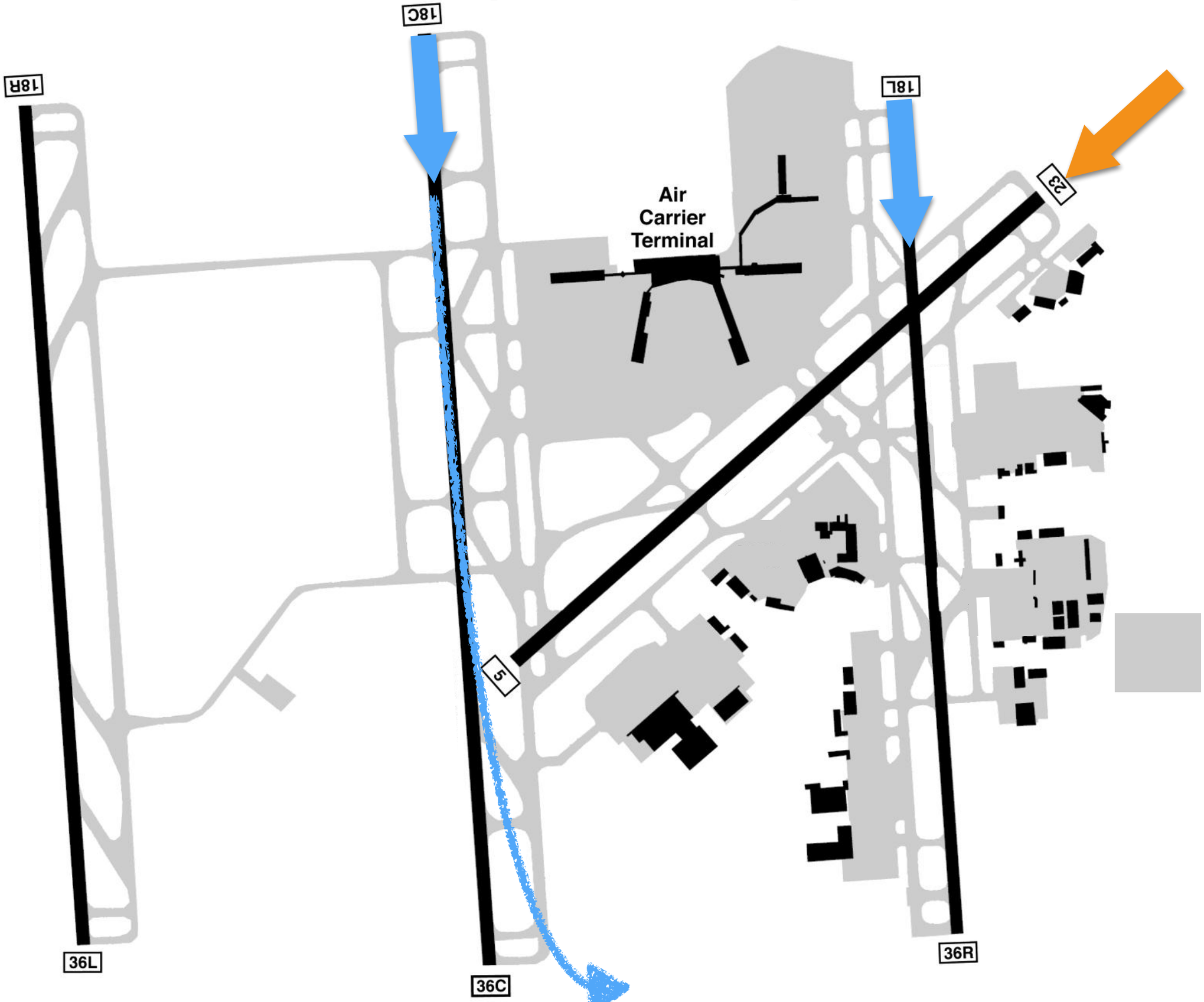

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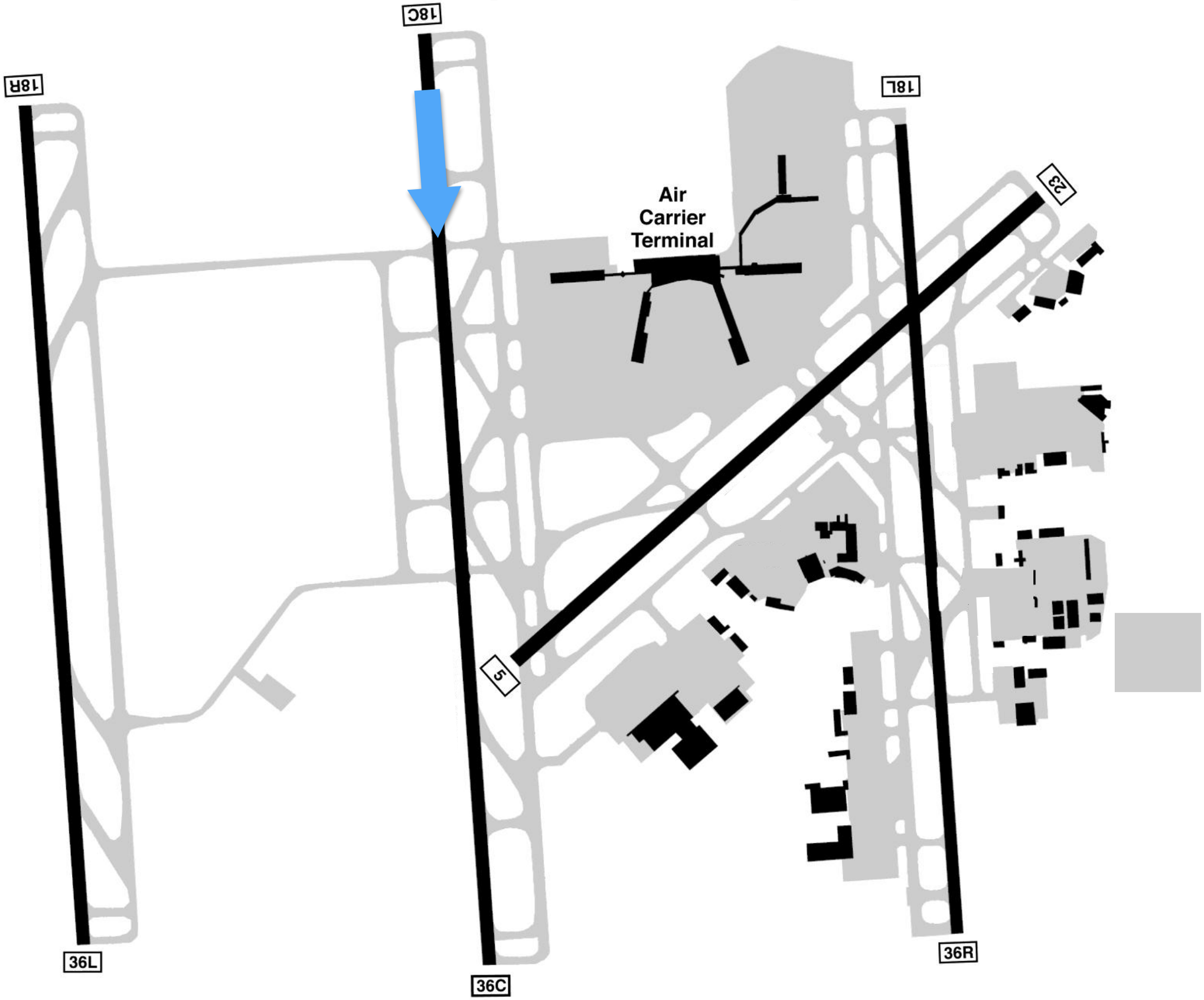

Airport Layout

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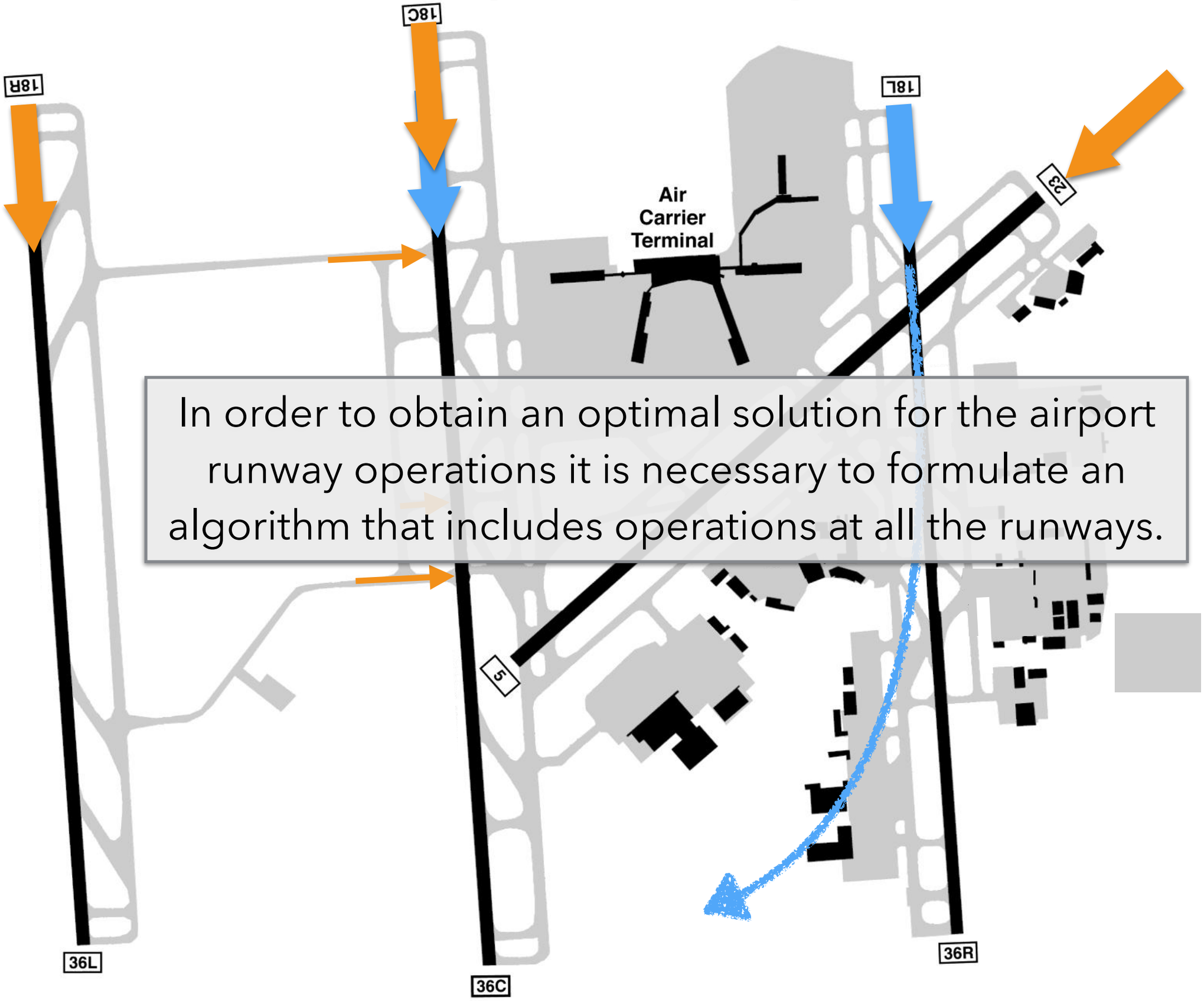

In order to obtain an optimal solution for the airport runway operations it is necessary to formulate an algorithm that includes operations at all the runways.

Runway Scheduler: Inputs

- Estimated runway queue entry times (for departures)
- Estimated runway time (for arrivals)
- Spot, runway, position and fix/exit for each aircraft
- Type (weight class) of each aircraft
- Separation requirements between pair of aircraft
- Individual time-windows of intended take-off times for departing aircraft (EDCT, CFR)

Separation Requirements

- Between departures on same runway (wake vortex and RNAV separation)
- Between arrivals and departures for mixed use runway, runway crossings and converging runway operations
- Separation between departure from parallel runways going to same fix
- Separation between departures going to same constraint fix (MIT)

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These separations are converted to time-based separations for use in the MILP

MILP Runway Scheduler

Decision Variables

- Let t_i denote the calculated time at which the aircraft uses the runway (take-off, land or cross)

- Let $Z_{i,j}$ be a binary sequencing variable

$$Z_{i,j} = \begin{cases} 1 & \text{if aircraft } i \text{ uses runway before } j \\ 0 & \text{otherwise} \end{cases}$$

MILP Runway Scheduler

Objective Function

- System Delay – cumulative waiting time of all aircraft
- Let α_i be a earliest available time

- System Delay:

$$\min \sum_{i \in F} (t_i - \alpha_i)$$

MILP Formulation

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- Linear ordering constraints : $Z_{i,j} + Z_{j,i} = 1$

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- FCFS constraints on crossing aircraft : $Z_{i,j} = 1, \text{ if } \alpha_i < \alpha_j$

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- FCFS constraints on MIT aircraft : $Z_{i,j} = 1, \text{ if } \alpha_i < \alpha_j$
- Constrained Position Shift (CPS) constraint on sequence of departures only

Simulation Setup

- Mixed operation runway with arrivals, departures and crossing traffic
- Another stream of arrivals was modeled to simulate converging runway operations
- Planning window of 15 minutes
- Number of aircraft in the scenarios was varied from 10 to 35 in increments of 5
- Hundred different scenarios generated for each aircraft count

Simulation Setup

- Earliest available times were uniformly distributed within 0-900 seconds
- Sixty percent of the traffic was chosen to be departures, 20% arrivals and 20% crossing aircraft
- 80% of type Large, 10% of type Heavy, 10% B75x
- Departure fix assigned randomly from 6 discrete choices

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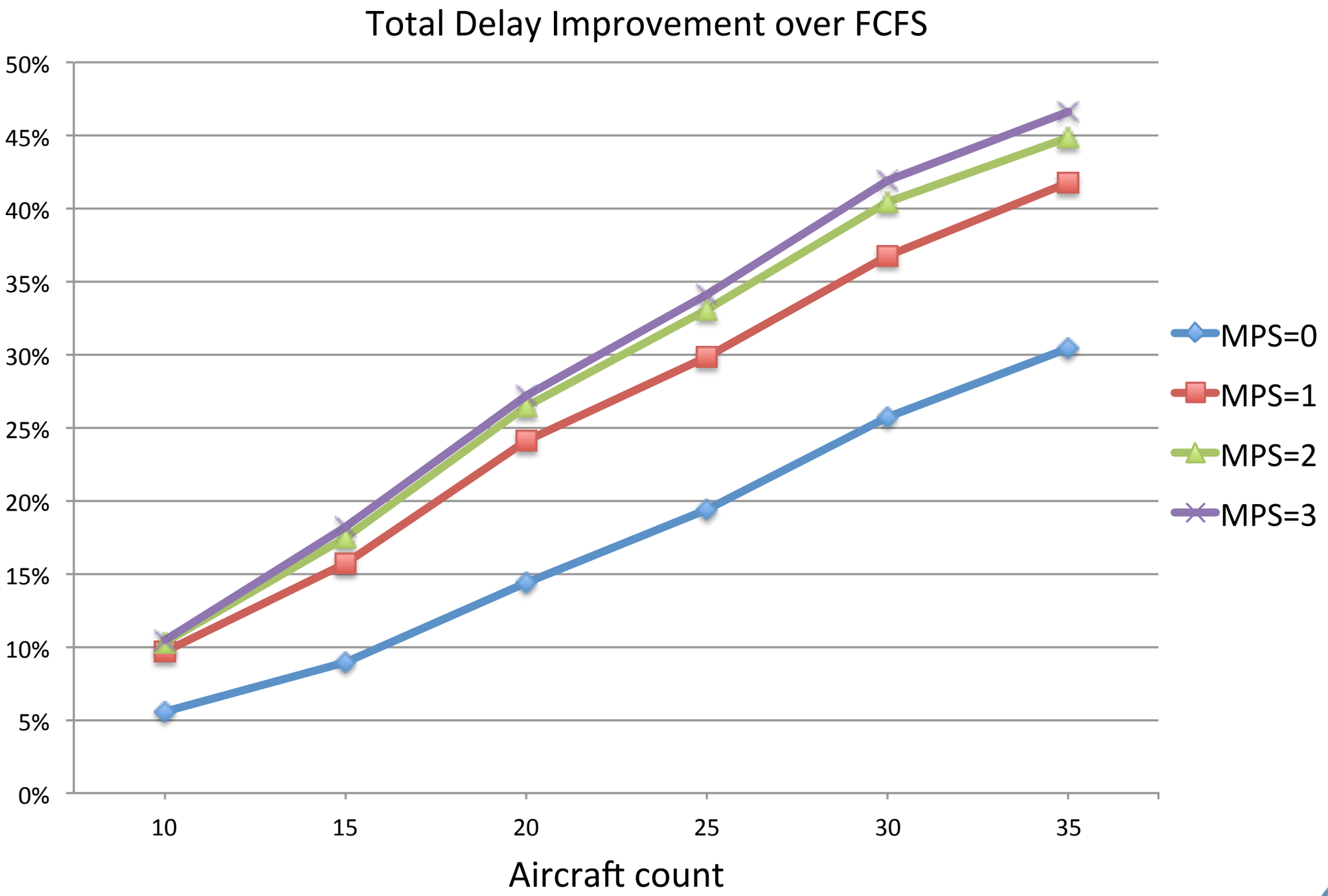
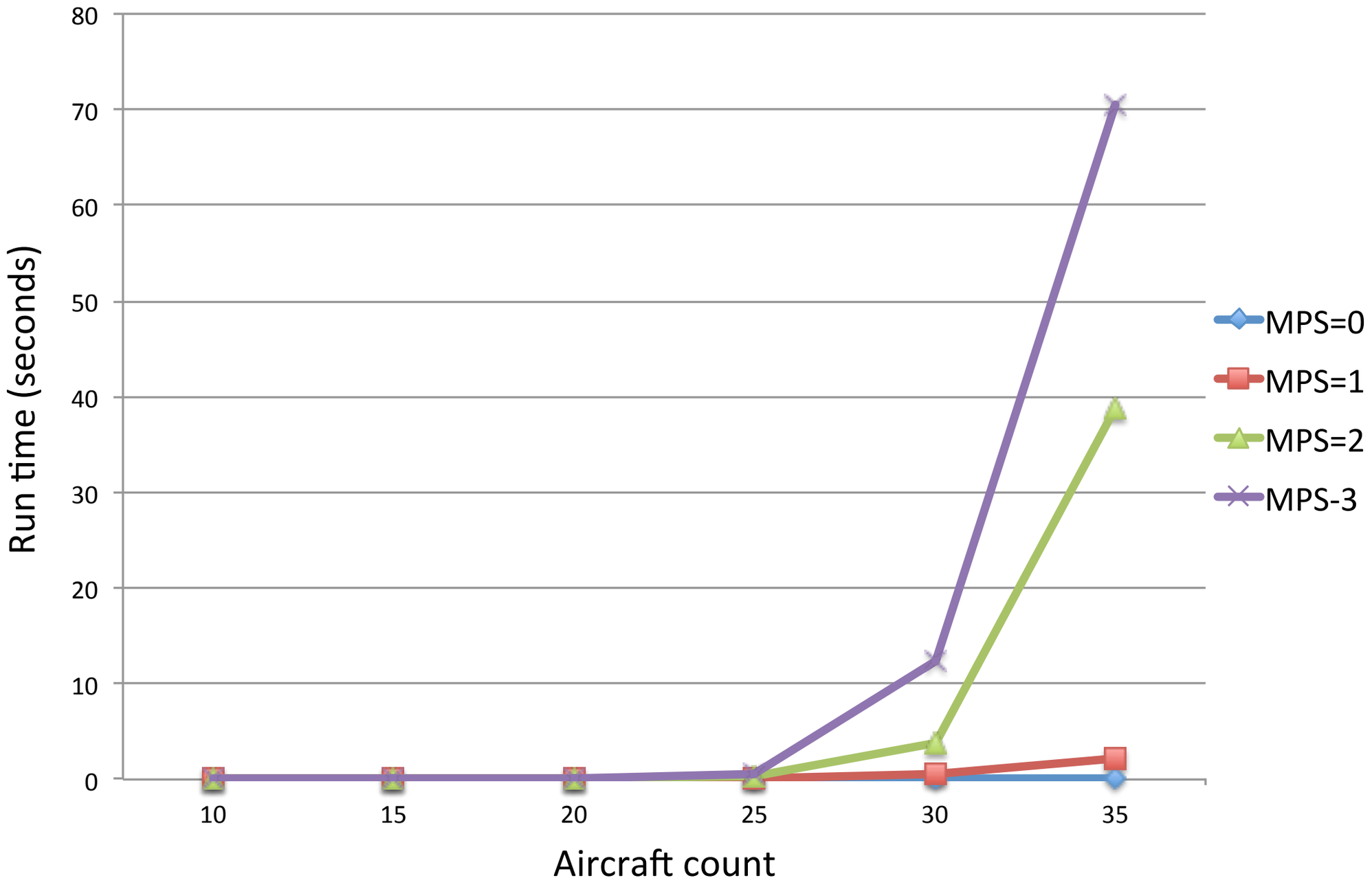
- Sixty percent of the traffic was chosen to be departures, 20% arrivals and 20% crossing aircraft
- 80% of type Large, 10% of type Heavy, 10% B75x
- Departure fix assigned randomly from 6 discrete choices
- MILP formulation is compared with a FCFS to examine the benefits of the proposed algorithm
- The MILP is solved using Gurobi

Solution Quality



Computation times



Summary: Multiple Runway Scheduling

- A MILP formulation for multiple runway scheduling
- 30% average improvement in total delay over FCFS
- Maximum position shift (MPS) parameter value of 2 is a good trade-off between solution quality and computation times
- MPS value of 0 and 1 are also good for cases with limited computational resources


NASA