Evaluating the Robustness and Feasibility of Integer Programming and Dynamic Programming in Aircraft Sequencing Optimization

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Airport Delays are Expensive

Flight delays cost many stakeholders both directly and indirectly

- **Airlines**
- **Customers**
- **U.S. Economy**

One estimate puts the cost of delay for the U.S. in 2007 at

$31.2 billion

Some strategies to reduce delay include:

- **Adding new infrastructure**
- **Increasing peak period pricing**
- **Limiting landings and takeoffs per hour**

Air Traffic Control (ATC)

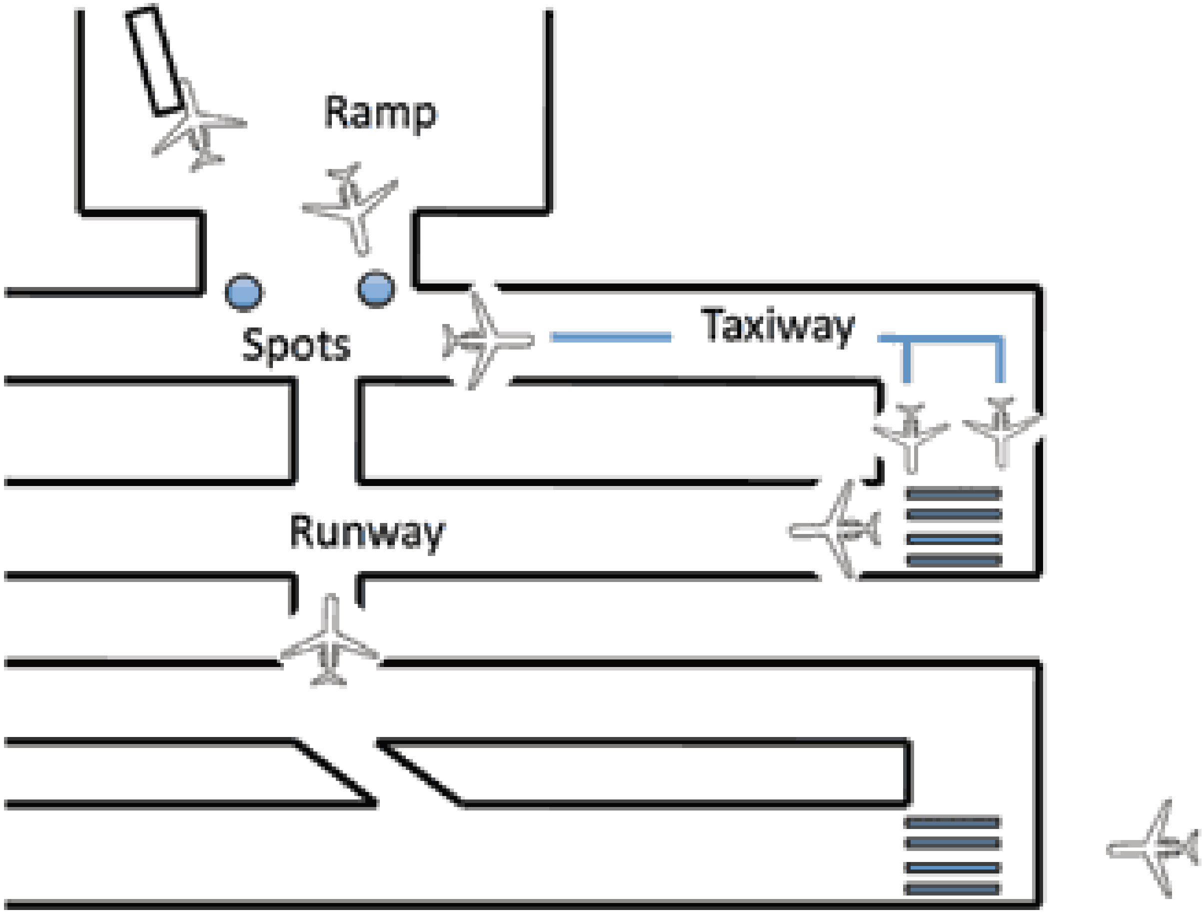

Figure 1: Generic Airport Configuration (NASA Aviation Systems Division, 2011)

Air Traffic Control (ATC)

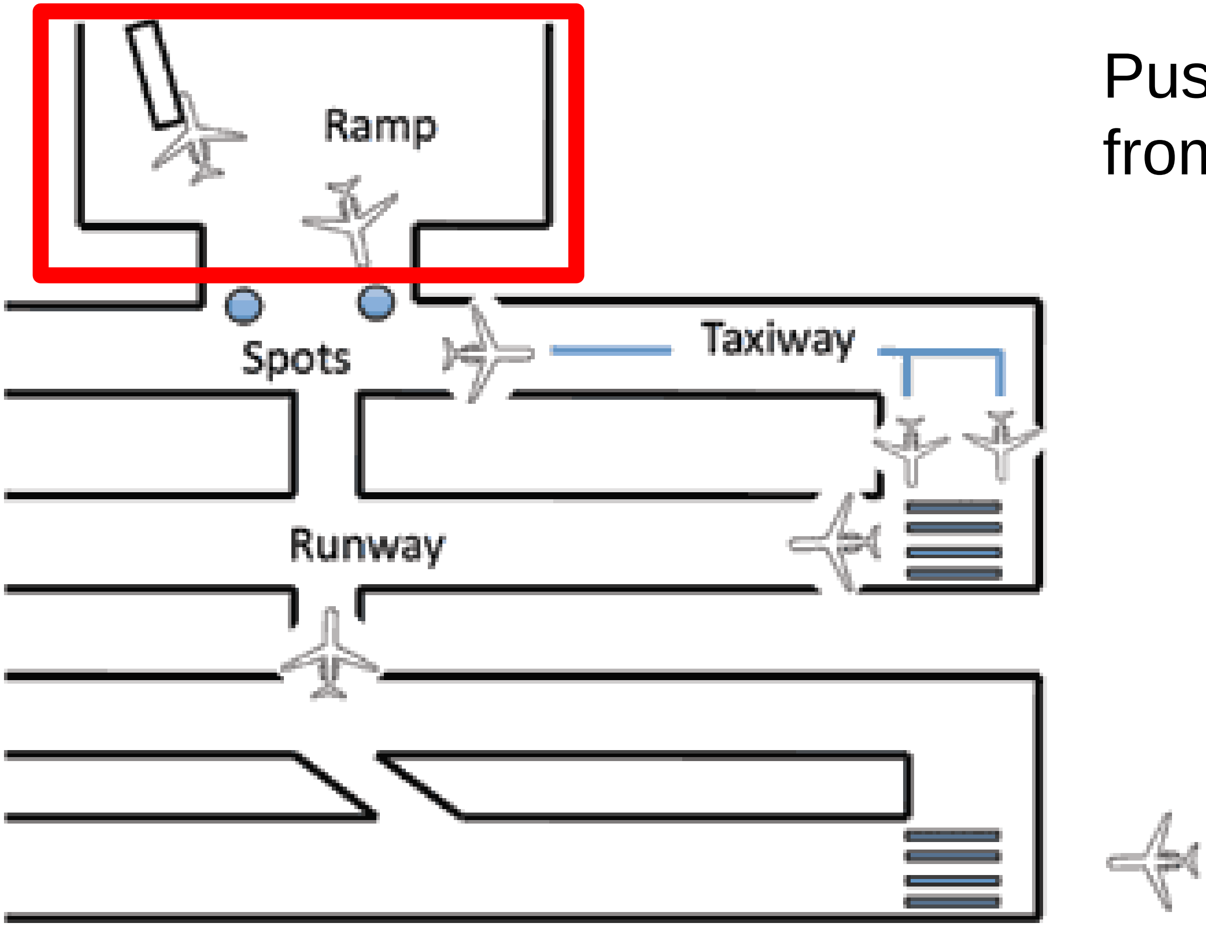

Figure 1: Generic Airport Configuration (NASA Aviation Systems Division, 2011)

Pushback
from the gate

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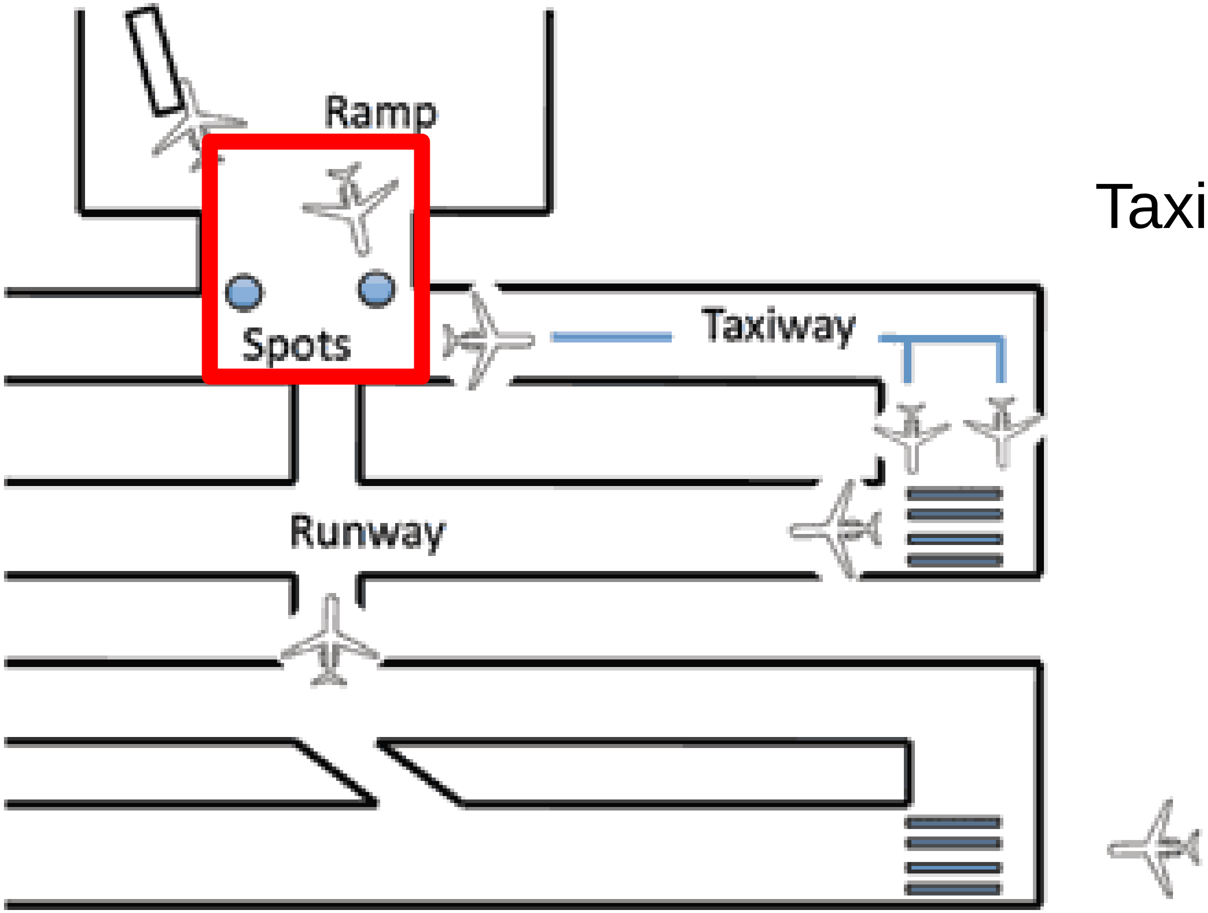

Figure 1: Generic Airport Configuration (NASA Aviation Systems Division, 2011)

Taxi to a “spot”

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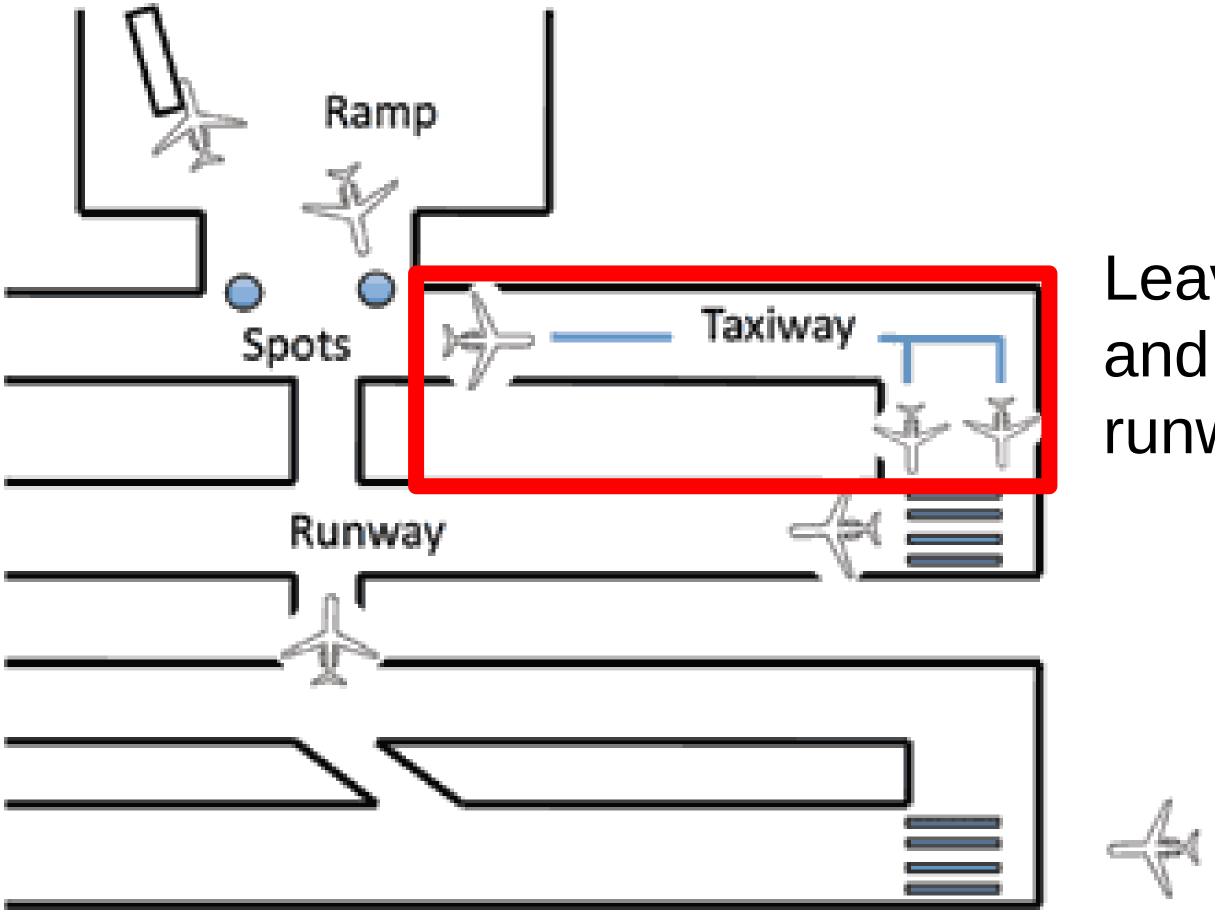

Figure 1: Generic Airport Configuration (NASA Aviation Systems Division, 2011)

Leave the spot and taxi to a runway queue

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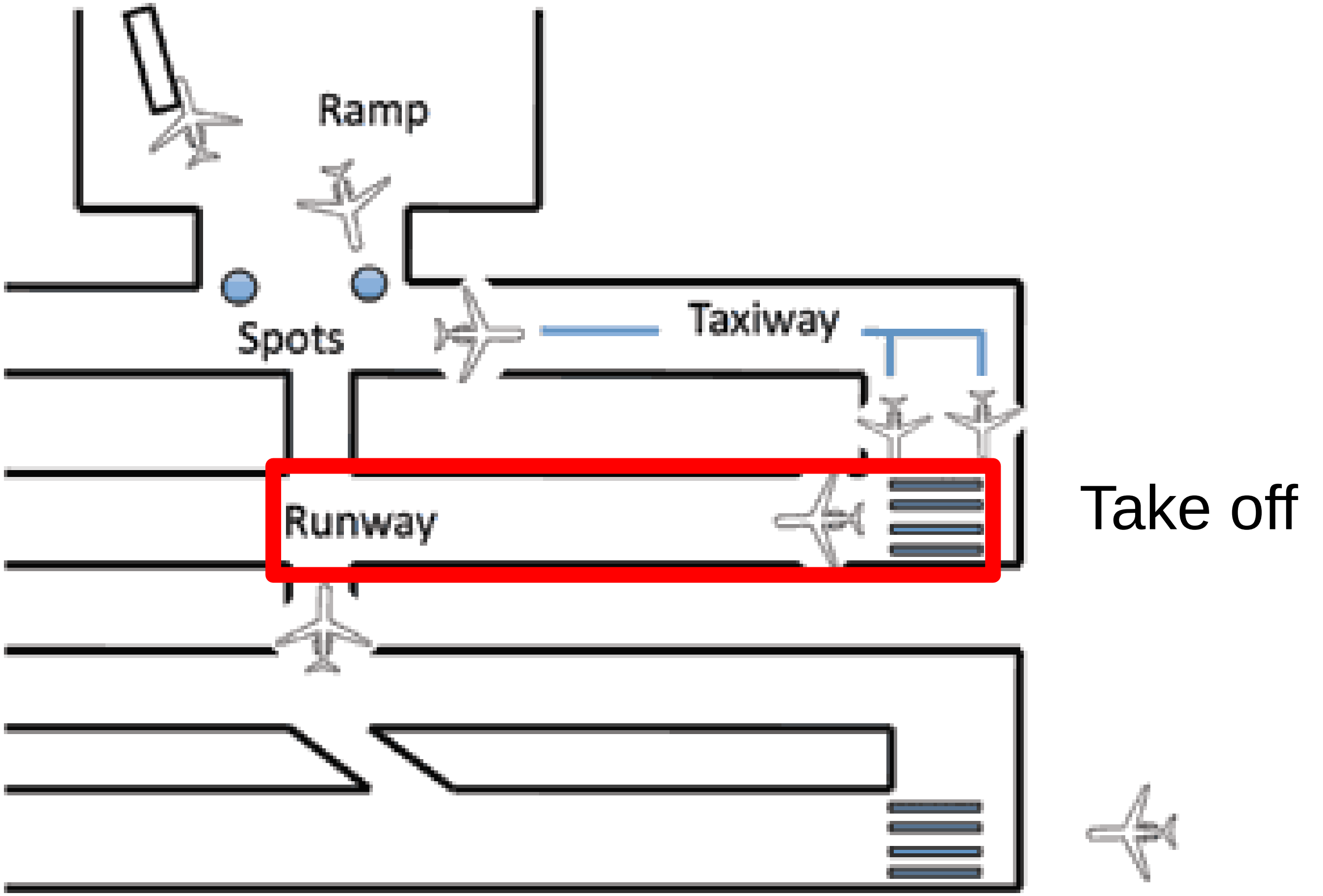

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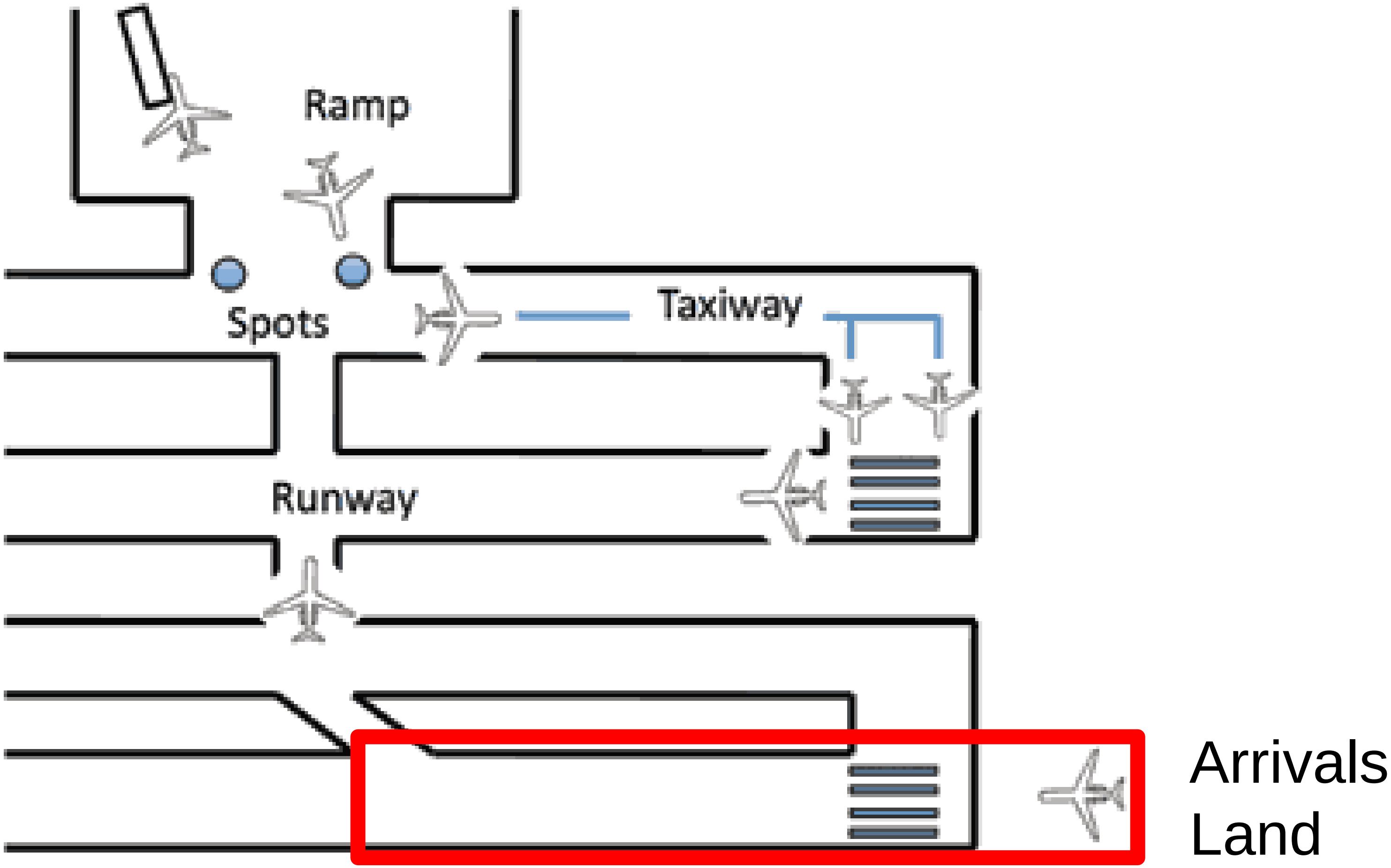

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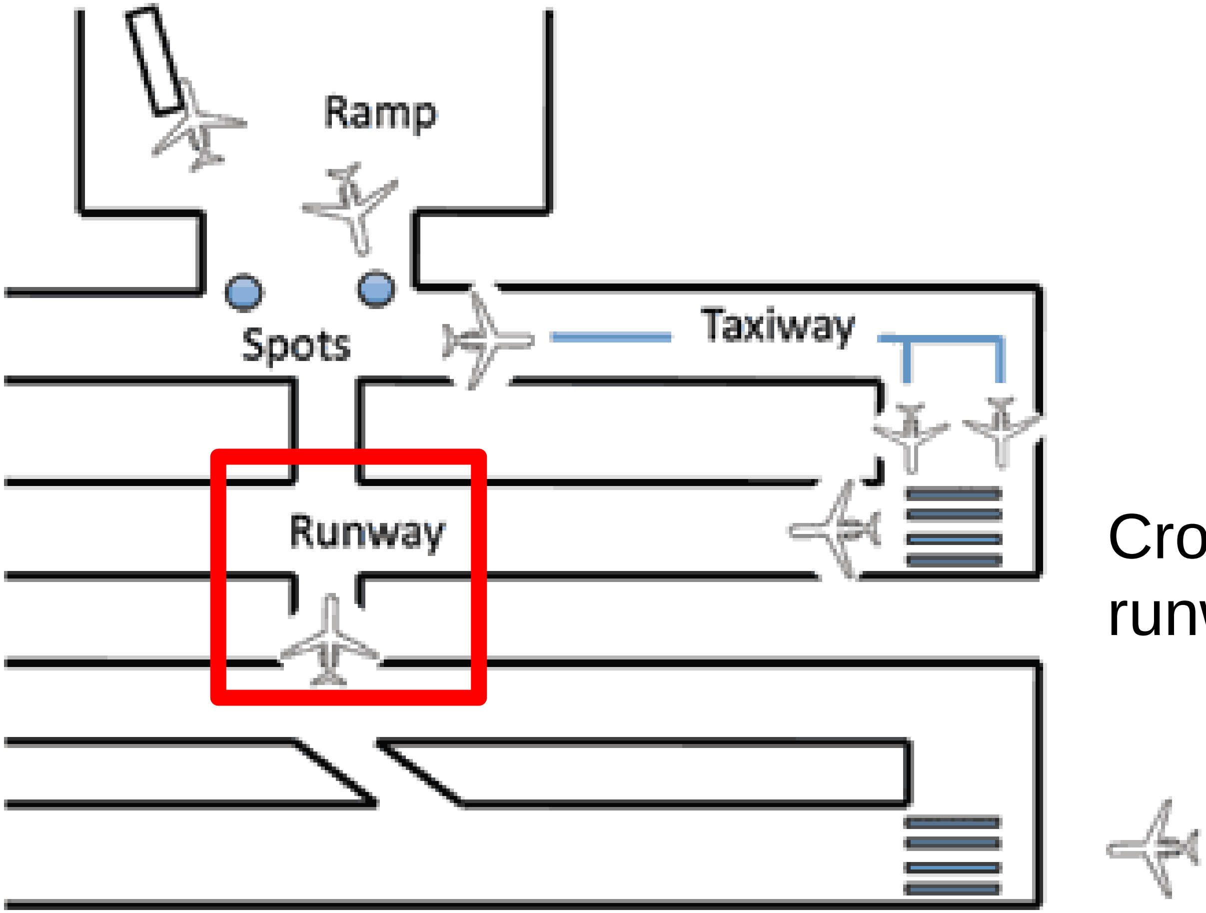

Figure 1: Generic Airport Configuration (NASA Aviation Systems Division, 2011)

Cross the runway

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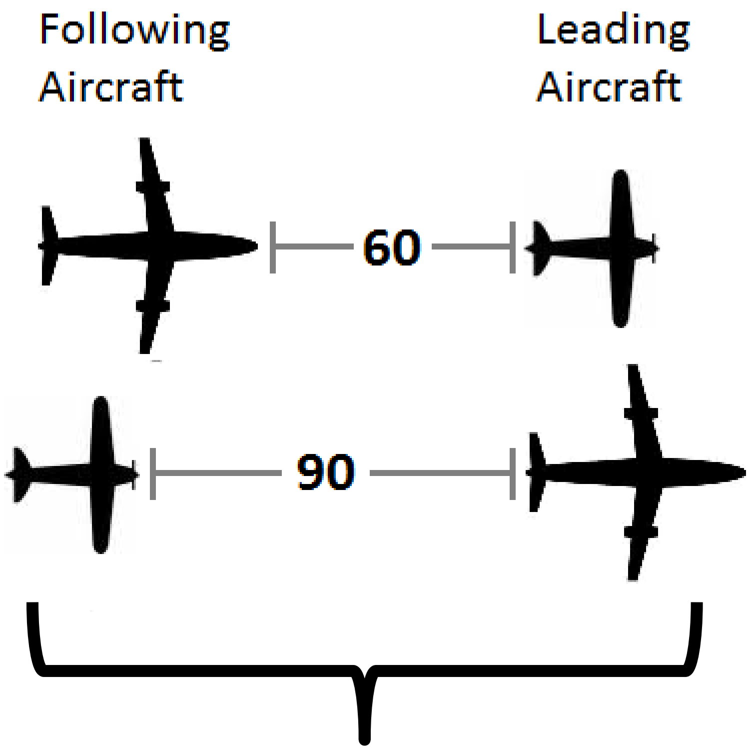
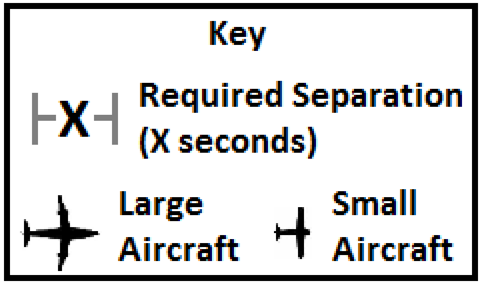
Separation Requirements Between Takeoffs





Delay Benefits of
Re-sequencing

		Following		
		Small	Large	Heavy
Leading	Small	60	60	60
	Large	90	60	60
	Heavy	120	120	90

Separation times in seconds

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Methods to Reduce Delay

1) Re-sequencing

   Reduces delay

2) Metering- holding aircraft until they can taxi unimpeded

   Reduces fuel burn and congestion on taxiways

Project Goal

Compare the feasibility of the Mixed Integer Linear Programming (MILP) and Dynamic Programming (DP) methods and the robustness of the solutions when stochastic variables were added into the optimization problem.

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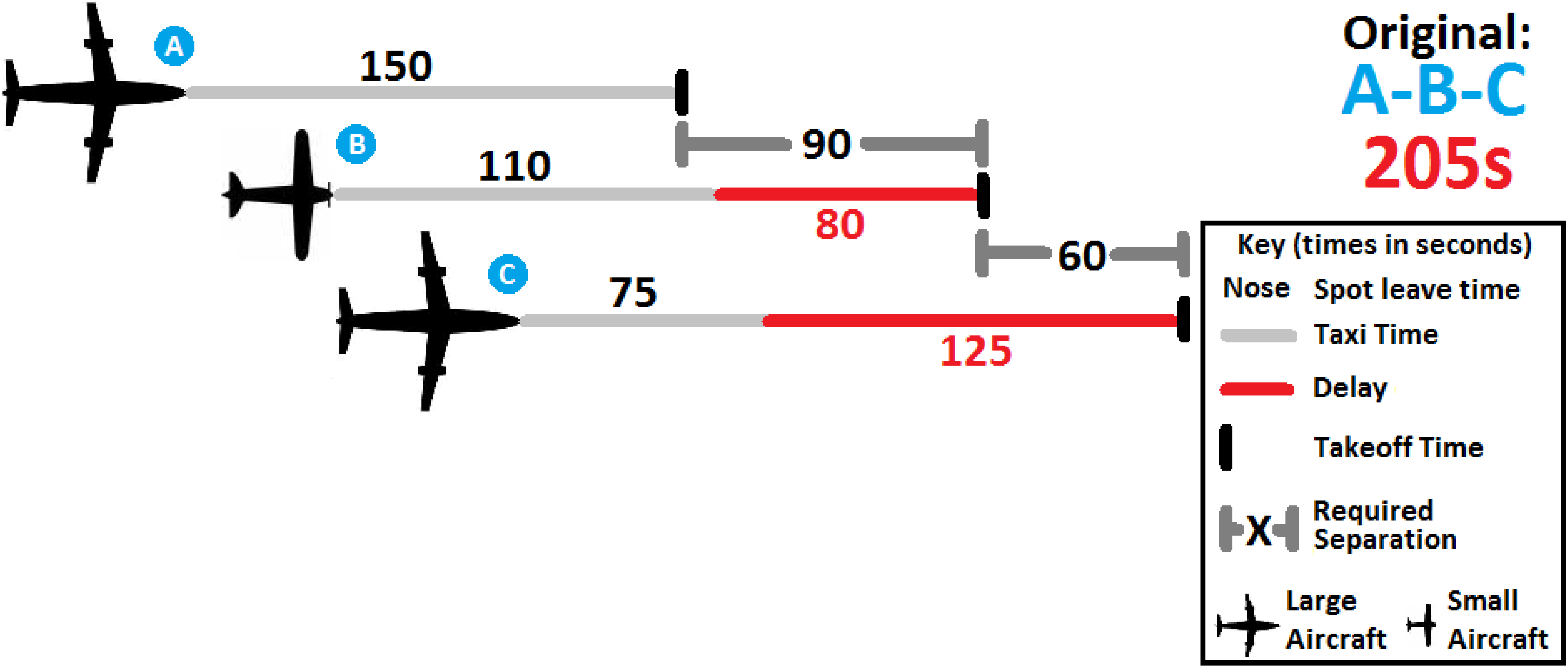
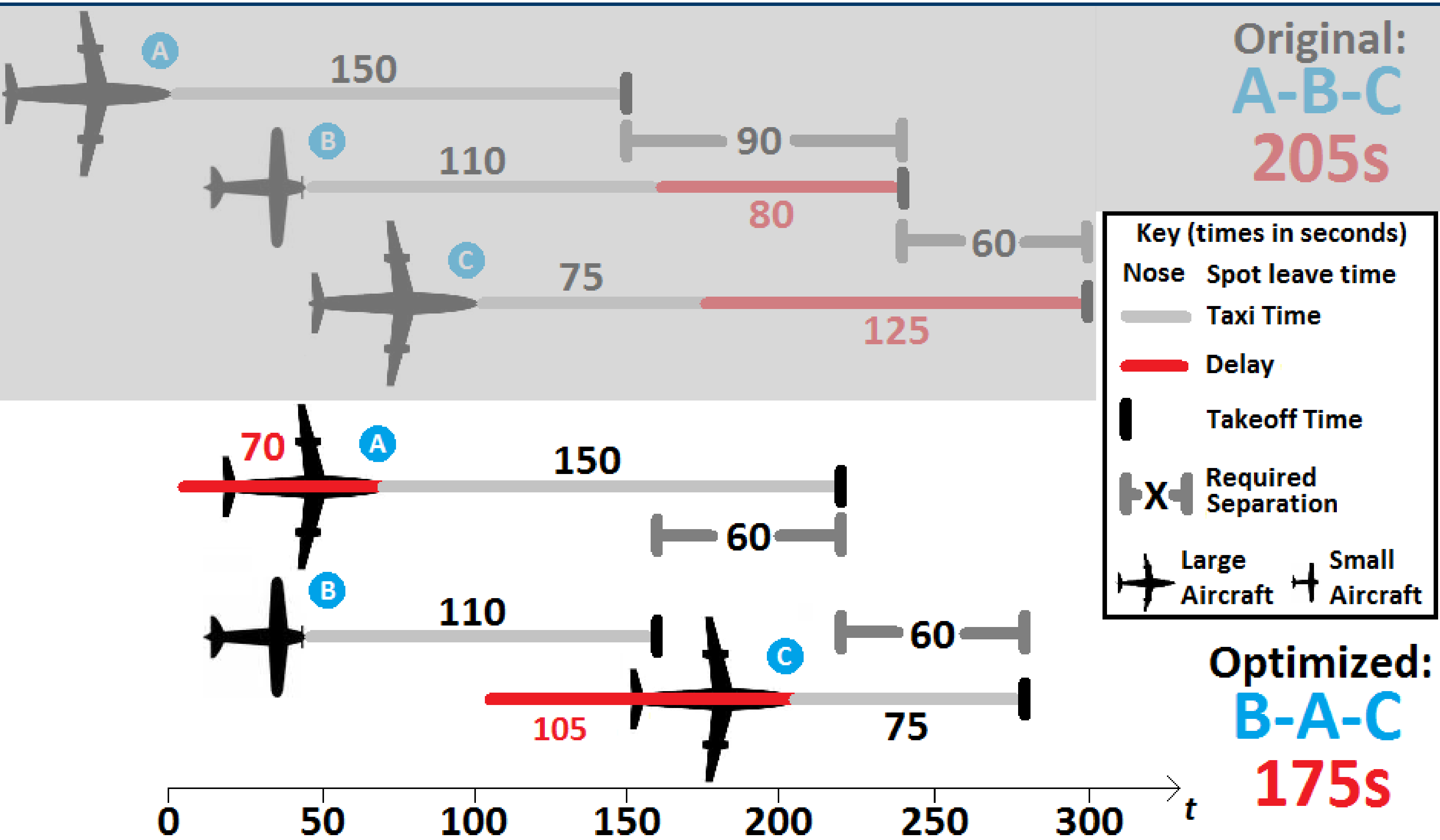
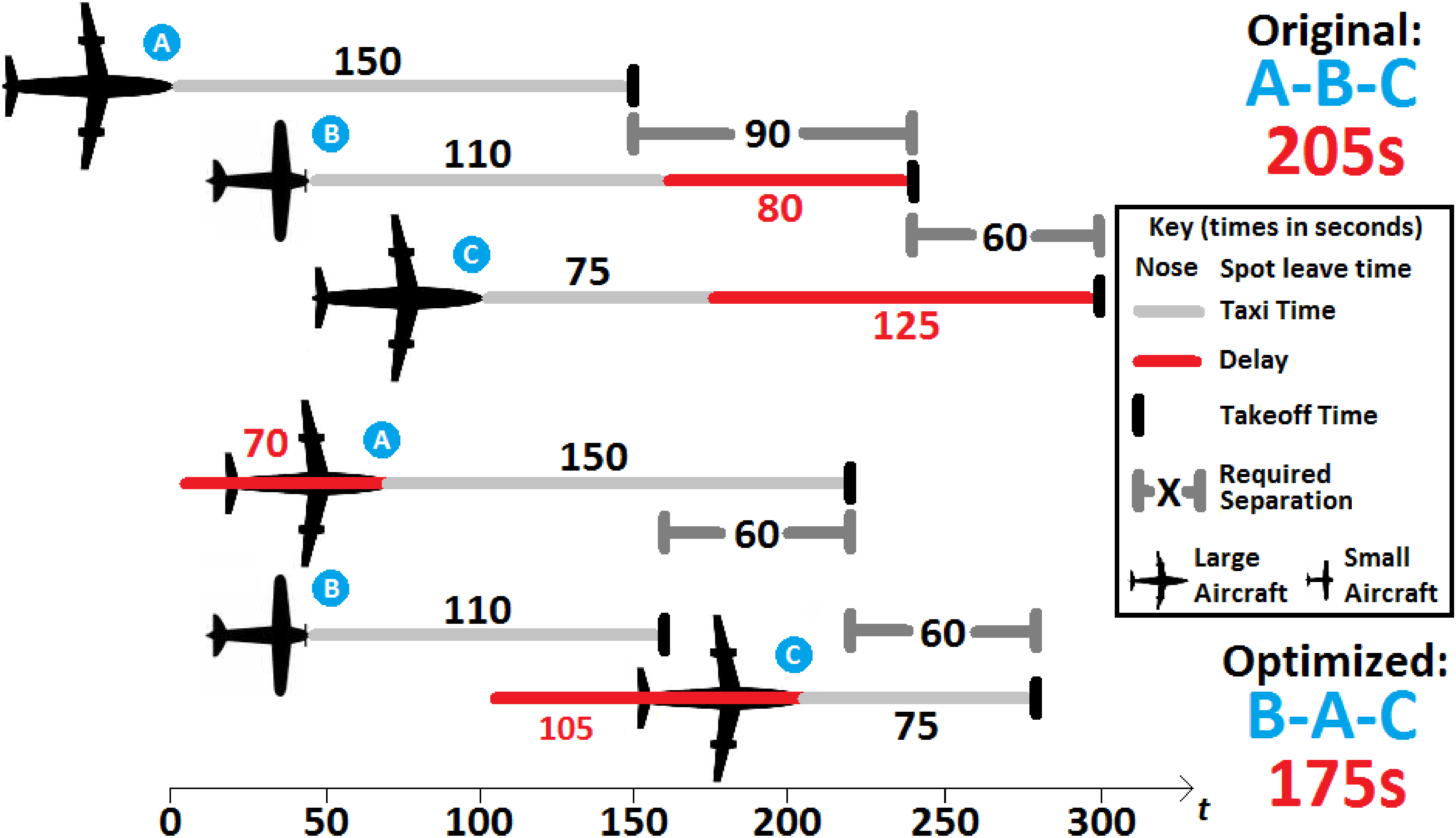
Optimization



Optimization



Optimization



Optimization Formulation

Objective:

Minimize departure delay

Constraints:

An aircraft cannot take off before it is ready

Separation times are not violated

Constrained Position Shifting (CPS) is obeyed

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Methodology

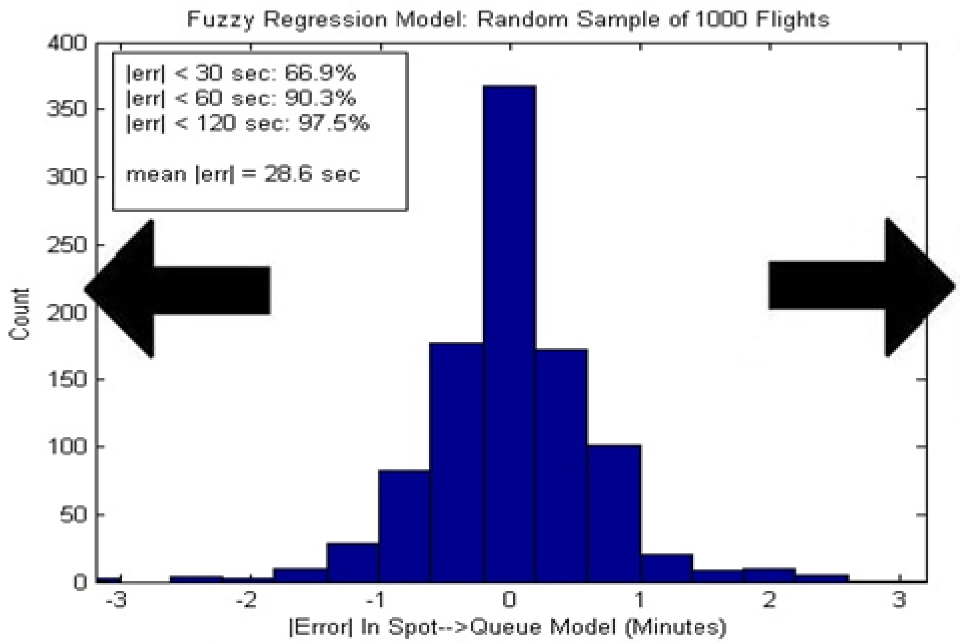
Unoptimized Schedule

+

Randomly Perturbed Taxi Times

=

New Schedule #1



Triangular Distribution Model for Taxi Time Uncertainties

Optimized Schedule

+

Randomly Perturbed Taxi Times

=

New Schedule #2

Repeat both of these for 500 iterations

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Measuring Robustness and Feasibility

Robustness in stochastic situations

- **Departure delay comparison**
- **Sequence change**
- **Separation time violations**

Operational feasibility in real-time applications

Running times measured on a Dell desktop with:

- **Linux**
- **4 dual-core processors**
- **4GB RAM**

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Mixed Integer Linear Programming (MILP)

- Linear Programs plan activities by solving for a set of variables to minimize or maximize an *objective function* while also obeying certain constraints

- A MILP is a Linear Program that has at least one integer constraint. This is the case for the traffic optimization in order to determine the sequence of the aircraft

- Cannot solve for a full day’s worth of data (~400 aircraft)

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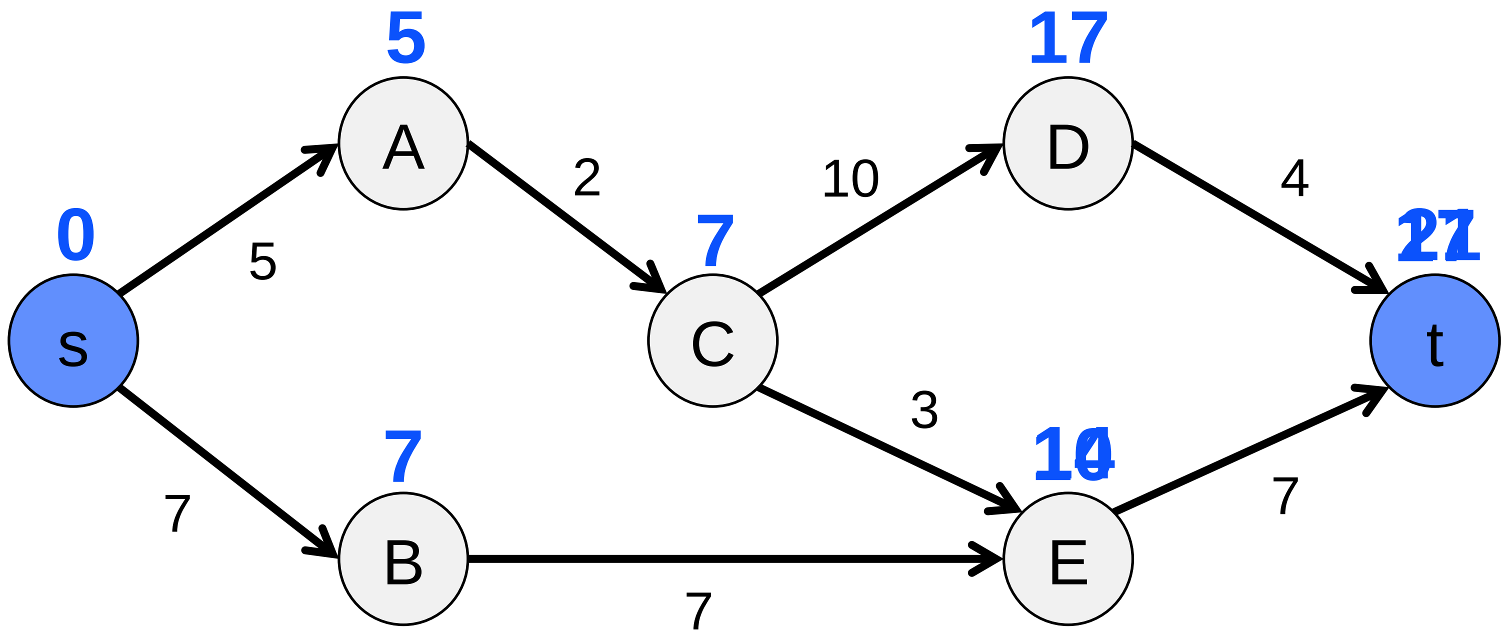
Dynamic Programming

Breaks a problem down recursively until reaching the simplest sub-problem, then iteratively solves the problem step by step until the entire problem is solved.



The shortest path from s to t is A-C-E with a cost of 17

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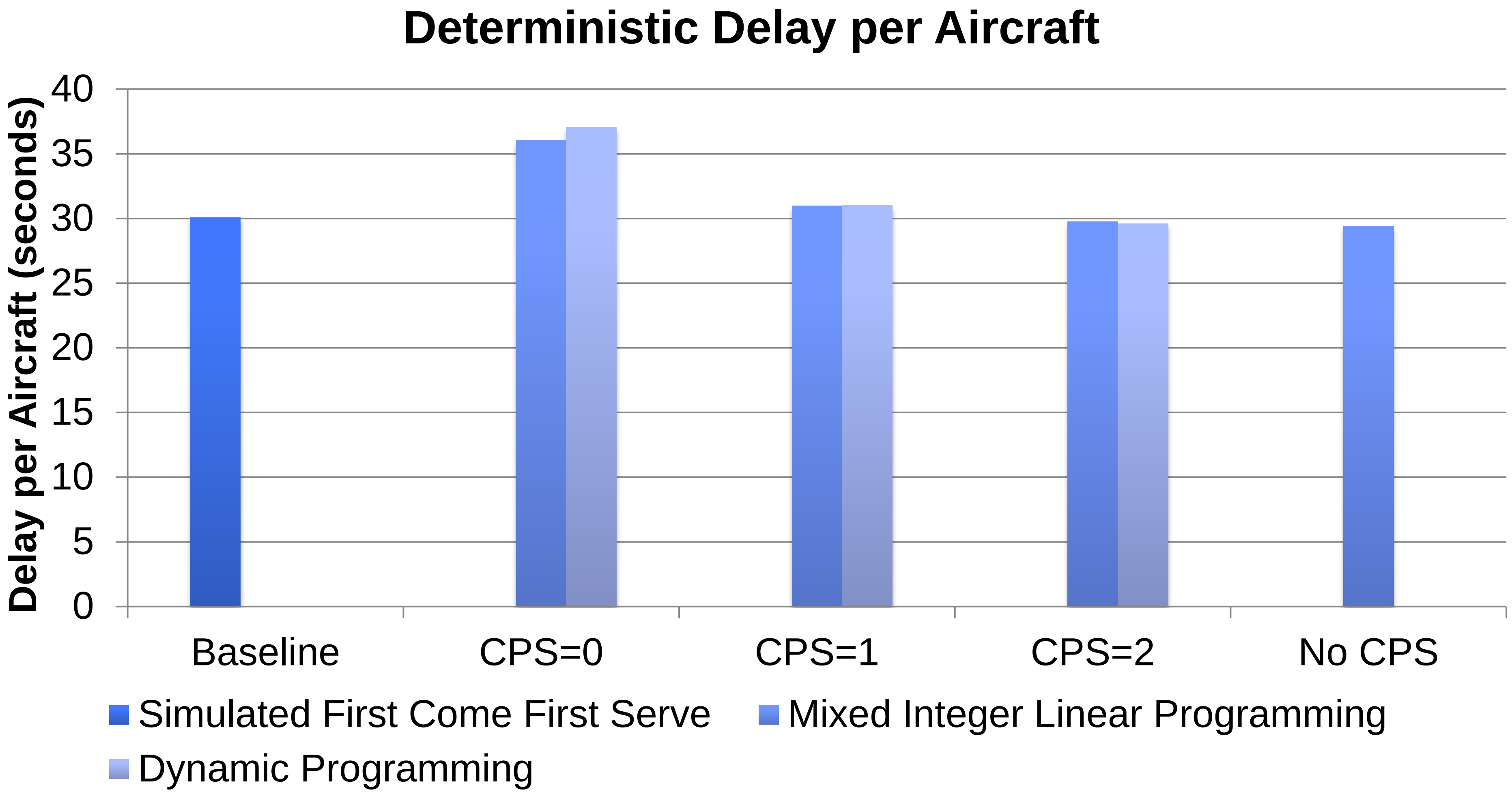
Departure Delay Results



* CPS = Constrained Position Shifting

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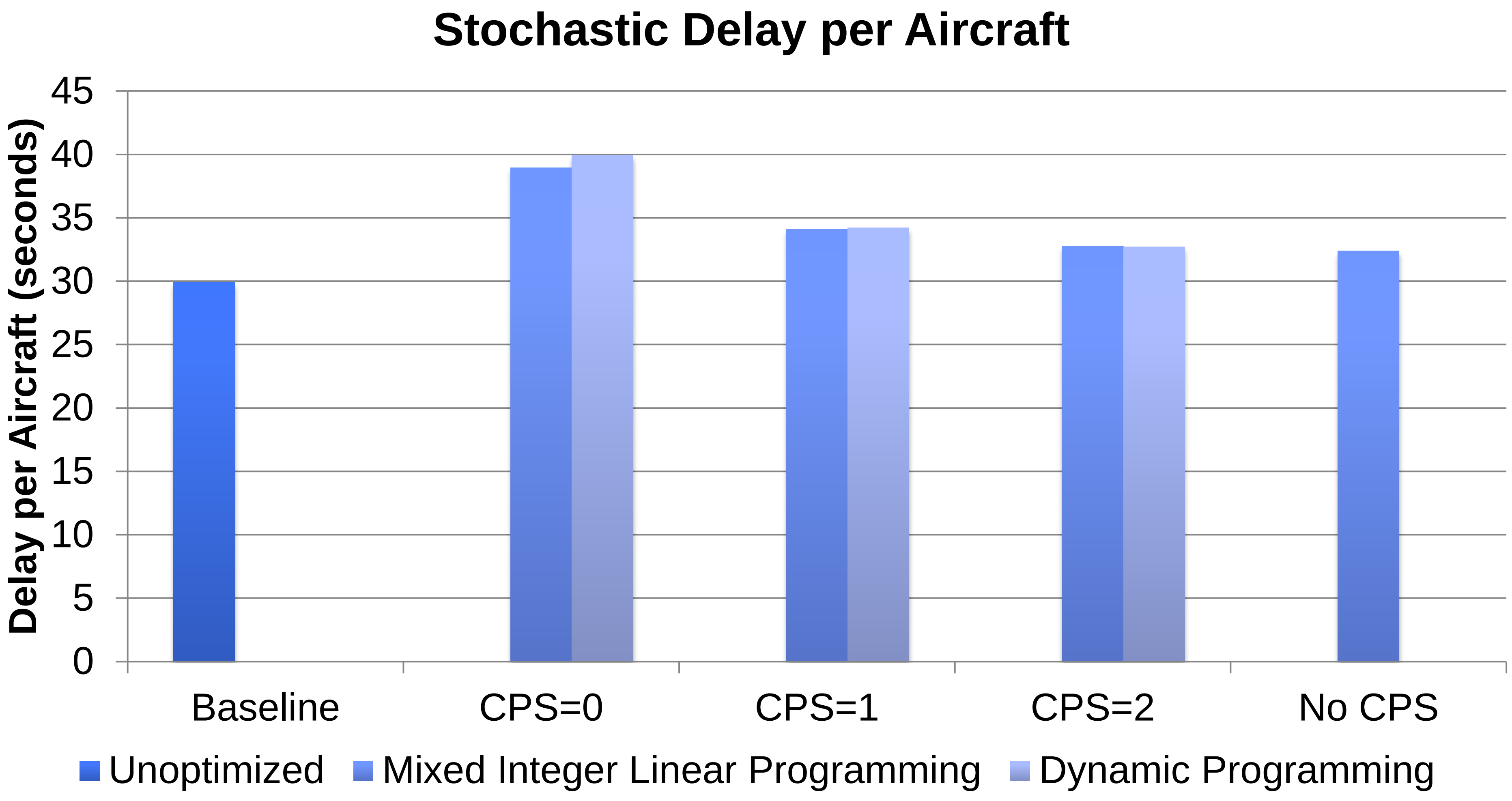
Departure Delay Results (cont.)



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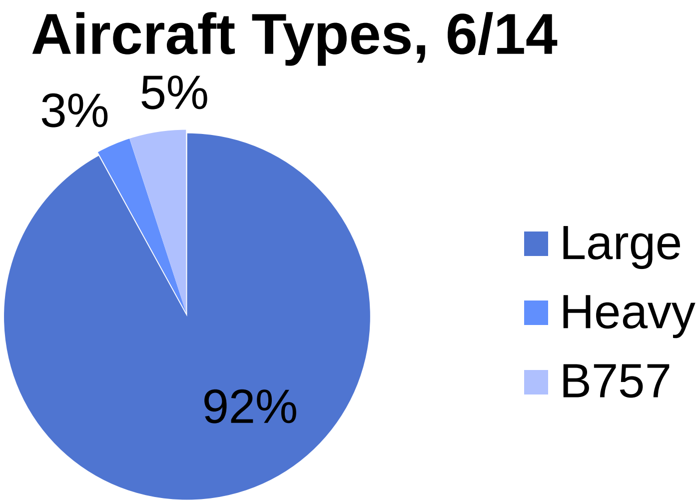
Timing Results

Method	Avg. Running Time
Mixed Integer Linear Programming	45 seconds
Dynamic Programming, CPS=0,1	< 1 second
Dynamic Programming, CPS=2	30 seconds

* CPS = Constrained Position Shifting

Limitations



Data

- Lack of demand
- Missing data
- Homogeneous aircraft mix

Methods

- Both the Dynamic Programming and Mixed Integer Linear Programming are heuristics

Results

- Arrival crossings not considered

Conclusions

DFW could achieve lower departure delay by not holding aircraft longer than necessary at the runway

CPS needs to be high enough for the deterministic optimizations to improve on Simulated FCFS

Our deterministic optimizations complete in a reasonable amount of time, but are not robust enough for real-world situations

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Future Work

Add in arrival crossings

Include priority departures

Execute second optimization at the runway

Consider other stochastic variables

- **Adherence to separation times**
- **Spot ready time calculations**

Explore different runway layouts

Develop stochastic optimization algorithms

Acknowledgements

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Our project site, Lincoln Laboratory

Members from Group 43

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Mixed Integer Linear Programming Difficulties

Computationally intractable on a full day's worth of flights (~400 aircraft)

Necessities:

- **Split data into smaller time windows, called bins**
- **Obey separation requirements at runway**
- **Obey constrained position shifting (CPS) at spot**

Problem:

- **Differing unimpeded taxi times can cause the optimization to be unaware of both the spot and runway sequence causing the requirements to not be met**

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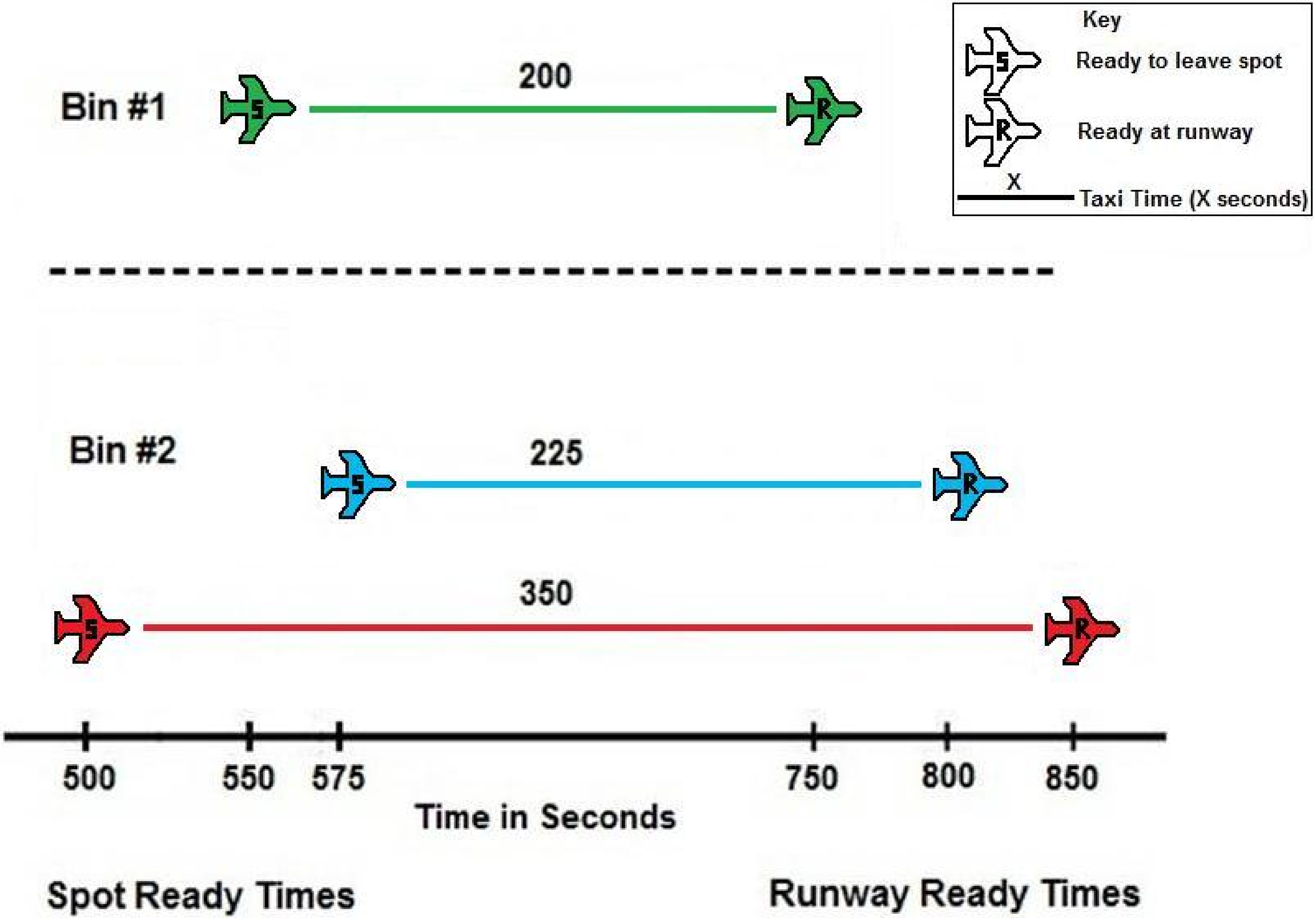
Binning



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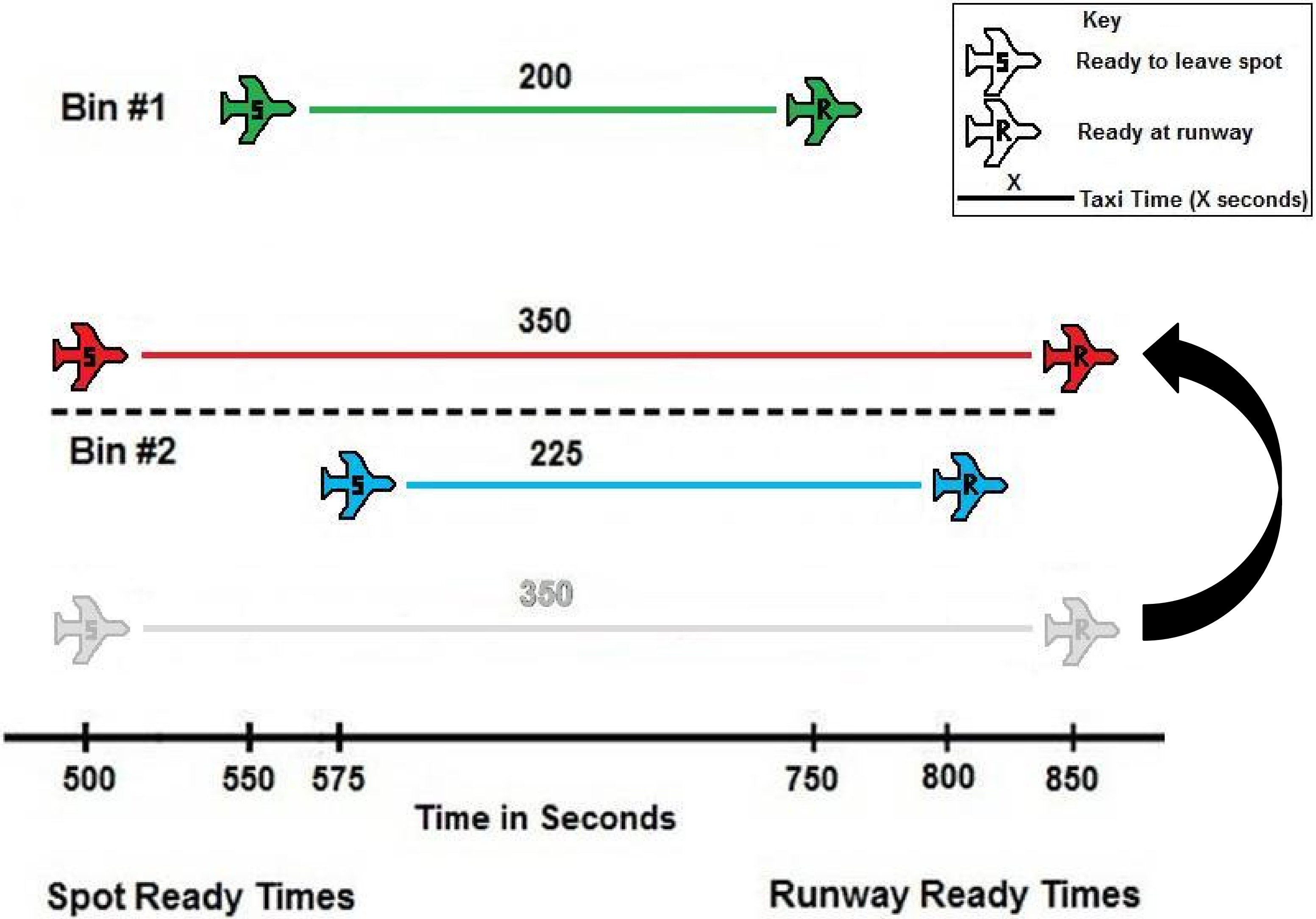
Add aircraft which were ready at the spot before any aircraft in Bin 1



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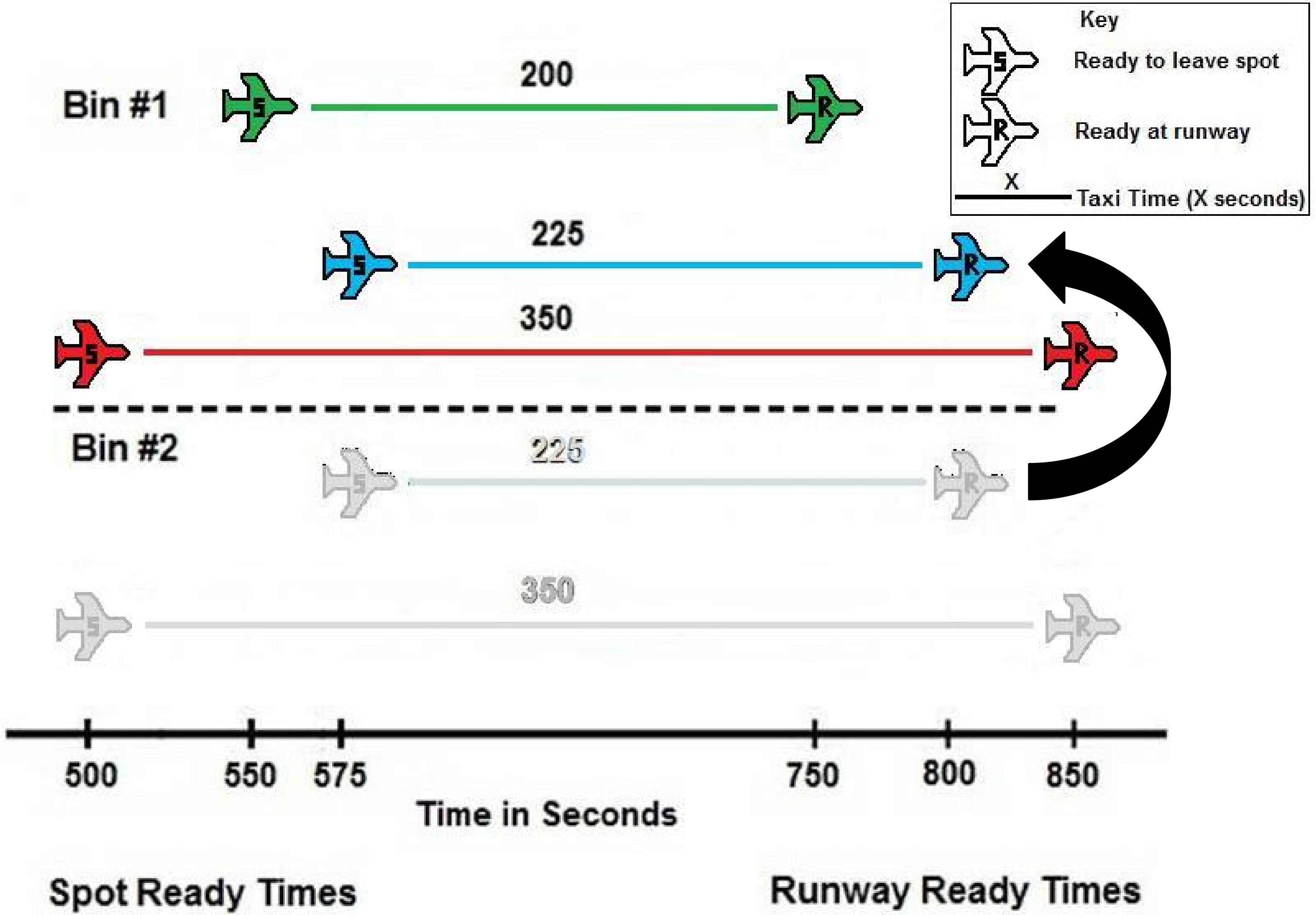
Add aircraft which were ready at the runway before any aircraft in Bin 1



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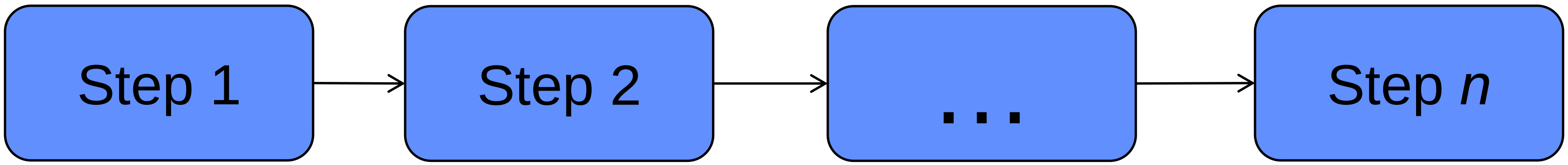
Dynamic Programming Difficulties

Optimal substructure:



Our problem: