# Comparison of First-Come First-Served and Optimization Based Scheduling Algorithms for Integrated Departure and Arrival Management

**Bae-Seon Park*, Hyeonwoong Lee, and Hak-Tae Lee / Yeonju Eun and Daekeun Jeon**
**Inha University / Korea Aerospace Research Institute**

**Zhifan Zhu / Hanbong Lee and Yoon C. Jung**
**Stinger Ghaffarian Technologies / NASA Ames Research Center**

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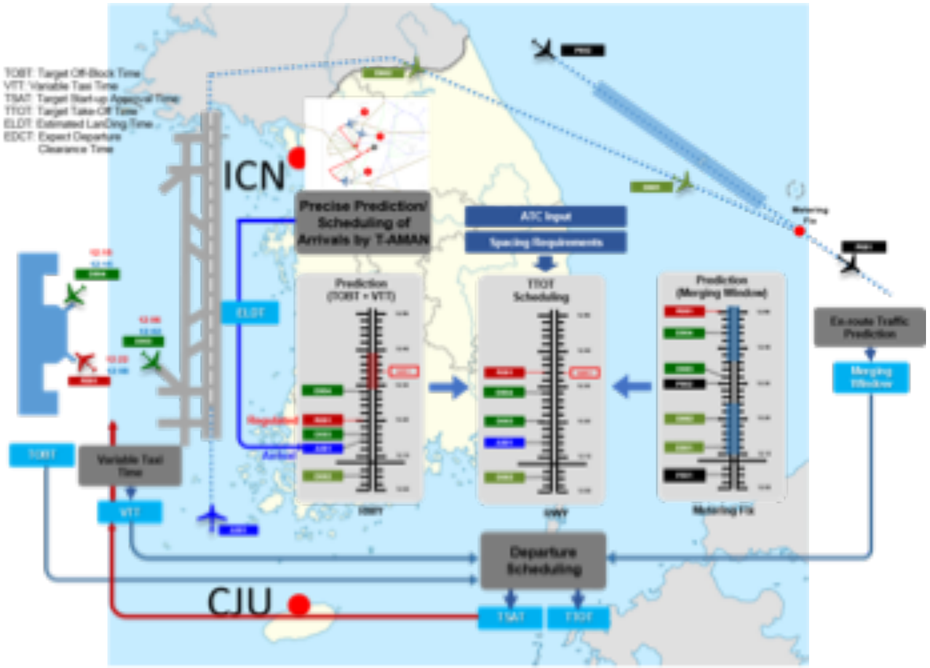
# Outline

- Background
- Two Scheduling Approaches
- Scheduling Result Comparison
- Conclusions

# BACKGROUND

# Background

- ICN, GMP, and CJU
  - Heavy traffic
- KARI is developing an integrated departure and arrival management system.
  - Schedulers (Dep., Arr.)
  - Taxi time estimation
  - Data management
  - Controller display



# Motivation

- Scheduling algorithms are one of the key components.
  - The Extended First-Come First-Served (EFCFS) scheduler has been developed in Inha University.
  - The Mixed Integer Linear Programming (MILP) based scheduler has been developed in KARI in collaboration with NASA.
- Compare two different scheduling algorithms systematically
  - Cross verification
  - Examine the performance differences between EFCFS and MILP

# TWO SCHEDULING APPROACHES

Extended First-Come First-Served Approach

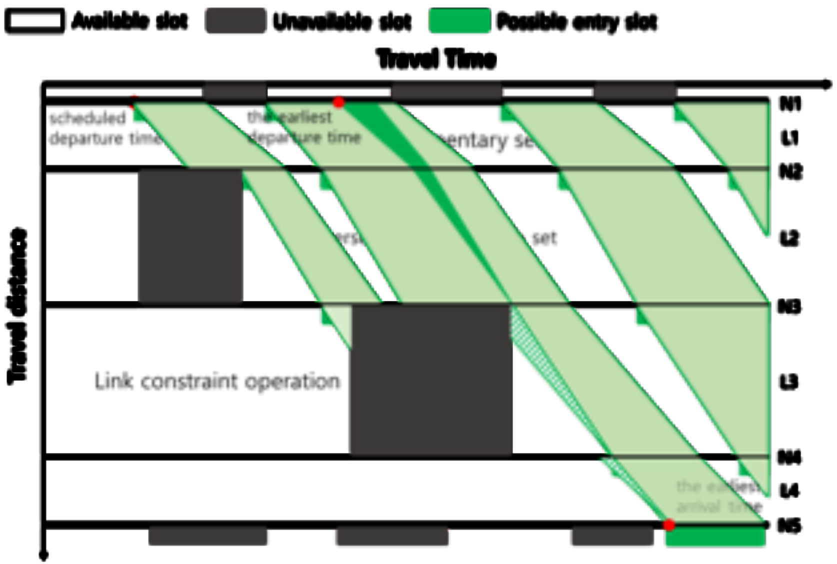
Optimization Based Approach

Compatibility of the Two Algorithms

EFCFS Enhancements

# Extended First-Come First-Served Approach*

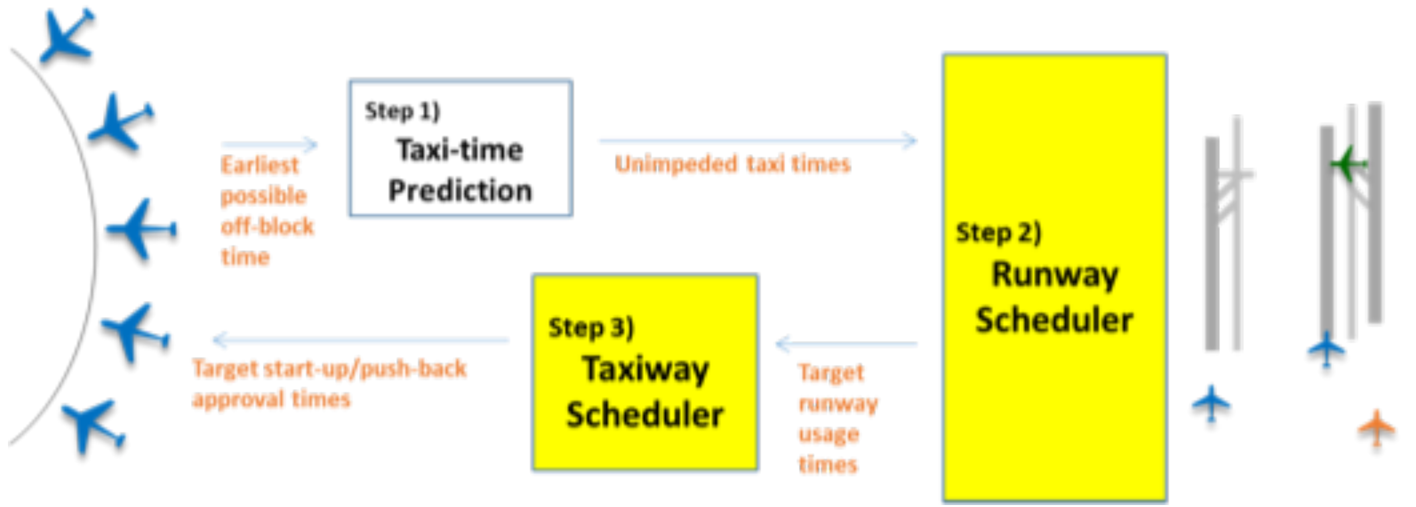
- Sequential scheduling based on priority
- Schedule of the higher priority aircraft is frozen first.
- Departure sequence can be switched.
- Minimum delay solution for each flight




* Park, B., Lee, H., and Lee, H., "Extended First-Come First-Served Scheduler for Airport Surface Operation," International Journal of Aeronautical and Space Sciences (IJASS), Vol.19 (2), 2018.

# Optimization Based Approach*

- Based on 3-step approach
  - Scheduling problems of the Step 2 and 3 were formulated as MILP optimization




* Eun, Y., Jeon, D., Lee, H., Jung, Y., Zhu, Z., Jeong, M., Kim, H., Oh, E., and Hong, S., "Optimization of Airport Surface Traffic: A Case-study of Incheon International Airport," *the 17th AIAA Aviation Technology, Integration and Operations (ATIO) Conference*, Denver, CO, 2017.

# Optimization Based Approach

- Runway scheduling

$$\text{minimize} \sum_{i\in D}\left(t_i - \text{EarliestT}_i\right)$$

Earliest possible Takeoff Time

Decision variable: takeoff time of the departure aircraft i

- Taxiway scheduling

Decision variable: passage times at all intersections along the taxi routes

$$\text{minimize}\ \alpha_p\underbrace{\left(\sum_{i\in D, r\in R}\max\left[t_{i,r} - \text{DesiredOffT}_{i,r},\ 0\right]\right)}_{\text{Late Take-off Time}} + \alpha_d\underbrace{\left(\sum_{i\in D, r\in R} t_{i,r} - \sum_{i\in D, g\in G} t_{i,g}\right)}_{\text{Departure Taxi-out Time}} + \alpha_a\underbrace{\left(\sum_{i\in A, g\in G} t_{i,g} - \sum_{i\in A, r\in R} t_{i,r}\right)}_{\text{Arrival Taxi-in Time}}$$

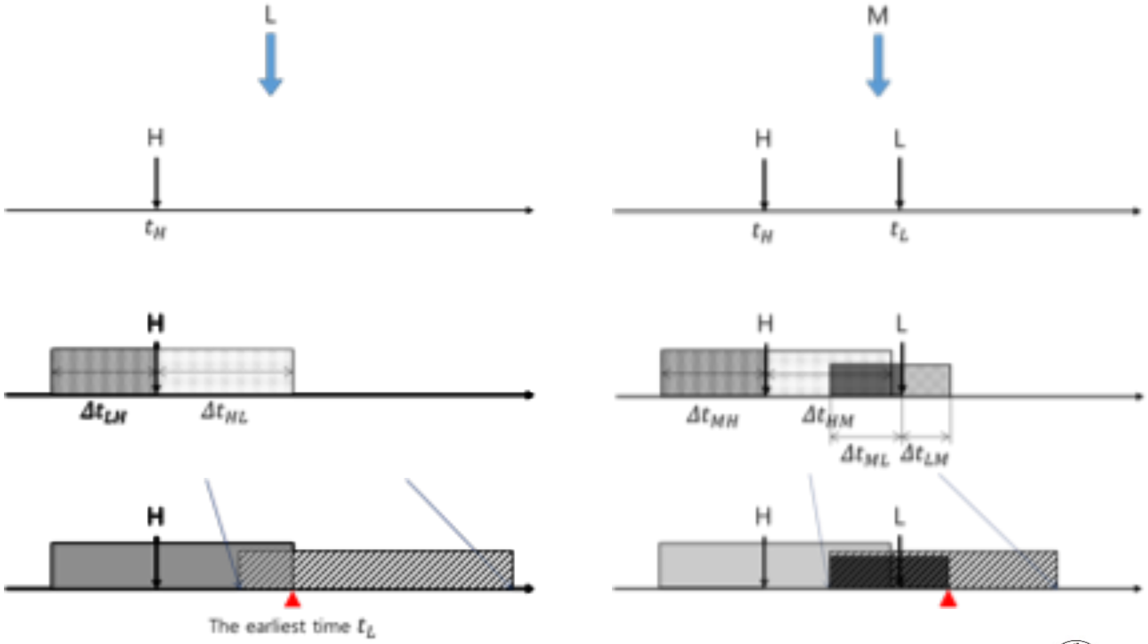
- Required separation between aircraft moving on the surface and other considerations about aircraft movements were all formulated as linear equality/inequality constraints.

# Compatibility of the Two Algorithms

- Use the same predetermined routes
- For arrival flights, taxi scheduling only
  - Estimated landing times are given.
- Common constraints
  - Earliest possible pushback times of departures
  - No deadlock in bi-directional taxiway links
  - Aircraft separation along the taxiways
  - Runway separation based on aircraft wake turbulence category (WTC)
  - Miles-In-Trails at selected fixes (MIT)

# EFCFS Enhancements

➢ Runway separation minima based on aircraft WTC*

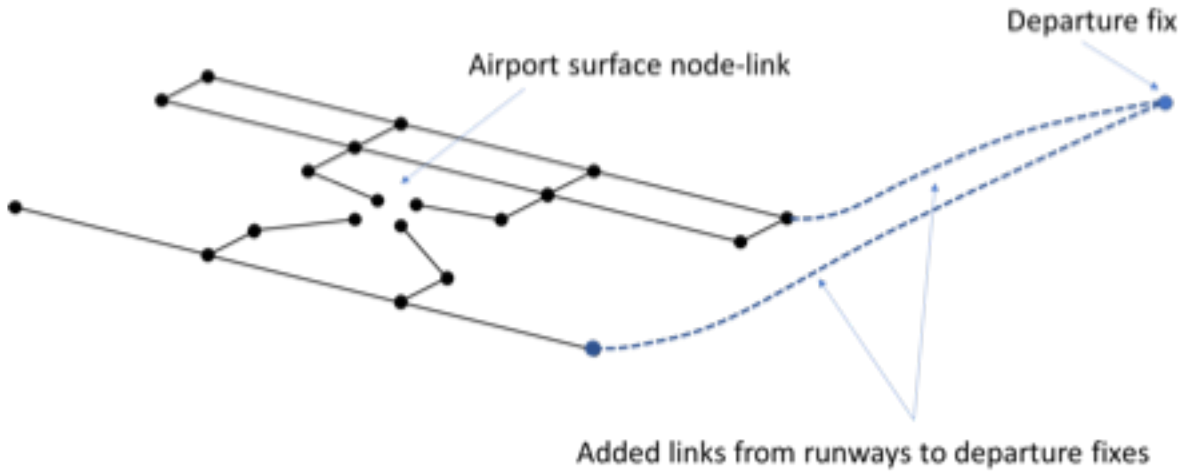





* Park, B., Lee, H., and Lee, H., "Extended First-Come First-Served Scheduler for Airport Surface Operation," International Journal of Aeronautical and Space Sciences (IJASS), Vol.19 (2), 2018.

# EFCFS Enhancements

- Applying MIT constraints
  - Extending the node-link from the runway to the metering fix




Extra node-link for departure fix

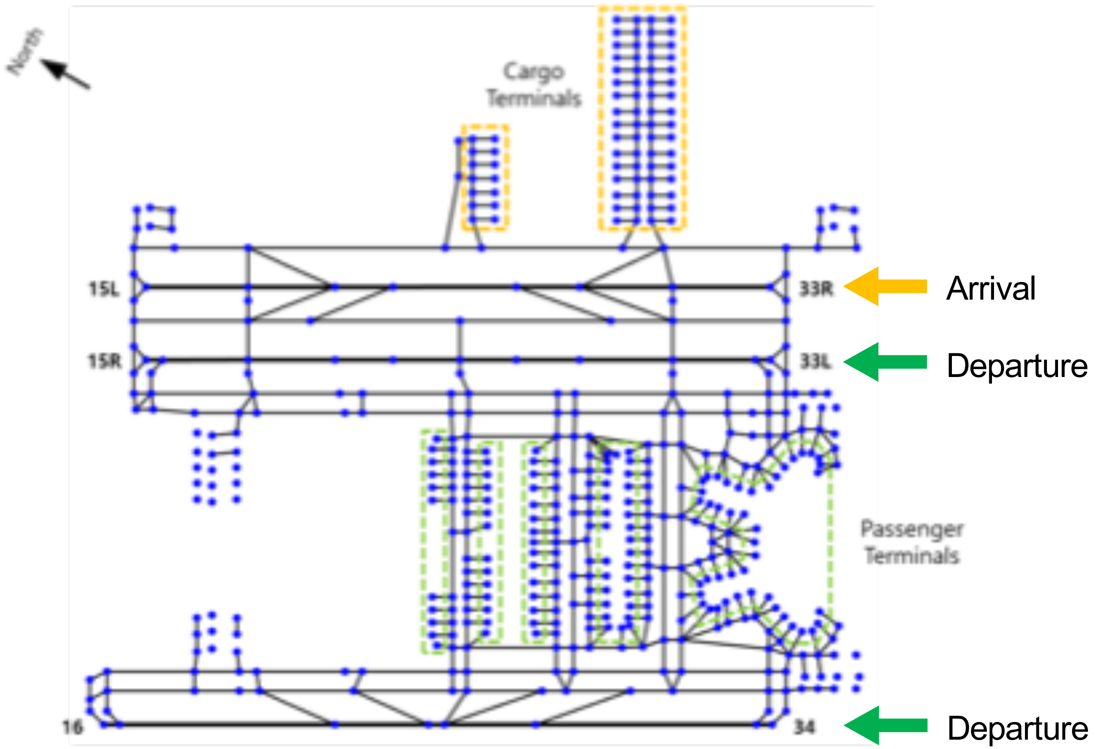
# SCHEDULING RESULT COMPARISON

Problem Set

Scheduling Results

Computation Times

# Incheon International Airport (ICN)



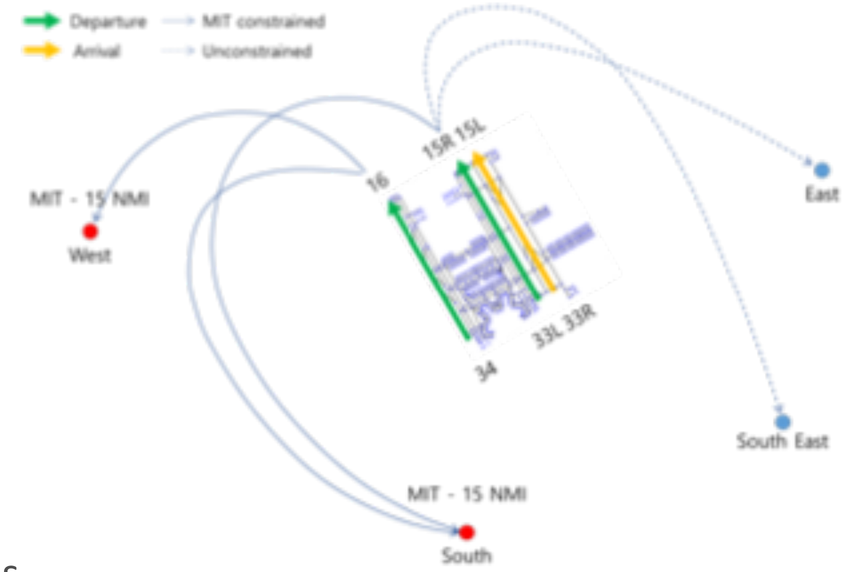
# Problem Set

- 40 departures and 20 arrivals around 1 hour at ICN
- Fleet mixes of all scenarios are equal
  - Departure: 14 Medium and 26 Heavy class aircraft
  - Arrival: 7 Medium and 13 Heavy class aircraft
- Arrival landing times were not adjusted
  - No landing delays
  - Taxi delays can be added while taxiing from runway exits to gates
- Randomly generated 100 scenarios
  - Gate departure times, estimated landing times, and gate numbers (Taxi routes) are randomly assigned.

# Problem Set

## ➢ Runways and departure fixes

| Departure fixes | Runways | # of flights | MIT |
|---|---|---|---|
| East | 15R/33L | 5 | X |
| South East | | 5 | X |
| South | 15R/33L | 6 | O |
| | 16/34 | 9 | |
| West | 16/34 | 15 | O |




## ➢ MIT constraints

- 15 nautical miles
- Applied to the West and South fixes
- The East and South East fixes were unconstrained

# Scheduling Results

- Accumulated results for 100 scenarios
- Case 1
  - Without MIT constraints (2 mins / 3 mins)
- Case 2
  - With MIT constraints (2 mins / 3 mins)
- Case 3
  - Artificially increased runway separation minima without MIT constraints for takeoffs (2 → 5 mins / 3 → 10 mins)

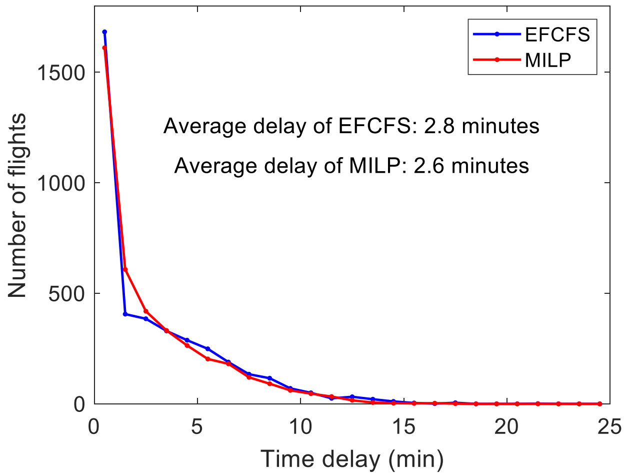
# Scheduling Results – Case 1

*** Delay definitions**

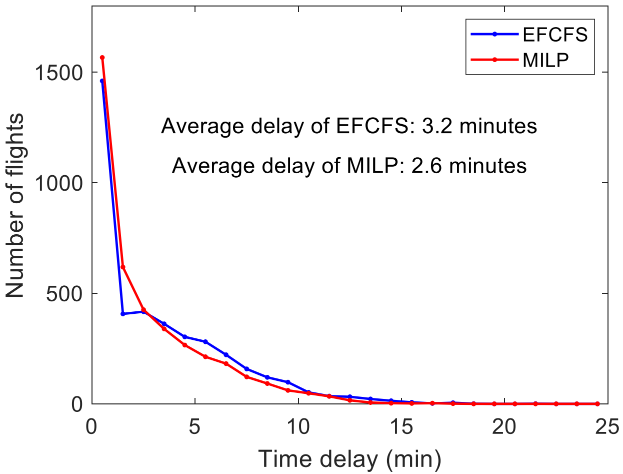
1. Gate delay
   = Calculated push-back time – Original push-back time
2. Takeoff delay
   = Calculated takeoff time – Original takeoff time
3. Original takeoff time
   = Original push-back time + Unimpeded taxi time

## ➢ Delay distributions

- MILP shows smaller average runway takeoff delay



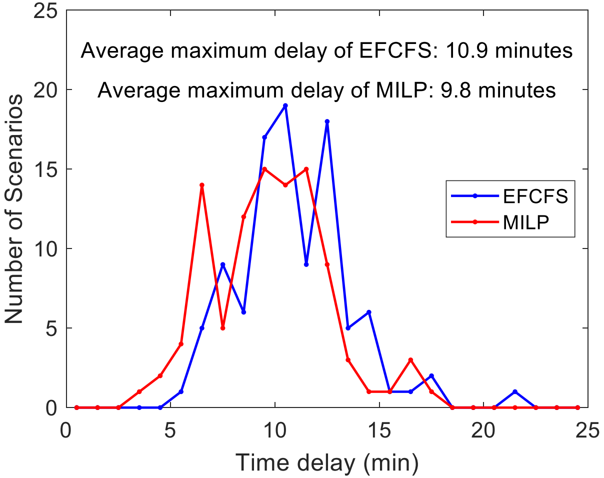

Gate departure delay



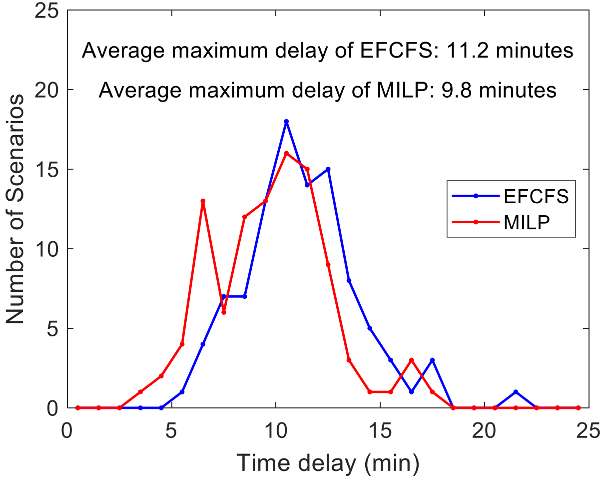

Runway takeoff delay

# Scheduling Results – Case 1

- Maximum delay distributions
  - MILP has better performances than EFCFS
  - EFCFS is slightly shifted to the right side



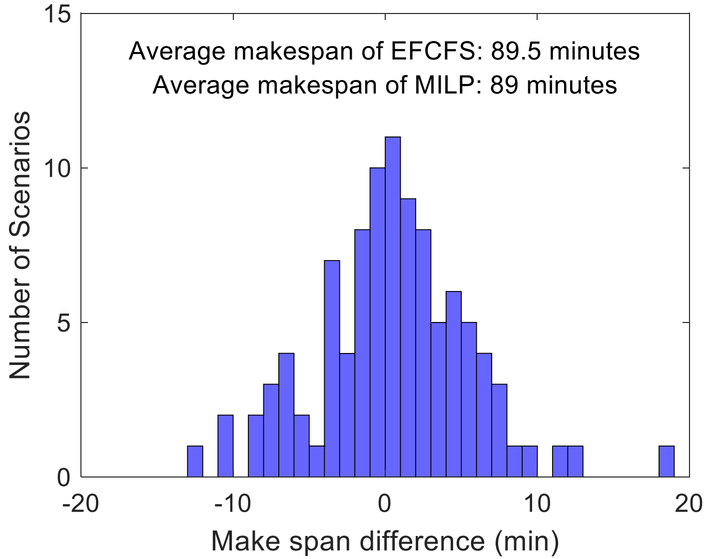

Gate departure delay




Runway takeoff delay

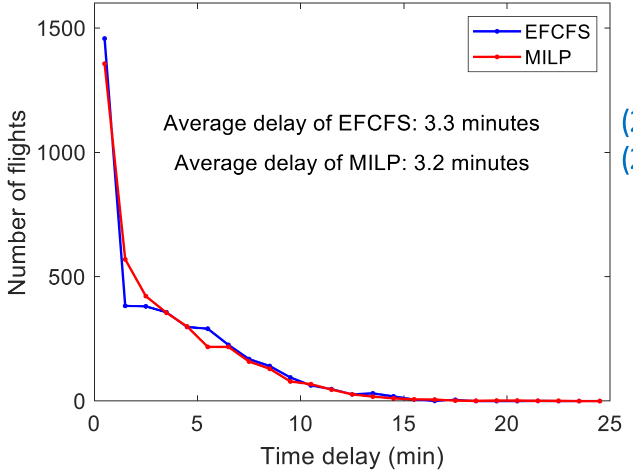
# Scheduling Results – Case 1

- Distribution of makespan differences
  - MILP shows slightly better performance



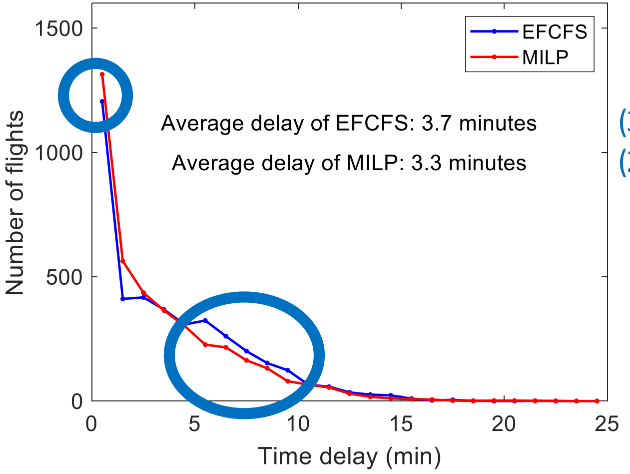
# Scheduling Results – Case 2

- Delay distributions
  - EFCFS has more flights with 5 – 10 minutes runway takeoff delays
  - MILP has more flights with the runway takeoff delays in 1 minute




Case 1
(2.8 minutes)
(2.6 minutes)

Gate departure delay

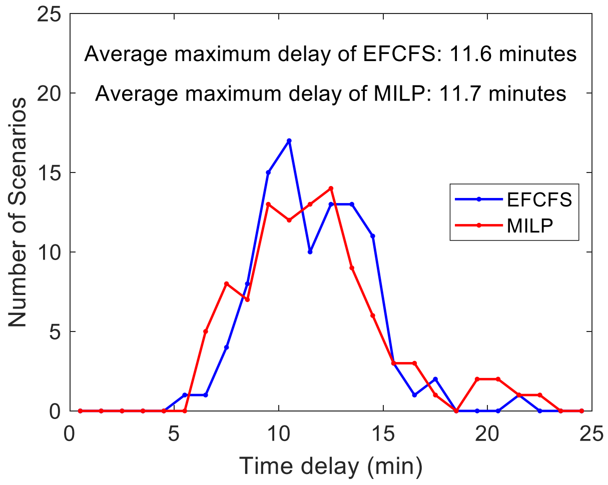



Case 1
(3.2 minutes)
(2.6 minutes)

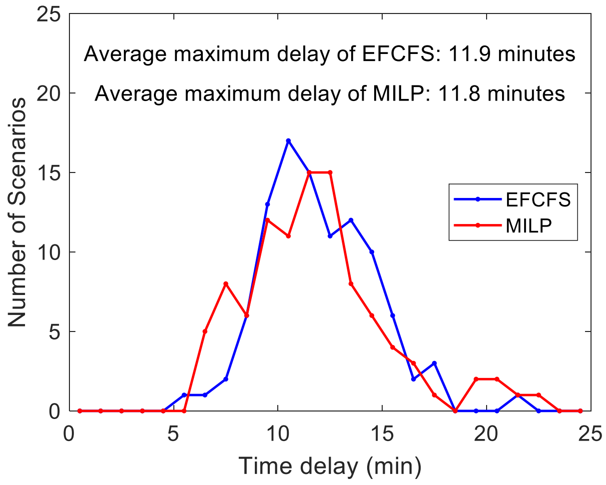
Runway takeoff delay

# Scheduling Results – Case 2

- Maximum delay distributions
  - The difference between MILP and EFCFS became smaller than Case 1



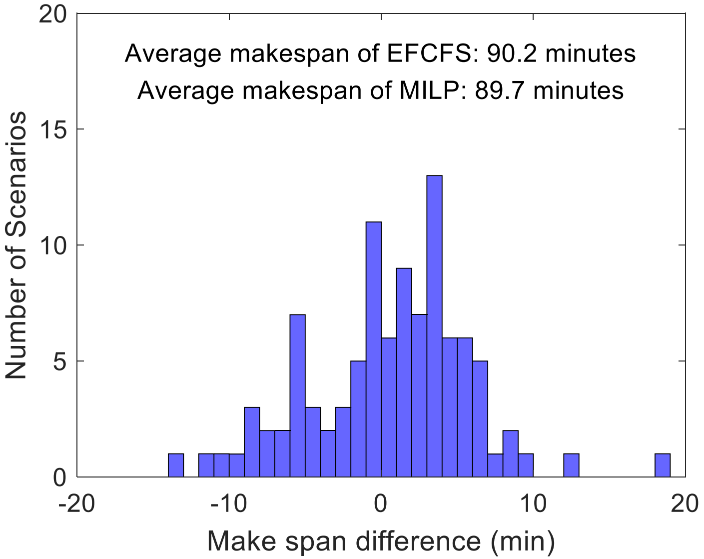
Gate departure delay



Runway takeoff delay

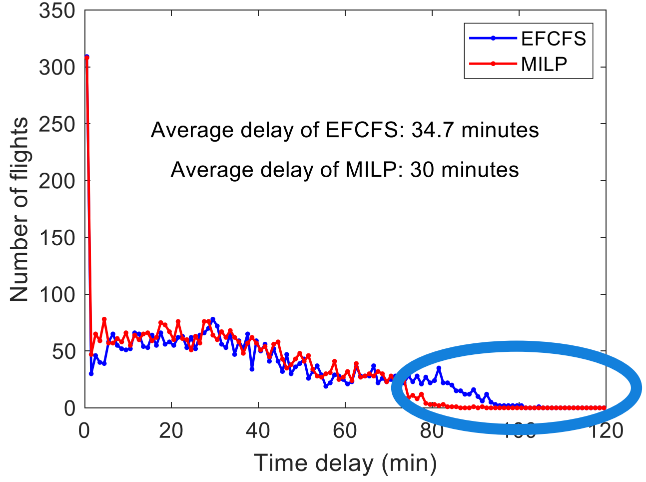
# Scheduling Results – Case 2

- Distribution of makespan differences
  - MILP shows slightly better performance

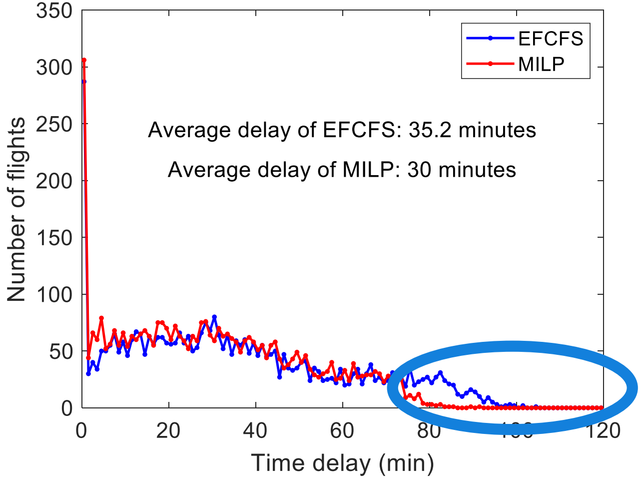


# Scheduling Results – Case 3

- Delay distributions
  - EFCFS shows larger average delays for both gate departure and runway takeoff
  - EFCFS has more flights with the delays larger than 70 minutes



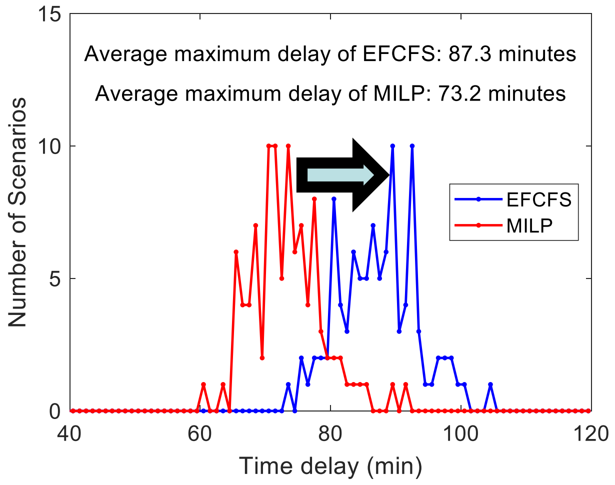

Gate departure delay



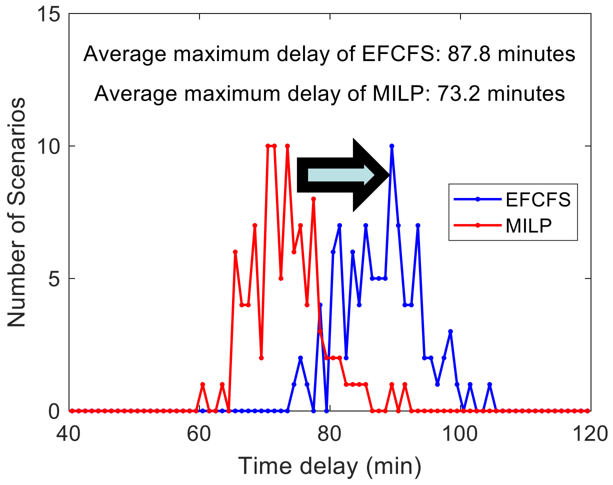

Runway takeoff delay

# Scheduling Results – Case 3

- Maximum delay distributions
  - EFCFS produced larger maximum delays
  - Distributions of EFCFS are shifted to the right side



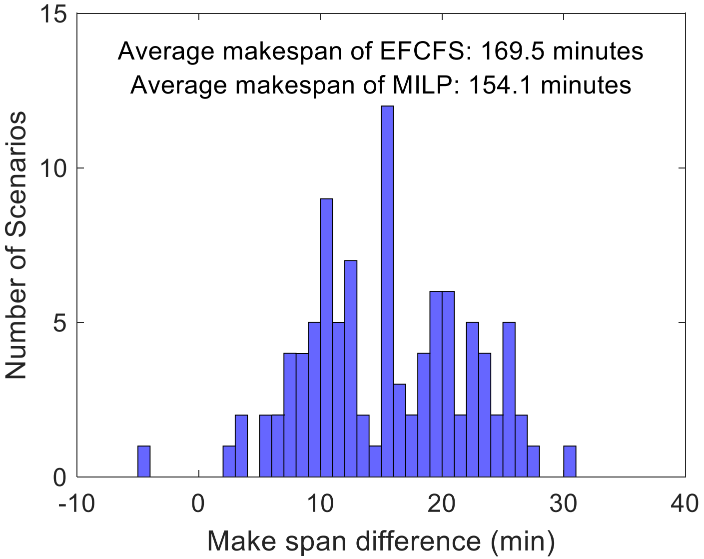

Gate departure delay




Runway takeoff delay

# Scheduling Results – Case 3

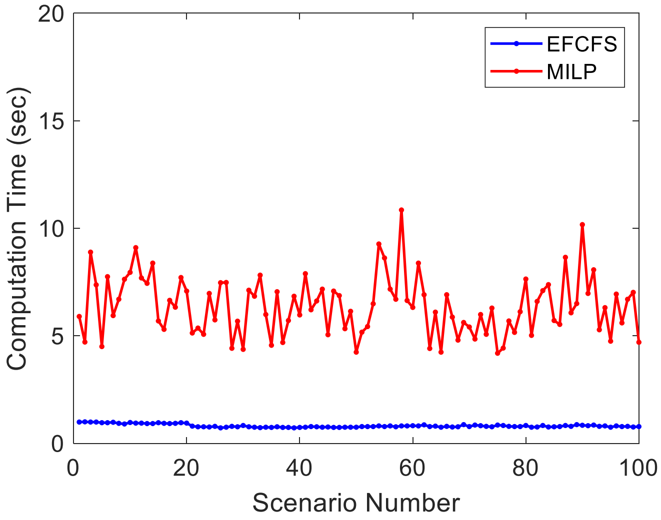
- Distribution of makespan differences
  - The Makespan differences are biased in the positive direction
  - MILP shows much better performance with large runway separations



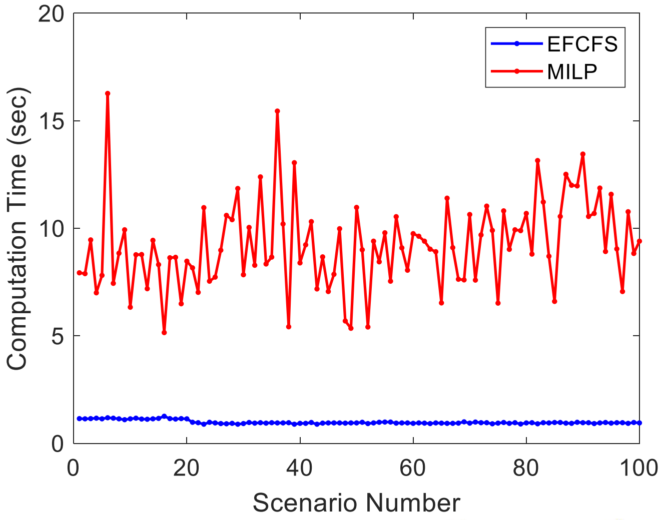
# Computation Times

*** Desktop specification**
Intel i7-6820HQ, 2.79 GHz / 32GB RAM

- Case 1 (No MIT)
  - EFCFS: 0.82 seconds
  - MILP: 6.39 seconds




- Case 2 (with MIT)
  - EFCFS: 0.99 seconds
  - MILP: 9.22 seconds



# Scheduling results – Summary

- MILP
  - Slightly smaller average and maximum takeoff delays
  - Slightly smaller average makespans
- EFCFS is about 10 times faster for the given problem size.
- MILP's advantage is more noticeable in high delay situations.
- Applying MIT constraints
  - The differences in results between EFCFS and MILP became smaller.
  - The computation times of MILP were increased.

# CONCLUSIONS

# Conclusions

- Two different scheduling approaches were compared
  - Common constraints were considered
  - 100 scenarios were randomly generated
- MILP generally showed better performance in terms of minimizing delays, but the differences were small.
- EFCFS is much faster in computational performance
  - Real time situations
  - Scheduling large number of aircraft

# Future Research Plans

- Testing more scenarios considering higher delay such as operations with severe weather condition or future traffic demand
- Handling uncertainty
  - Add buffer times
  - Update periodically with fast-time simulation
  - Use probabilistic model

# Questions?