IMPACT OF GATE ASSIGNMENT ON GATE-HOLDING DEPARTURE CONTROL STRATEGIES

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Outline

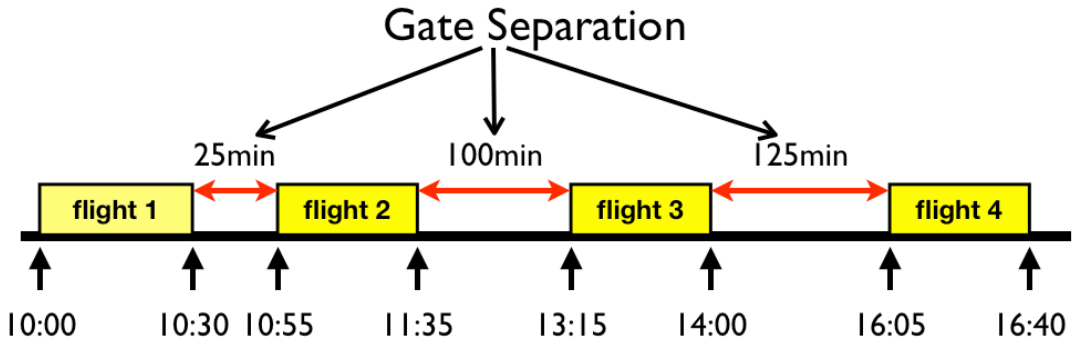
Gate Holding

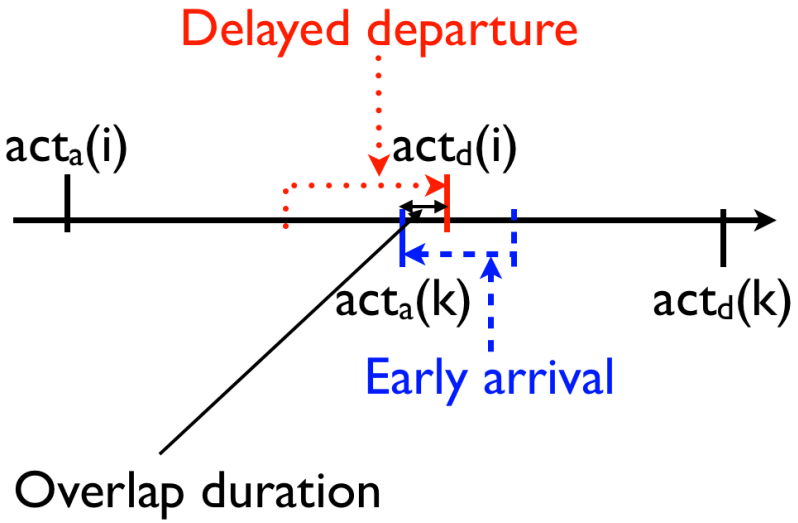
- Reduce taxi delays and emissions in the departure process while maintaining airport departure throughput (take-off rate).
- Motivated by the fact that the number of take-offs per minute is saturated when the number of aircraft that taxi out (N) is greater than a saturation point (N^*).[1, 2]
- Keep N near N^* by controlling pushback clearances.
- Implemented experimentally at Boston Logan Airport.[3]
- Gate separation constrains the efficiency of gate holding.

Issue

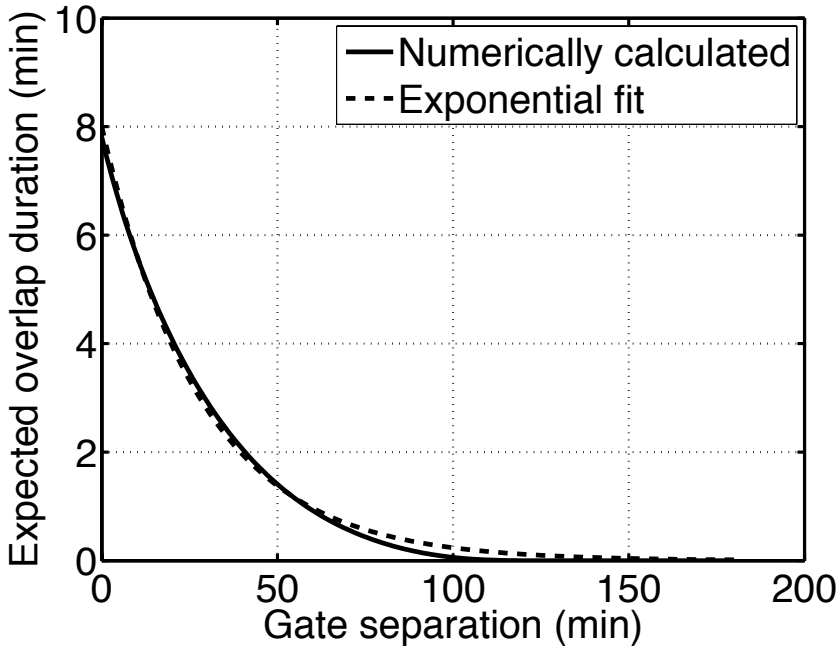
Gate-holding strategy can be detrimental to the free access of arriving flights to the terminals.

Robust Gate Assignment





(a) Gate Conflict



(b) Exponential fit $A \times B^{sep(i,k)}$

Problem Formulation

Objective function

$\min \sum_{i \in \mathcal{F}} \sum_{k \in \mathcal{F}, k>i} A \times B^{sep(i,k)} \sum_{j \in \mathcal{G}} x_{ij}\ x_{kj}$

Decision variable x_{ij}

indicates that flight i is assigned to gate j

Constraints

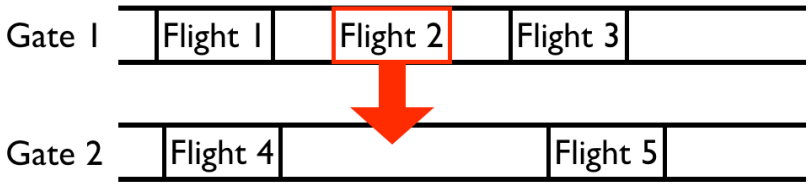
- Every flight should be assigned to a gate.
- Gate separation should be longer than buffer time.

- $\mathcal{F}$ is the set of flights, and $\mathcal{G}$ is the set of gates.
- $sep(i, k)$ is the gate separation between flight i and flight k.

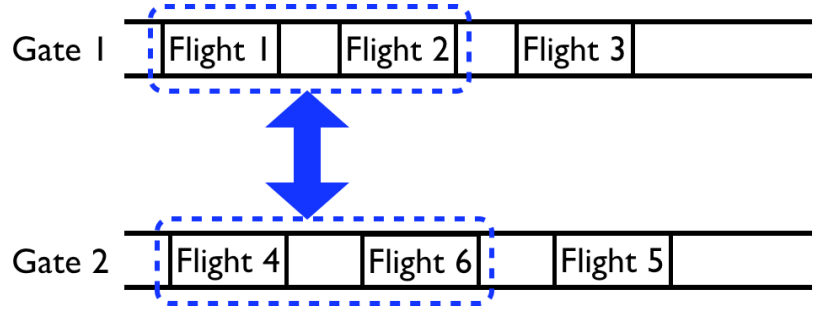
It is hard to solve. Therefore we implement a heuristic algorithm - Tabu Search.

Tabu Search Algorithm

- Tabu Search (TS) is a meta-heuristic algorithm introduced by Glover.
- TS outperforms Branch and Bound and Genetic Algorithm in solution time and solution accuracy.[4]
- TS searches the neighborhood of the current solution using short term memory (tabu memory).
- In order to escape from local optima, tabu restriction prevents reverting to previous states.
- Aspiration criterion: Tabu restriction can be overridden if the candidate move makes the solution better than the current best.

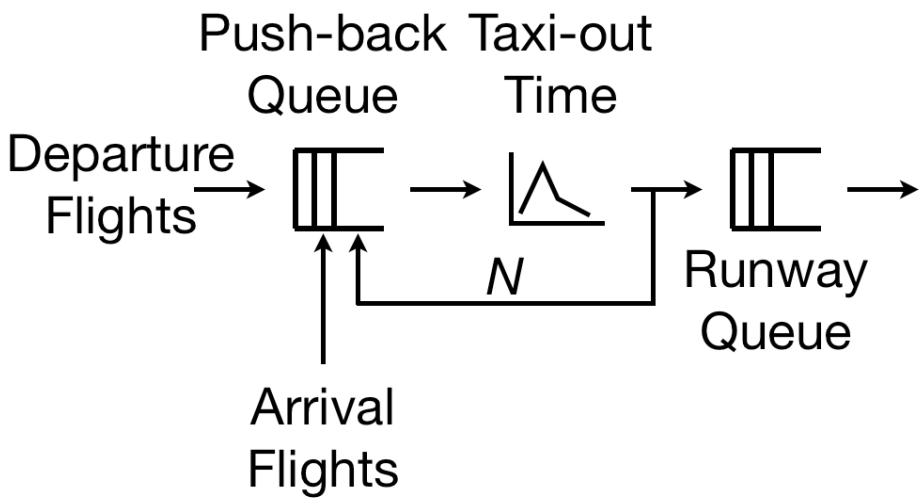


(c) Insert Move



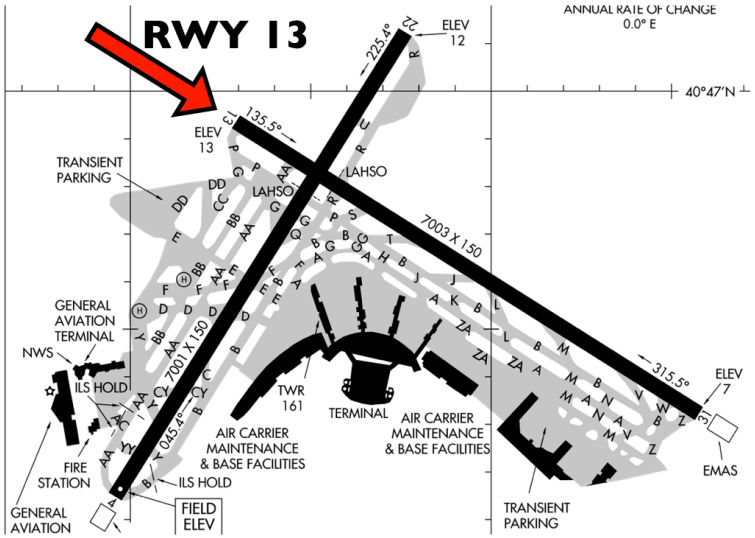
(d) Interval Exchange Move

Queuing Model



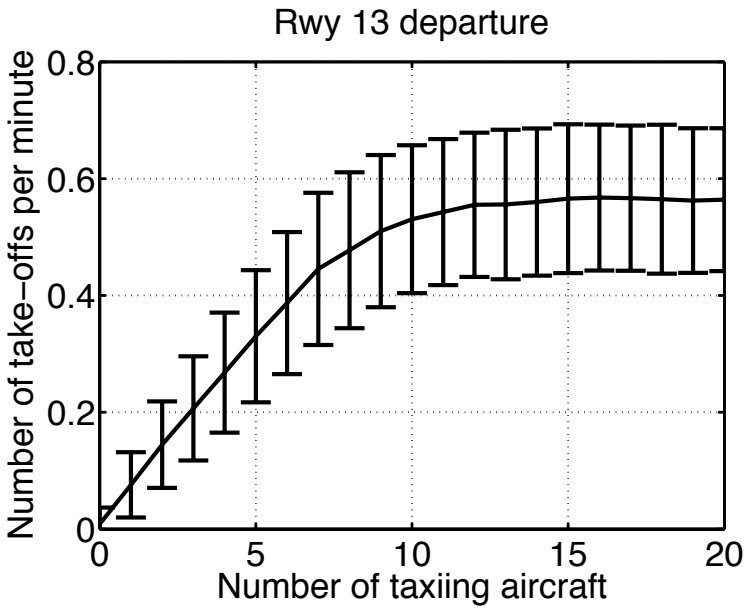
- When an aircraft is ready for push-back, it enters a push-back queue.
- A push-back is cleared on a First-Come-First-Served (FCFS) basis.
- After the aircraft is cleared for push-back, the taxi-out time to a runway threshold is generated.
- When the aircraft reaches the runway threshold, it enters a runway queue and is cleared for take-off on a FCFS basis.

Data Source



- The queuing model is calibrated to La Guardia Airport (LGA) using 2009 data from Aviation System Performance Metrics (ASPM).
- Runway 13 operated for 3456 hours (39.5% of the year) and served 83143 push-backs (47.6% of push-backs that year).
- The queuing model is calibrated with departures from runway 13.

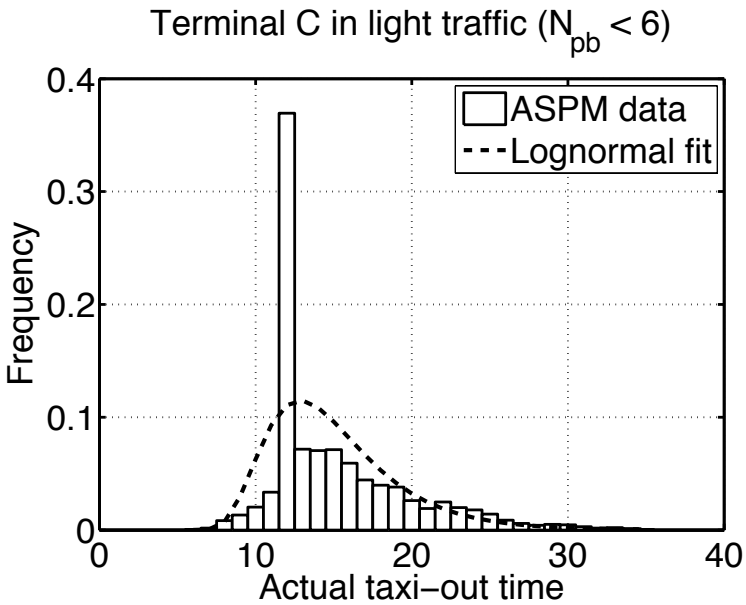
Take-off Model

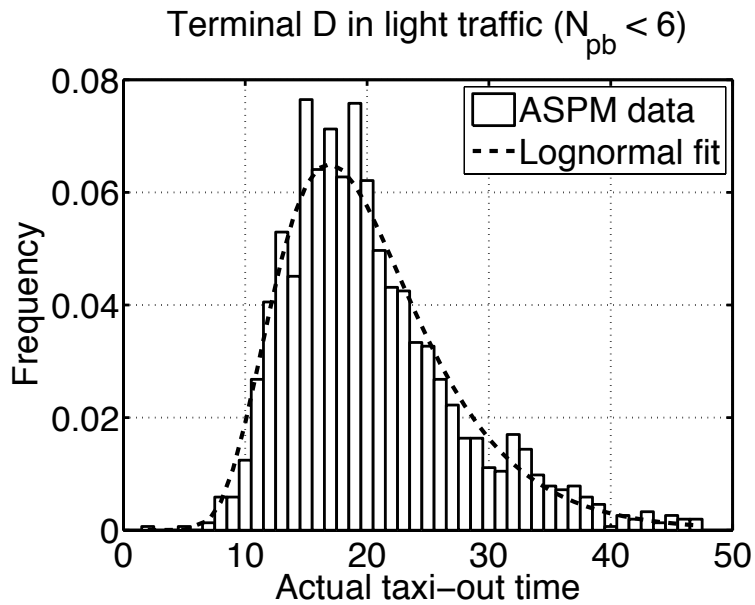


- 0.82 aircraft per minute with probability 0.5134.
- 0.96 aircraft per minute with probability 0.1248.
- 0.04 aircraft per minute with probability 0.3618.

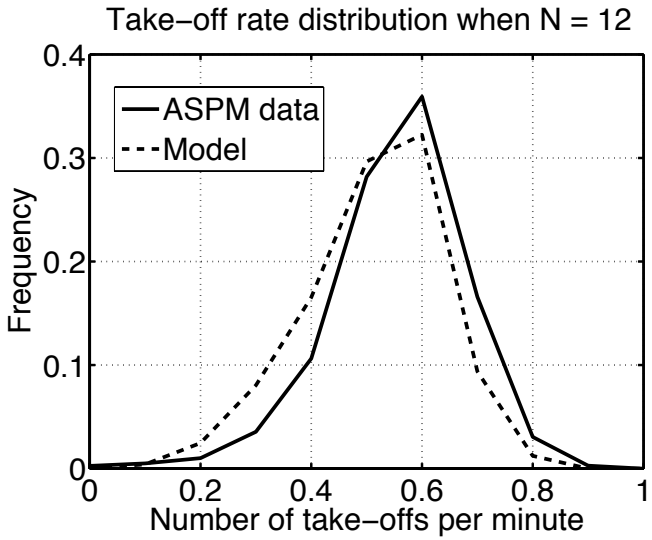
Taxi-out Time Estimator

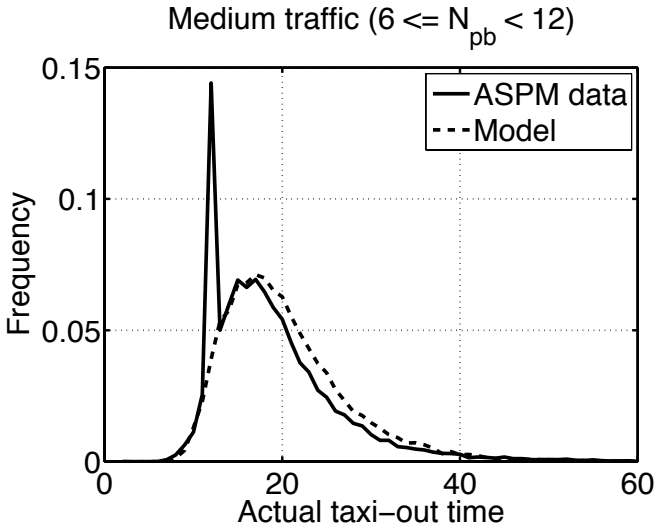
- Taxi-out times in ASPM data are grouped by each terminal in LGA.
- Taxi-out times are filtered by the number of taxi-out aircraft when an aircraft pushes back (N_{pb}).
- Nominal taxi-out times are obtained when there is light traffic on surface: $N_{pb} < 6$.
- Lognormal distribution is used to model the nominal taxi-out time.

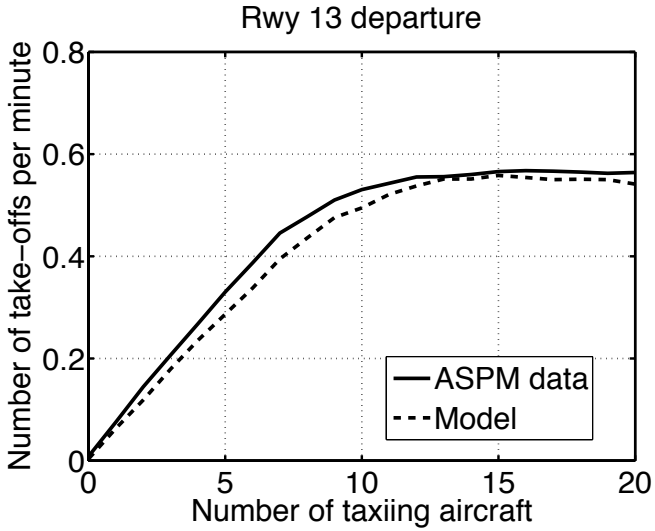


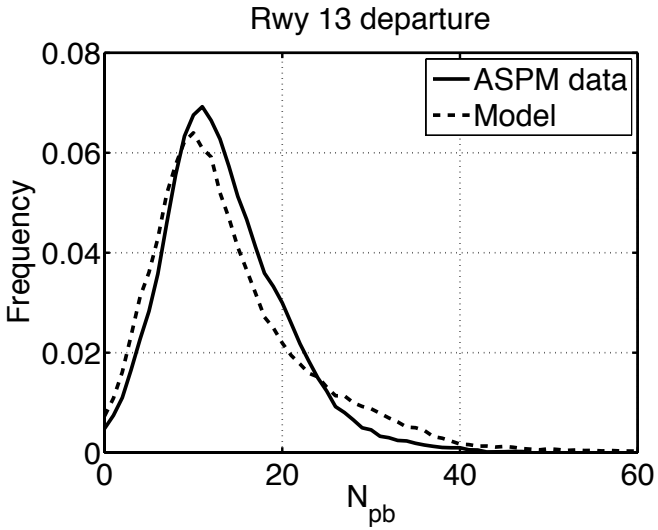


Validation


Take–off rate distribution when N = 12
ASPM data
Model
Frequency
Number of take–offs per minute
0
0.1
0.2
0.3
0.4
0.2
0.4
0.6
0.8
1


Medium traffic (6 <= N_pb < 12)
ASPM data
Model
Frequency
Actual taxi–out time
0
0.05
0.1
0.15
20
40
60

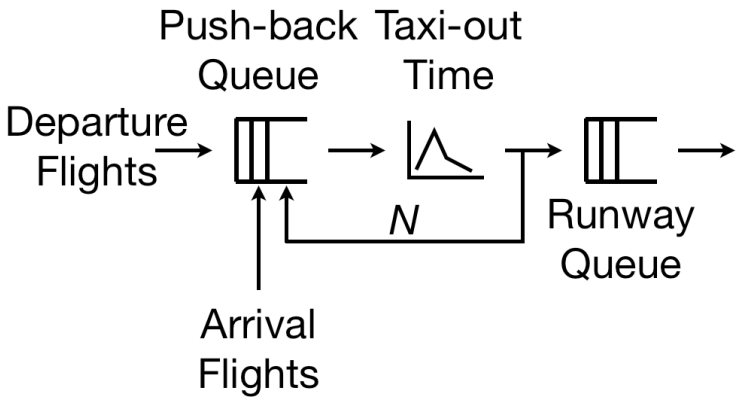

Rwy 13 departure
ASPM data
Model
Number of take–offs per minute
Number of taxiing aircraft
0
0.2
0.4
0.6
0.8
5
10
15
20


Rwy 13 departure
ASPM data
Model
Frequency
N_pb
0
0.02
0.04
0.06
0.08
20
40
60

Gate Assignment

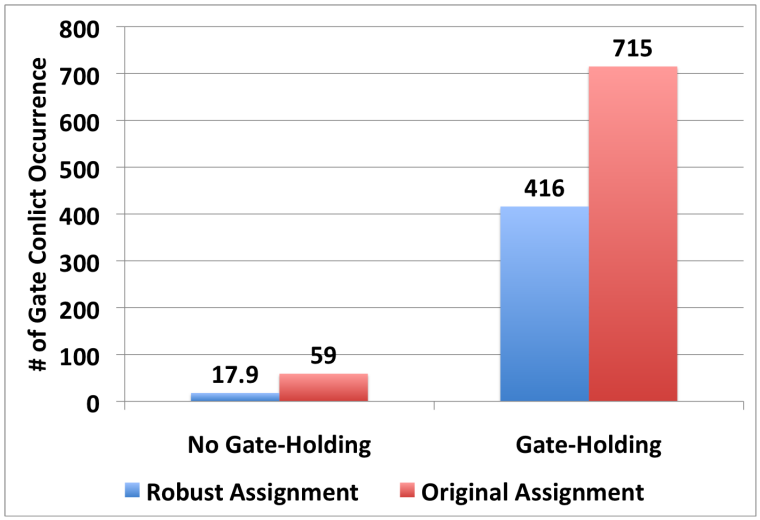
- The original gate assignment is obtained from a website (www.flightstats.com).
- The robust gate assignment is generated based on the schedule of the day because airport gates are assigned prior to the actual operation day.
- It is found frequently in the original gate assignment that two arrivals use a gate consecutively and the gate is used for two consecutive departures: towing aircraft.
- Each airline can use a subset of gates in LGA.

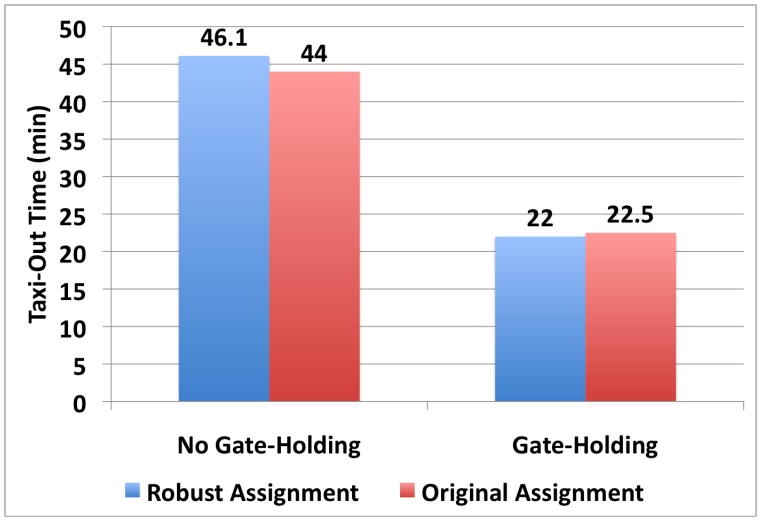
Simulation Structure



- When a departure is ready to push back, it enters the push-back queue.
- A push-back is cleared FCFS, but if an arrival requests an occupied gate (gate conflict), the departure occupying the gate is cleared immediately.
- If gate holding is active, push-back is not cleared until N is below N^*.
- Taxi-out time is randomly generated according to the departure terminal.
- Take-off is cleared FCFS.

Simulation Result





- 5-day schedules are simulated 10 times and averaged.
- With original assignment, 1122.4 flights (out of 2409 departures) are held at gates for 33.3 minutes on average.
- With robust assignment, 1419.2 flights (out of 2409 departures) are held at gates for 35.7 minutes on average.
- The robust gate assignment helps gate holding get benefits with fewer disturbances to the gate assignment.

Summary

- Analyze the impact of gate assignment on gate-holding departure control.
- In order to simulate the airport departure process, a queuing model is proposed, consisting of a push-back queue, a taxi-out time estimator, and a runway queue.
- The model is validated and reproduces airport departure throughput close to the data.
- Because the performance of gate holding relies on gate separations, a robust gate assignment is introduced.
- The results show that gate holding shifts some taxi-out times to gate delays, and it causes gate conflicts between the gate-held departures and arrivals.
- The robust gate assignment reduces the occurrence of gate conflicts under gate-holding departure control strategies and helps the control strategies to utilize gate-holding times to an extent by maximizing gate separations.

Thank you!

References

- Shumsky, R., *Dynamic Statistical Models for the Prediction of Aircraft Take-off Times*, Ph.D. thesis, Massachusetts Institute of Technology, 1995.
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- Simaiakis, I., Balakrishnan, H., Khadilkar, H., Reynolds, T., Hansman, R., Reilly, B., and Urlass, S., "Demonstration of Reduced Airport Congestion Through Pushback Rate Control," 2011.
- Kim, S., Feron, E., and Clarke, J.-P., "Gate Assignment to Minimize Passenger Transit Time and Aircraft Taxi Time," *Journal of Guidance, Control, and Dynamics*, in Press.