Towards An Integrated Tool for Airport Optimization in the Presence of Uncertainties

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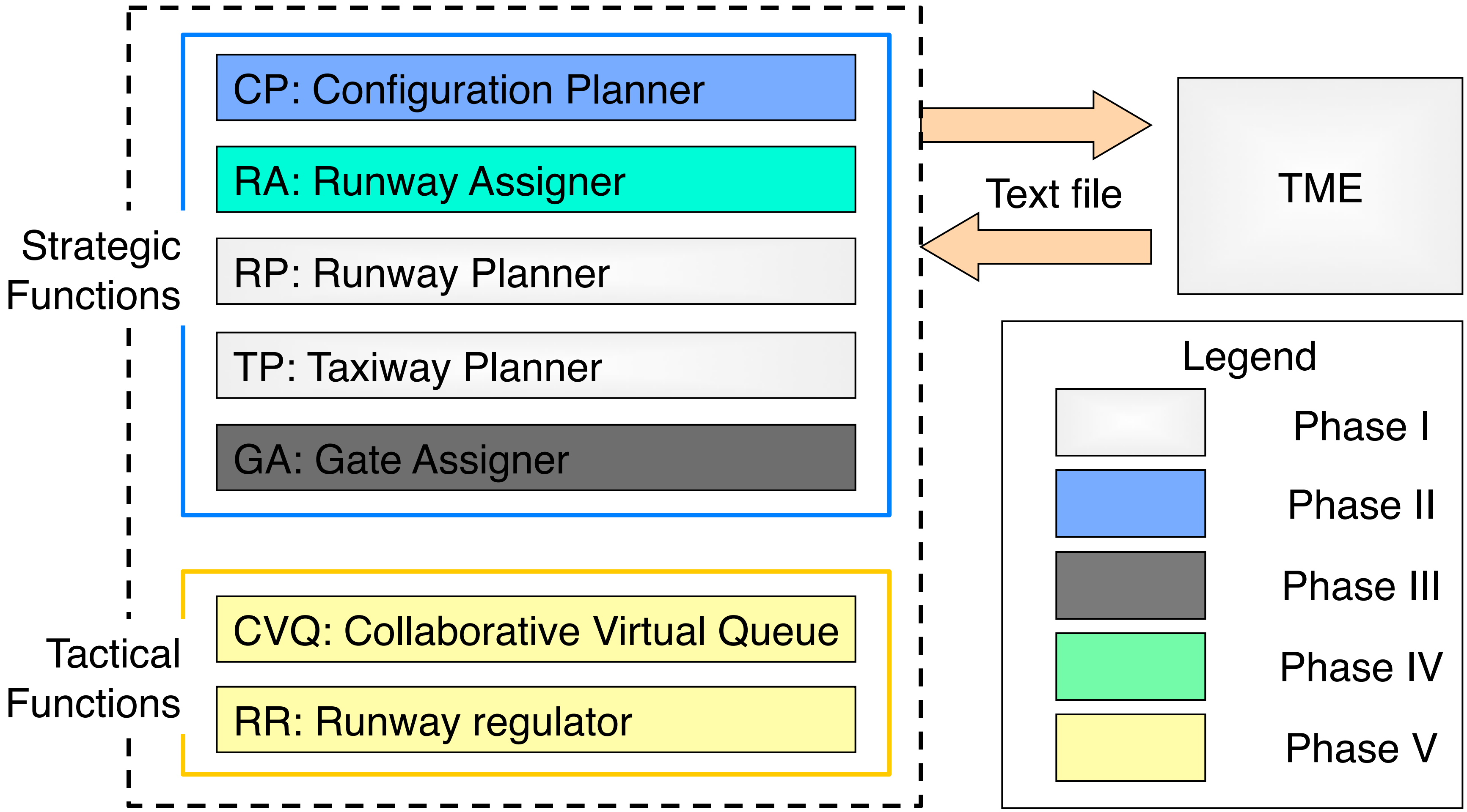
Motivation

- Understand the constraints on surface operations that reduce capacity and…
- Improve surface operations by implementing procedures and automation that…
  - Reduce delays
  - Reduce noise and emissions (i.e. greener)
  - Increase robustness
  - Satisfies safety requirements

Technical Approach

- Characterize constraints and uncertainties
  - Identify surface domain, constraints, uncertainties and related phenomena
  - Characterize performance impacts from qualitative and quantitative perspectives
  - Leverage research results and airport site visits
- Develop optimization strategies, architectures, algorithms
- Define strategy for performance evaluation
  - Define evaluation scenarios by spanning dimensions of future demand, weather, and ATM concepts
  - Define evaluation metrics with capacity, efficiency, robustness, and environmental impacts
- Quantify performance of algorithms and strategies

Optimization-Simulation Architecture



Configuration Planner (CP)

- Decide (for set of runways)
  - Configuration (decision variables)
  - Time of change
- Given
  - Uncertain wind and traffic
  - Capacity of configurations
  - Cost of configuration change
- To
  - Maximize throughput
- While
  - Maintain safety requirements
  - Satisfy noise quota agreements

CP: Computational Study

- JFK
  - 100 simulation runs with the traffic and weather
  - Reduced delays and configuration changes relative to ASPM

		Schedule from Model				Historical Configuration Records			
		land		takeoff		land		takeoff	
		average	max.	average	max.	average	max.	average	max.
1/4	mean	3.63	22.35	6.09	37.57	4.96	33.35	31.04	127.59
	std	0.95	5.32	1.22	8.27	1.01	6.18	3.53	8.82
1/11	mean	2.67	19.50	3.10	19.05	20.54	65.34	4.88	25.37
	std	0.61	3.66	0.71	4.33	3.35	7.80	1.30	6.59

- Configuration Planner in integrated test bed
  - Schedule time interval 15 minutes
  - Minimum configuration change lead time 30 minutes
  - Configuration time horizon 6 hours

Runway Assigner (RA)

- Decide (for each aircraft)
  - Runway (and arrival and departure fixes in the future)
- Given
  - Capacity of runways and fixes
  - Flight distances and speeds
  - Taxi distances and speeds
  - Aircraft performance
- To
  - Minimize fuel burn and emissions
- While
  - Satisfying safety requirements
  - Satisfying noise quota agreements

RA: Computational Study

- Given 20 arrivals, 18 departures, and the following scenarios:
  - (a) FCFS and no-assignment (closest runway to fix)
  - (b) FCFS and runway assignment
  - (c) Sequencing and assignment

average delay(sec)		
case(a)	case(b)	case(c)
136.1	88.6	75.8

	amount of emission	
% vs case(a)	case(b)	case(c)
	96%	92%

Runway Planner (RP)

- Decide
  - Schedule of operations for each runway
  - “Cutoff” for arrival/departure stream during configuration change
- Given
  - Uncertain availability or “readiness”
  - Configuration information and interactions between runways
  - Aircraft performance
  - Historical stochastic behavior
- To
  - Maximize throughput
  - Minimize fuel burn and emissions
- While
  - Satisfying safety requirements
  - Satisfying noise quota agreements
  - Provide adequate time to perform configuration change

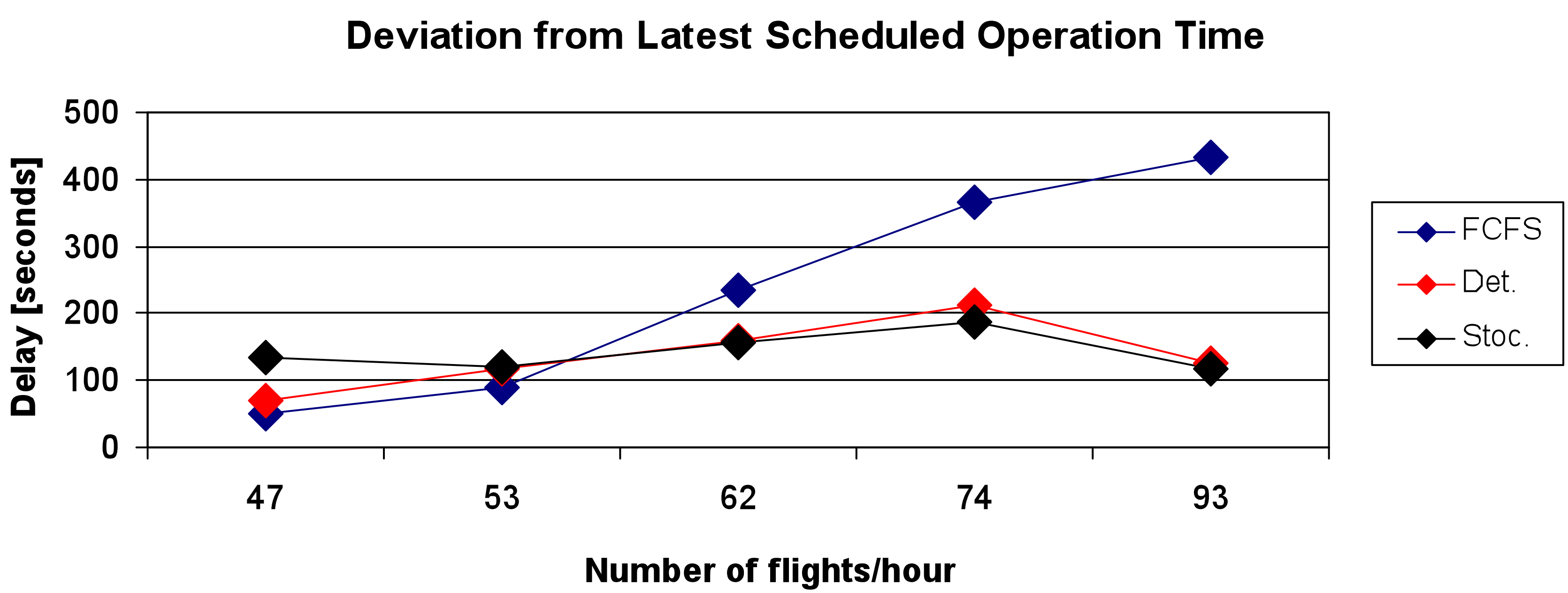
RP: Problem Versions

	Deterministic Model	Stochastic Model

Single Runway	• Arrivals and departures considered
	• Deterministic arrival and departure availability
	• Trade-off between throughput and fuel cost.
		• Stochastic arrival and departure availability
		• Virtual Runway
		• 2-stage formulation
		  • Identify optimal sequence for aircraft types, considering uncertainty in aircraft availability
		  • Identify minimum cost feasible schedule by assigning flights to the optimum sequence, after event times are known with certainty.

Multiple Runways	• Arrivals, departures and runway crossings considered • Deterministic arrival and departure availability • Trade-off between throughput and fuel cost.	

RP: Stochastic Model – Computational Study (2)



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Taxiway Planner (TP)

- Decide (for each aircraft)
  - Taxi entry and exit times
  - Taxi path
- Given
  - Uncertain availability or “readiness”
  - Aircraft performance
- To
  - Minimize taxi time, fuel burn and emissions
- While
  - Satisfying safety requirements

TP: Simulation at DTW

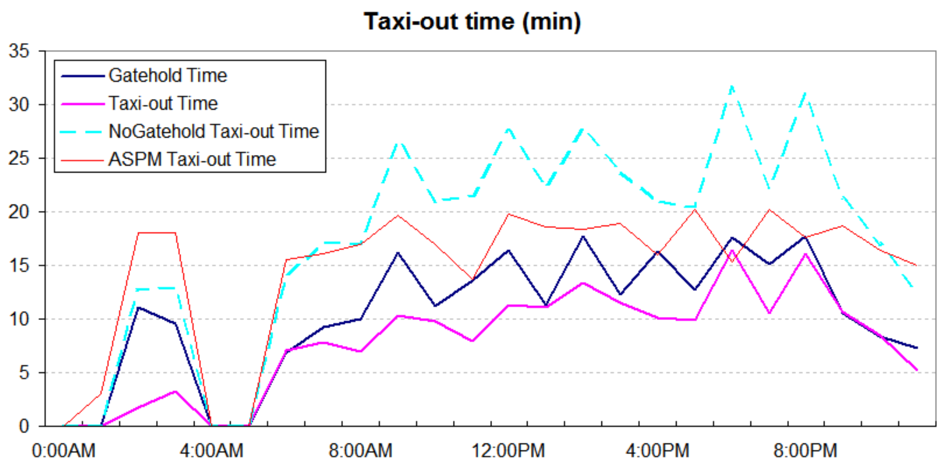
- Run for whole day flights on 9/26/2006
  - Runway configuration
    - 22R | 21L (arrival), 21R | 22L (departure)
- Implementation
  - 30 min rolling horizon with 15 min overlap
    - 15 min time period shift for the next optimization
  - Time discretization: 5 seconds
- Integrated with Runway Planner and TME
- Problem formulated as an Integer Program
- Solved using AMPL/CPLEX

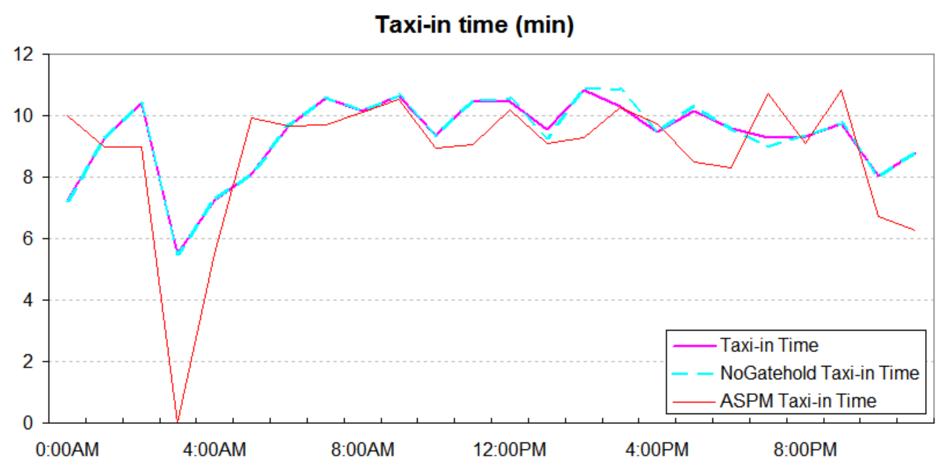
TP: Simulation at DTW

- Output data
  - Controlled pushback times for departures (gate holding strategy)
  - Gate-in times for arrivals
- Taxi speed limits
  - Max. taxi speed determined from unimpeded taxi times
    - Gates: 0.3 – 3 knots; Ramp area: 0.7 – 7 knots; Taxiways: 6 – 18 knots

TP: Simulation Results

- # departures: 673 aircraft
  - Avg. gate-hold time: 13.6 min; avg. taxi-out time: 10.9 min
  - No gate-hold case taxi-out time: 22.9 min
    - Gate-hold strategy reduces the taxi-out time (not considering gate holding time) by 55%.
- # arrivals: 669 aircraft
  - Avg. taxi-in time: 9.8 min; no gate-hold case: 9.9 min

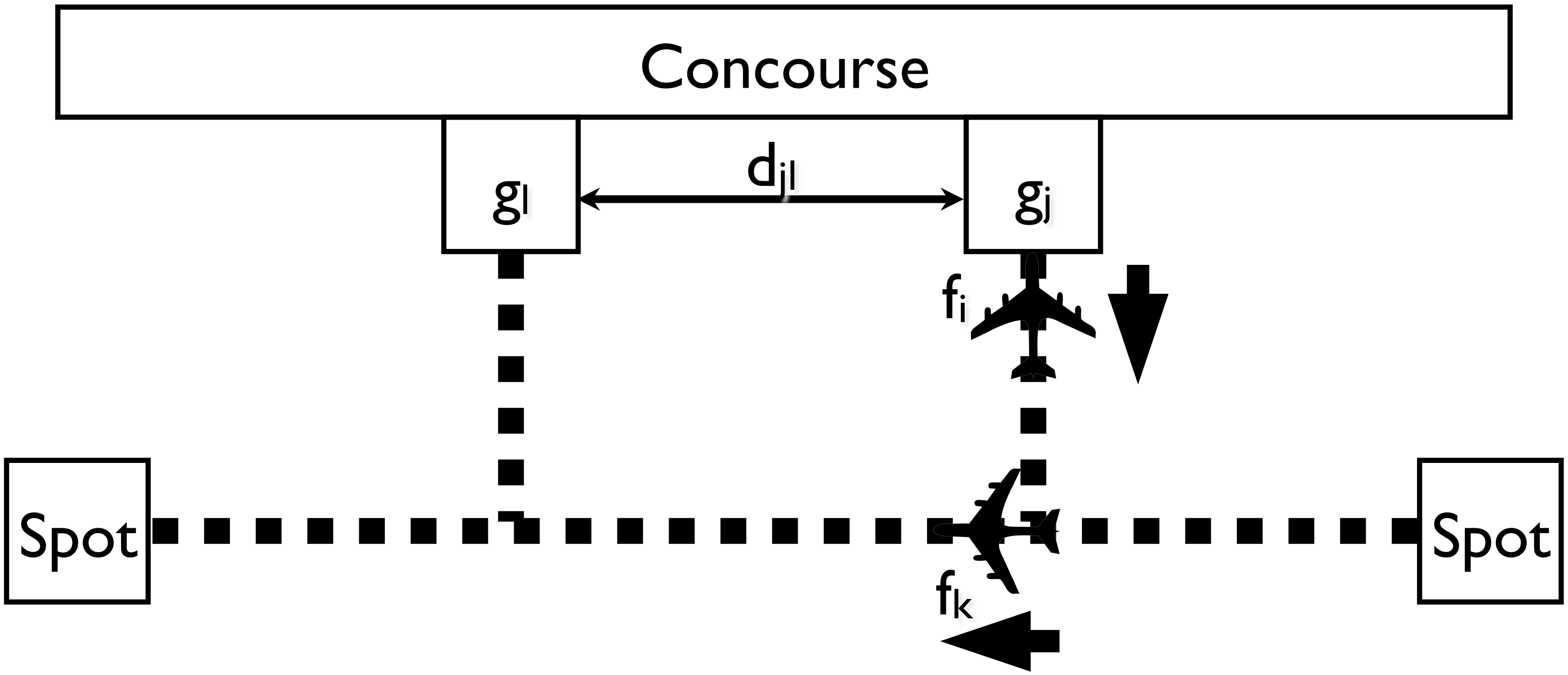




Gate Assigner (GA)

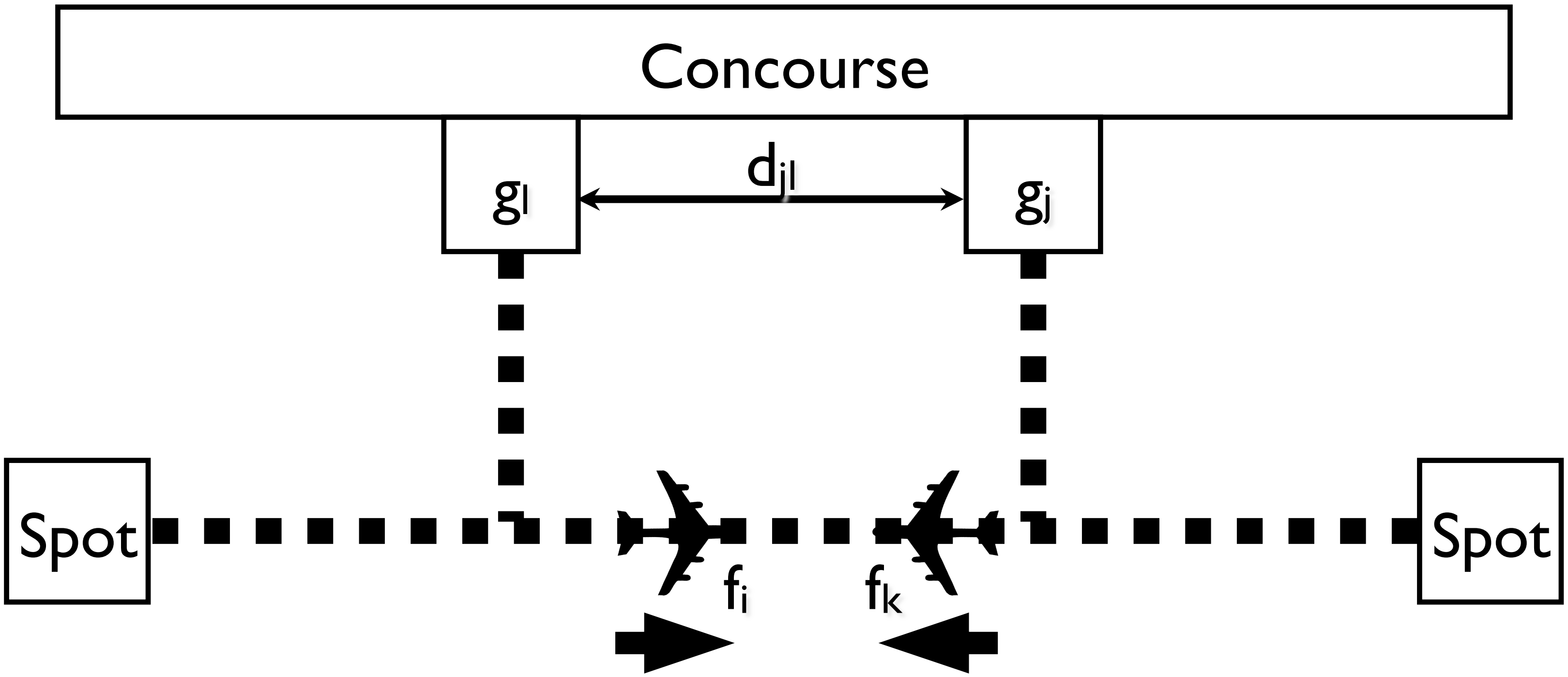
- Decide (for each aircraft)
  - Gate
- Given
  - Uncertain availability or "readiness"
  - Interactions in ramp area
- To
  - Minimize passenger connection time (including ramp congestion)
- While
  - Satisfying safety requirements

GA: Modeling Push-back Blocking



- The push-back trajectory of flight i is blocked by flight k.
- Push-back or taxi will be delayed.

GA: Modeling Taxi Blocking



- Two aircraft taxi in opposite directions.
- Taxi will be delayed.

GA: Problem Formulation

$$\min \sum_{i,k \in F} \sum_{j,l \in G} (C^w_{ijkl} + C^d_{ijkl}) x_{ij} x_{kl} + \sum_{i \in F} \sum_{j \in G} C^t_{ij} x_{ij}$$

$$\sum_{j \in G} x_{ij} = 1, \forall i \in F$$

$$(t_{out_i} - t_{in_k}) \times (t_{out_k} - t_{in_i}) \leq \mathrm{M}(1 - x_{ij} x_{kj}), \forall i, k \in F, j \in G$$

$$\text{where } x_{ij} = \begin{cases} 1 & \text{if } f_i \text{ is assigned to } g_j \\ 0 & \text{otherwise} \end{cases}$$

F	Set of Flights
G	Set of Gates
C^w_{ijkl}	Passenger walking time from f_i to f_k
C^d_{ijkl}	Taxi delay induced by the physical conflict between f_i and f_k
C^t_{ij}	Taxiing time of f_i

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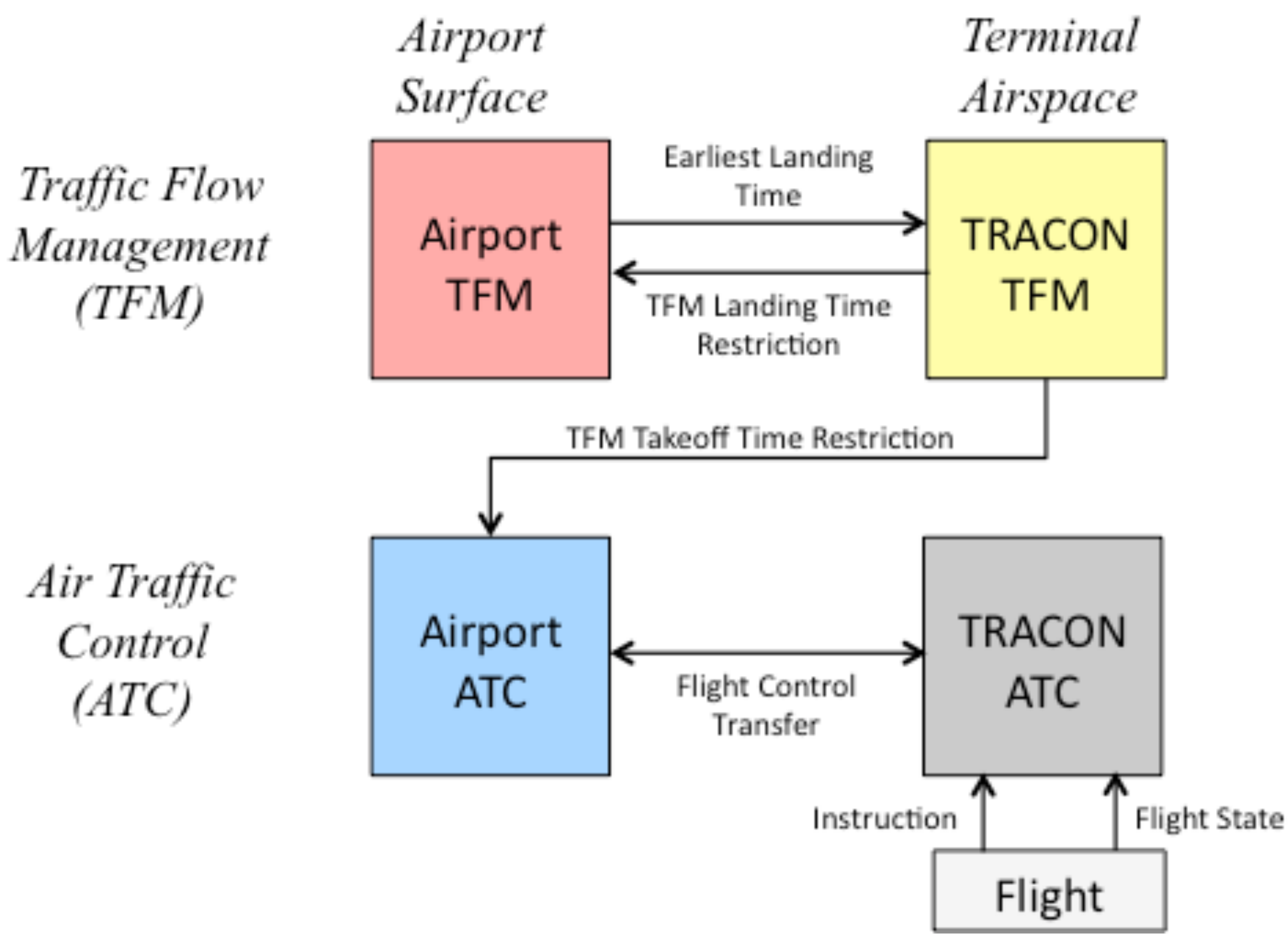
Terminal Model Enhancement (TME) of ACES 6.1

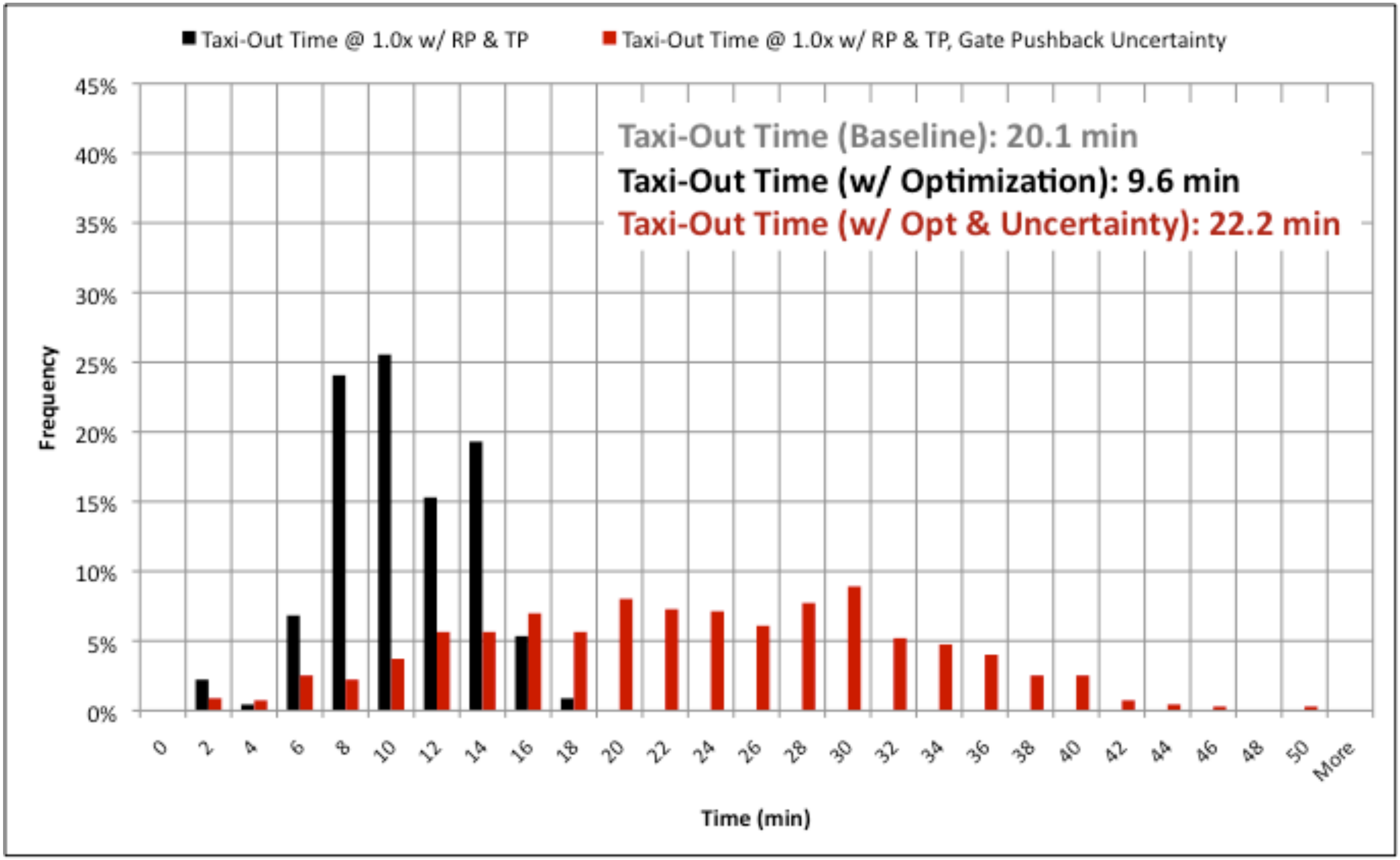
- ACES TME models terminal operations using Airport (TFM and ATC), TRACON (TFM and ATC), Flight agents



Phase I Evaluation – DONE!

- Focus
  - Runway and Taxiway Planners
- Scenarios
  - 1.0X, VFR, No optimization
  - 1.0X, VFR, RP (FCFS), TP
  - 1.0X, VFR, RP, TP
  - 1.0X, VFR, RP, TP, Gate Pushback Uncertainty
  - 1.5X, VFR, RP, TP
- Metrics
  - Departure/Arrival Count
  - Taxi-in and Taxi-out Time
  - Taxi-in and Taxi-out Delay
  - Gate Holding Time

Effect of Optimization and Gate Pushback Uncertainty on Taxi-Out Time



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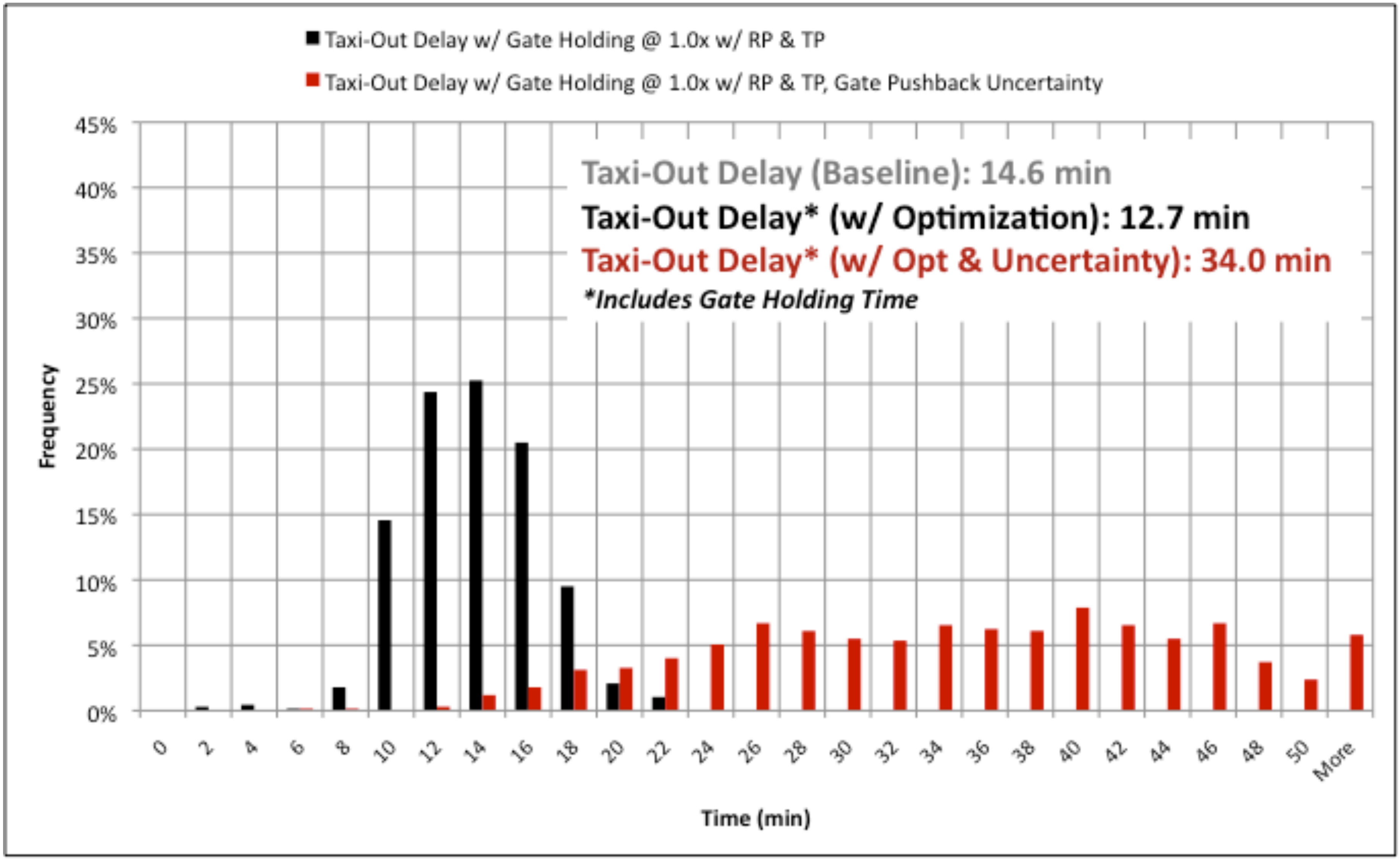
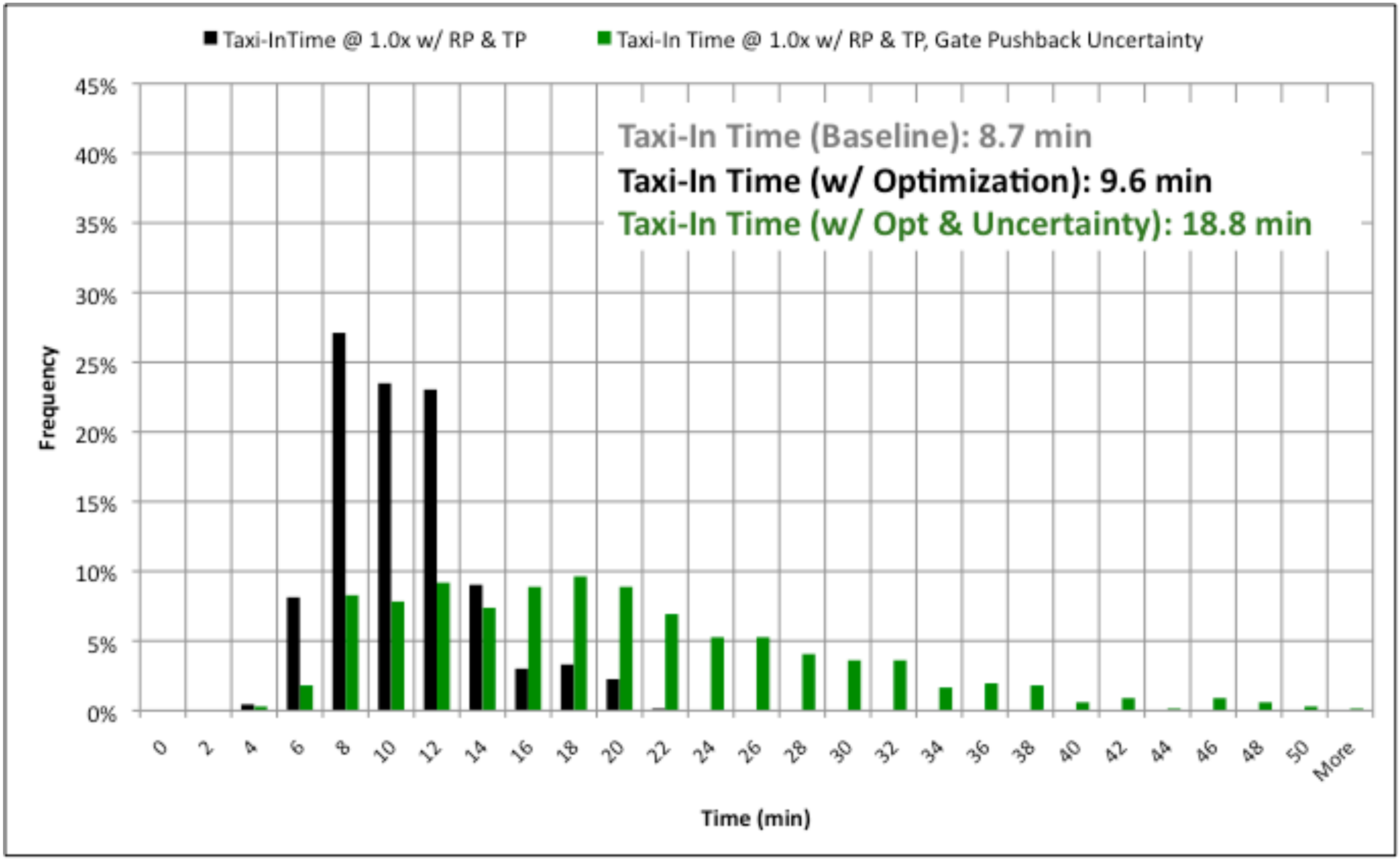
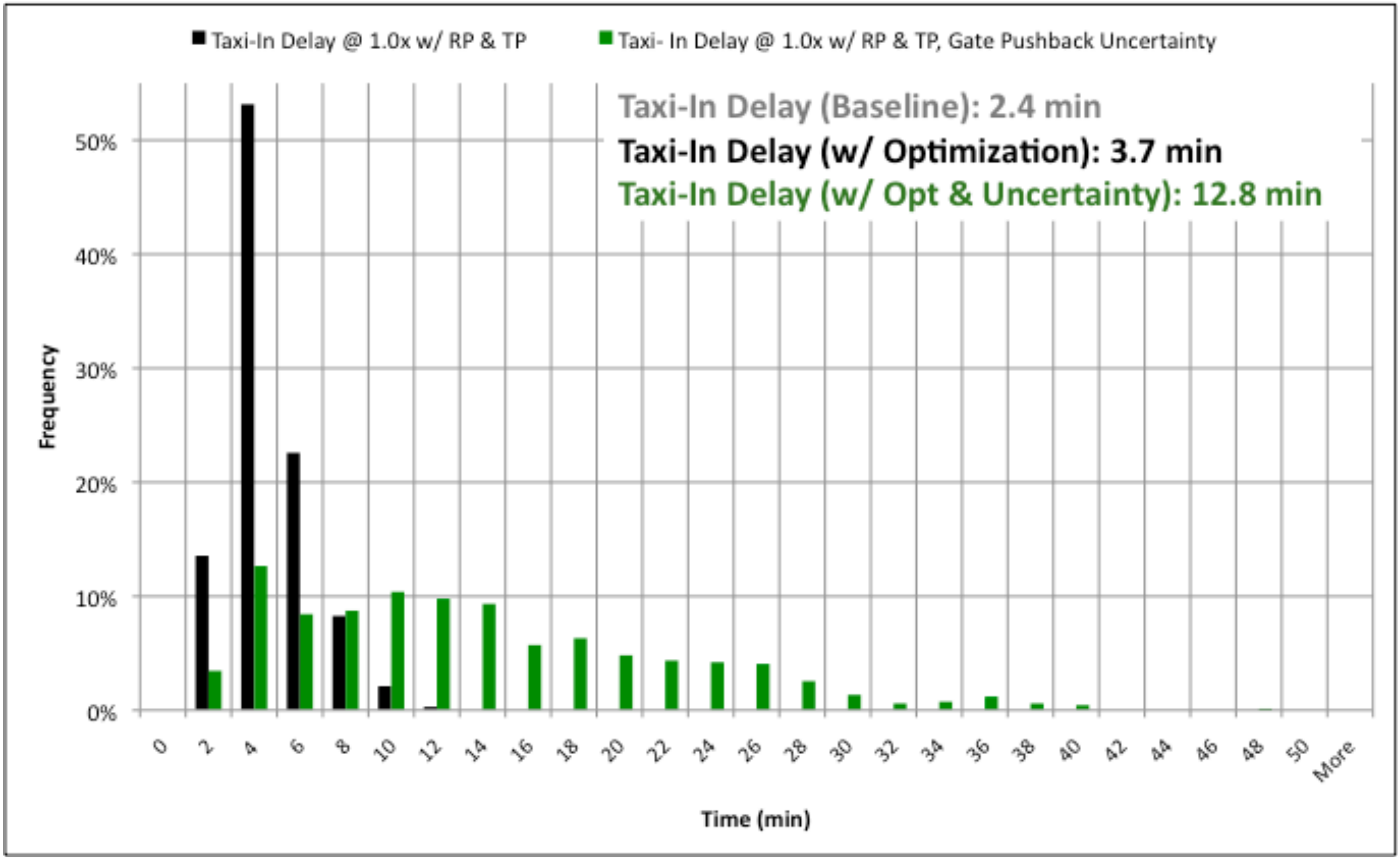
Effect of Optimization and Gate Pushback Uncertainty on Taxi-Out Delay



Effect of Optimization and Gate Pushback Uncertainty on Taxi-In Time



Effect of Optimization and Gate Pushback Uncertainty on Taxi-In Delay



Collaborative Virtual Queue (CVQ)

- Decide (for ramp area)
  - Sequence of aircraft leaving ramp
  - Pushback schedule
- Given
  - Uncertain availability or “readiness”
  - User business objectives
  - Interactions in ramp area
- To
  - Minimize ramp congestion
  - Maximize user performance
- While
  - Satisfying safety requirements

Runway Regulator (RR)

- Decide (for each set of closely spaced parallel runways)
  - Time to issue automated takeoff clearance
  - Time to issue automated abort-takeoff clearance (if necessary)
- Given
  - Improved position information for arrivals (ADS-B, Multilateration)
  - Probability of missed approaches
- To
  - Maximize adherence to planned runway schedule
- While
  - Satisfying safety requirements