Georgia Tech Air Transportation Laboratory

Algorithms for Economically and Environmentally Efficient Surface Movement

John-Paul Clarke
Associate Professor, School of Aerospace Engineering
Director, Air Transportation Laboratory
Georgia Institute of Technology

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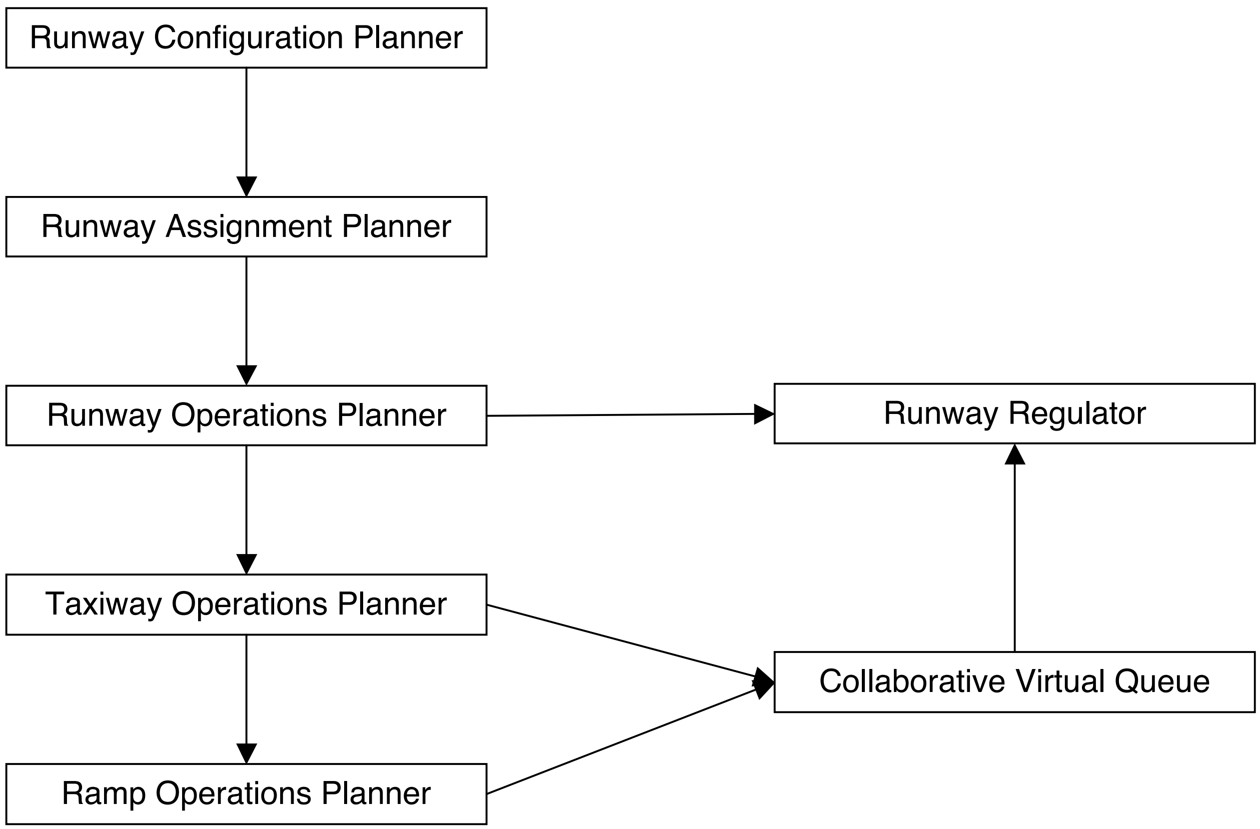
Optimization Architecture



Sensis
Seagull Technology Center

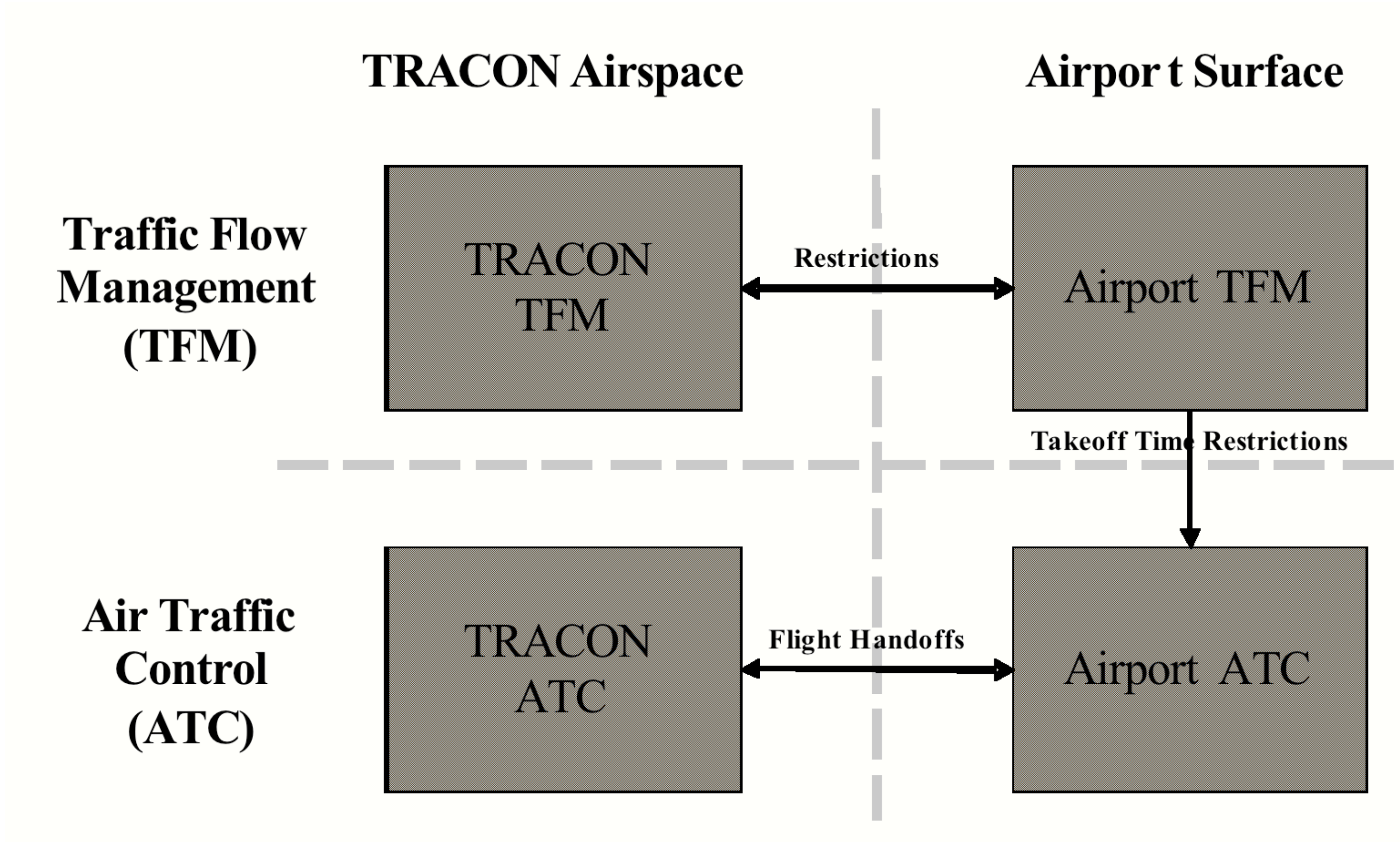
Fast-Time Simulation Environment

David Rappaport, Kathy Griffin, Peter Yu (Sensis)
with contributions by Georgia Tech and MIT

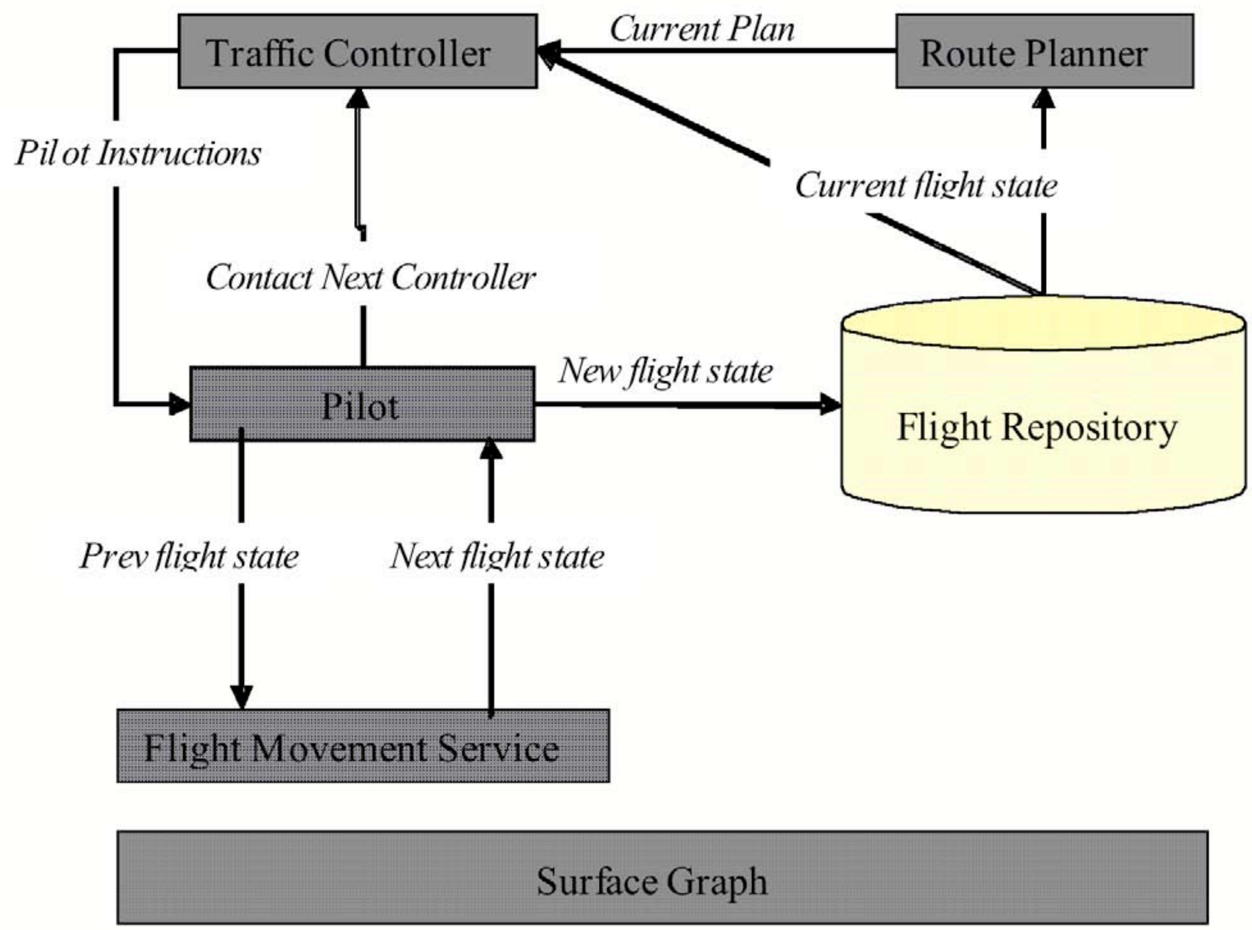
Overview

- **Simulation Engine**
  - Airspace Concept Evaluation System (ACES) Terminal Model Enhancement (TME)
- **Phase I Integration**
  - ACES-TME w/ Runway Operation Planner and Taxiway Operations Planner
- **Phase II Integration**
  - ACES-TME w/ Runway Configuration Planner, Runway Operation Planner and Taxiway Operations Planner
- **Phase III+ Integration**
  - ACES-TME w/ all planning and execution components

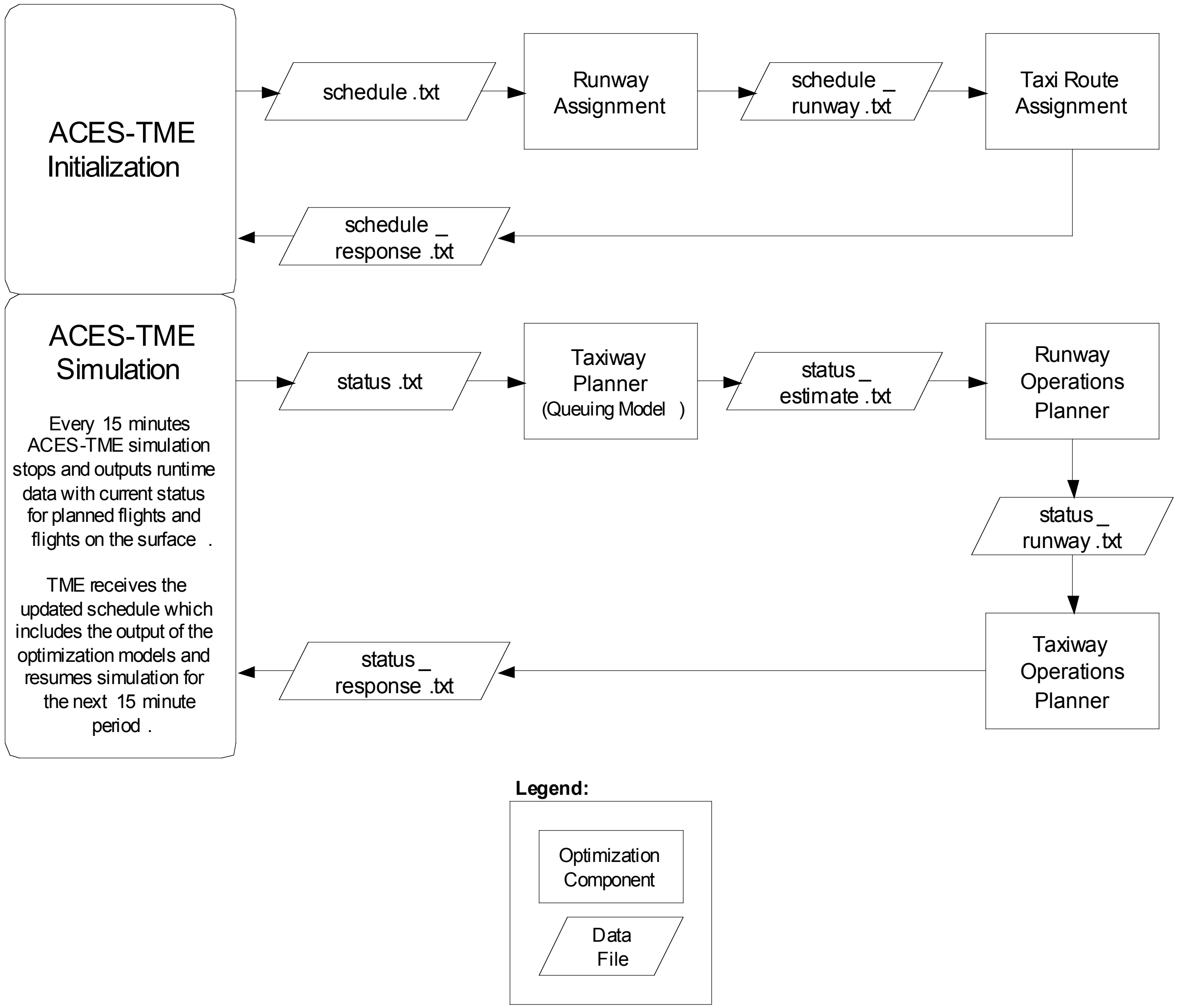
ACES-TME System Architecture



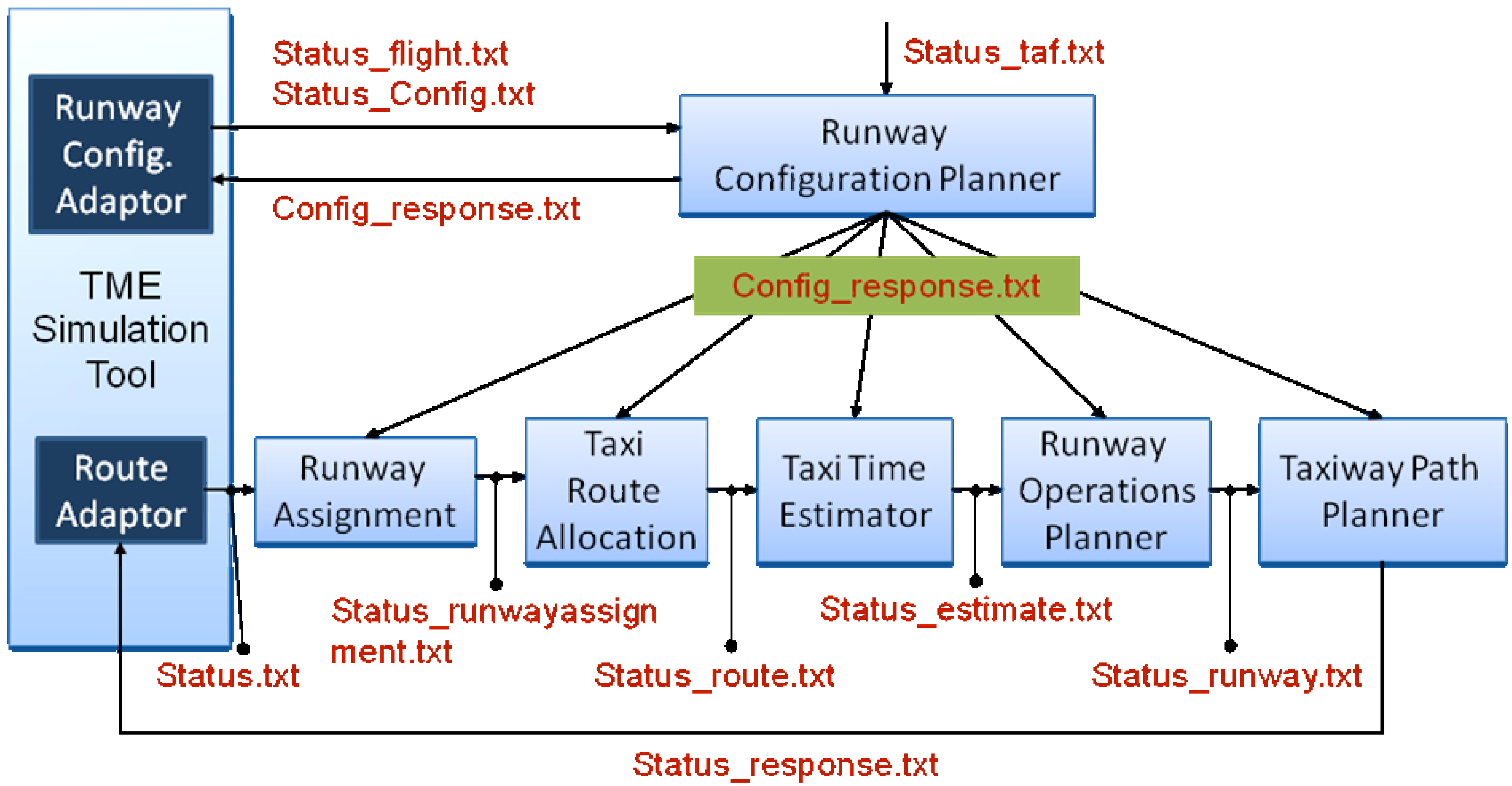
Airport ATC Agent Architecture



Phase I Simulation Process



Phase II Simulation Process



Runway Operations Planner

Gustaf Sölveling, John-Paul Clarke, Ellis Johnson (Georgia Tech)
Senay Solak (UMass Amherst)

Problem Definition

- **Given a list of arriving flights with attributes:**
  - Scheduled arrival times
  - Earliest possible arrival times
  - Aircraft types/classes

  and a list of departing flights with attributes:
  - Scheduled departure times
  - Latest possible departure times
  - Aircraft types/classes
- **Identify an arrival/departure schedule that:**
  - maximizes throughput while minimizing fuel costs (tradeoff model)
  - maximizes throughput while minimizing expected fuel costs if arrival and pushback times are random variables with known distributions (two-stage model)
    - based on deterministic two-stage model by Anagnostakis and Clarke (2002)

Overview

	Deterministic Tradeoff Model	Stochastic Two-Stage Model
One runway	**Single-Runway Deterministic Tradeoff Model**	**Single-Runway Stochastic Two-Stage Model**
More than one Runway	**Two-Runway Deterministic Tradeoff Model**	**Multi-Runway Stochastic Two-Stage Model**

Single-Runway Deterministic Tradeoff Model

❖ Parameters:

T_i^s : scheduled arrival/departure time for flight i
T_L^s : latest scheduled arrival/departure time for flight i
e_i : earliest possible arrival time for flight $i \in A$
l_i : latest possible departure time for flight $i \in D$
S_{ij}^{min} : minimum required time separation between the arrival/departures of flights i and j
f_i^a : fuel cost per unit change in scheduled arrival time for flight $i \in A$
f_i^d : cost per unit time delay in departure time for flight $i \in A$
F : savings per unit time decrease in cycle time for all flights

❖ Variables:

t_i : time of arrival/departure for flight i
t_l : time of latest arrival/departure

Single-Runway Deterministic Tradeoff Model

- **Objective:**
  - Trade-off between throughput (maximization) and cost (minimization)

$$\min \sum_{i\in A} f_i^a |t_i - T_i^s| + \sum_{i\in D} f_i^d (t_i - T_i^s) - F(T_L^s - t_l)$$

- **Constraints:**
  - Departures must occur no earlier than scheduled departure time

$$t_i - T_i^S \geq 0 \quad \forall I \in D$$

  - Minimum required separation is maintained between all pairs of aircraft

$$|t_i - t_j| \geq S_{ij}^{\min} \qquad \forall i, j \in D$$

  - Earliest arrival and latest departure requirements

$$t_i \geq e_i \quad \forall I \in A \qquad t_i \leq l_i \quad \forall I \in D$$

  - Define time of latest arrival/departure

$$t_l \geq t_i \quad \forall i$$

Single-Runway Deterministic Tradeoff Model

❖ Separation Requirements

A	Arrival
D	Departure
H	Heavy weight class
7	757 weight class
L	Large weight class
S	Small weight class

Following Operation

	AH	A7	AL	AS	DH	D7	DL	DS
AH	1.60	2.31	2.31	4.00	1.17	1.17	1.17	1.17
A7	1.60	1.85	1.85	3.33	1.00	1.00	1.00	1.00
AL	1.00	1.15	1.15	2.67	1.00	1.00	1.00	1.00
AS	1.00	1.15	1.15	1.67	0.83	0.83	0.83	0.83
DH	0.80	0.92	0.92	1.33	1.50	1.50	2.00	2.00
D7	0.80	0.92	0.92	1.33	1.50	1.50	2.00	2.00
DL	0.80	0.92	0.92	1.33	1.00	1.00	1.00	1.00
DS	0.80	0.92	0.92	1.33	1.00	1.00	1.00	1.00

Combined Model Sample Results: single-runway

- **Optimized Schedule with Separation Requirements Satisfied**

Event	Original Order	Scheduled Time	First come First Serve Time*	Event	Original Order	New Time
DH	#0	0	0	DH	#0	0
DH	# 1	1.13	1.5	DH	# 1	1.5
DL	# 2	2.03	3.5	DL	# 2	3.5
D7	# 3	3.56	4.5	D7	# 3	4.5
DH	# 4	4.42	6	A7	# 5	5.45
A7	# 5	5.45	6.92	DS	# 6	7.1
DS	# 6	7.1	7.92	DH	# 4	8.1
DL	# 7	7.84	8.92	AS	# 8	9.43
AS	# 8	9.15	10.25	D7	# 9	10.26
D7	# 9	10.13	11.08	D7	#10	11.76
D7	#10	11.29	12.58	A7	#11	12.68
A7	#11	12.65	13.5	DL	# 7	13.76
DS	#12	14.12	14.5	DS	#12	14.76
DH	#13	15.79	15.5	DH	#13	15.79
AH	#14	16.53	16.3	AH	#14	16.59
DS	#15	17.36	17.47	DS	#15	17.79
AL	#16	18.37	18.39	AL	#16	18.9
AL	#17	19.97	19.54	AL	#17	20.05
AS	#18	21.21	22.21	AS	#18	22.72
DH	#19	21.98	23.04	DH	#19	23.55
A7	#20	23.52	23.96	AS	#21	24.88
AS	#21	24.45	27.29	AS	#22	26.55
AS	#22	25.19	28.96	A7	#20	27.7
D7	#23	26.7	29.79	DL	#24	28.7
DL	#24	27.94	31.79	DH	#26	29.86
DH	#25	28.79	32.79	DH	#25	31.36
DH	#26	29.86	34.29	D7	#23	32.86

*If the original order is preserved and separation requirements are enforced.

Dual-Runway Deterministic Tradeoff Model

- **Motivated by configuration at DTW**
- **The two crossings are independent, so assuming runway assignments for flights known we can** focus on a single arrival-departure runway pair

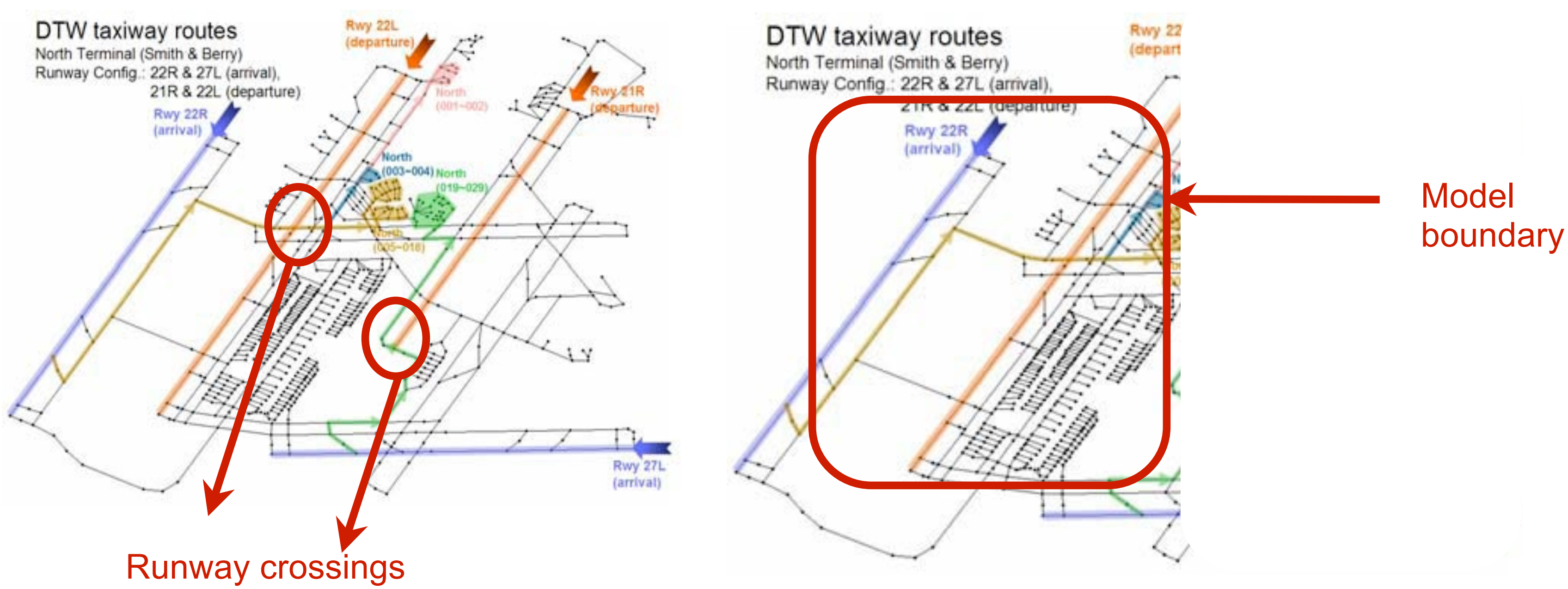


Figure from Balakrishnan and Lee (2008)

Dual-Runway Deterministic Tradeoff Model

- **Parameters (in addition to those in single-runway tradeoff model)**

$\underline{tt}_i$: minimum taxi time for arriving flight $i \in A$ until crossing
$\overline{tt}_i$: maximum taxi/queue time for arriving flight $i \in A$ until crossing
$\underline{S}_{ij}^C$: minimum separation required between crossing arrival i and departing flight j

- **Variables (in addition to those in single-runway tradeoff model)**

t_i^C : time that arriving flight i starts crossing the departure runway
r_i^+ : $= t_i - T_i^S$, if $t_i \geq T_i^S$, 0 otherwise
r_i^- : $= T_i^S - t_i$, if $T_i^S \geq t_i$, 0 otherwise
$y_{i,j}$: 1 if $t_i \leq t_j$, 0 otherwise

Dual-Runway Deterministic Tradeoff Model

- **Formulation**

$$
\begin{aligned}
\min \quad & \sum_{i \in A} f_i^a (r_i^+ + r_i^-) + \sum_{j \in D} f_j^d (t_j - T_j^s) - F(T_L^s - t_l) & \\
& r_i^+ - r_i^- = t_i - T_i^s & \forall i \in A \\
& t_j - T_j^s \geq 0 & \forall j \in D \\
& t_i \geq e_i & \forall i \in A \\
& t_j \leq l_j & \forall j \in D \\
& t_i - t_{i'} \geq S_{ii'}^{min} - M_{ii'} y_{ii'} & \forall i, i' \in A \\
& -t_i + t_{i'} \geq S_{i'i}^{min} - M_{ii'} (1 - y_{ii'}) & \forall i, i' \in A \\
& t_j - t_{j'} \geq S_{jj'}^{min} - M_{jj'} y_{jj'} & \forall j, j' \in D \\
& -t_j + t_{j'} \geq S_{j'j}^{min} - M_{jj'} (1 - y_{jj'}) & \forall j, j' \in D \\
& t_i - t_i^c \geq \underline{tt}_i & \forall i \in A \\
& t_i - t_i^c \leq \bar{tt}_i & \forall i \in A \\
& t_i^c - t_j \geq \underline{S}_{ij}^c - M_{ij} y_{ij} & \forall i \in A, j \in D \\
& -t_i^c + t_j \geq \underline{S}_{ji}^c - M_{ij} (1 - y_{ij}) & \forall i \in A, j \in D \\
& \mathbf{t}, \mathbf{r} \in \mathcal{R}; \mathbf{y} \in \mathcal{B} &
\end{aligned}
$$

Stochastic Two-Stage Model – 1st Stage

- **Objective:**
  - Identify an optimum sequence of arrivals/departures according to aircraft classes only
- **Assumptions:**
  - Let G(N,A) be a complete graph such that N contains a node for each aircraft that is scheduled to arrive/depart, which is represented by the aircraft class and event type
  - N also contains a source node ‘0’
  - Let $S_{ij}^{\min}$ be the required separation time if flight j is scheduled after flight i
- **Approach:**
  - The solution of the Traveling Salesman Problem on G is an optimal sequence for throughput maximization in the first stage of the stochastic problem

Stochastic Two-Stage Model – 1st Stage

- **Given the following sets, parameters and variables:**

Sets:

I:	set of operations, defined with direction (arrival/departure) and aircraft class (H,7,L,S)
N:	$I \cup \{0\}$ set of nodes in the graph over which a TSP is solved
A:	set of arcs in the graph. $A = \{(i,j) \mid i \in N, j \in N, i \neq j\}$

Parameters:

$S_{i,j}^{\min}$:	minimum required time separation between operation i and j $S_{0,i}^{\min} = 0$ and $S_{i,0}^{\min} = 0$ for all operations i

Variables:

t_i :	time of arrival/departure for operation i
$x_{i,j}$:	1 if operation i is immediately followed by operation j, 0 otherwise

Stochastic Two-Stage Model – 1st Stage

- **The model can now be formulated as:**

$$
\begin{aligned}
\min \quad & \sum_{f\in F} f^{+}(r^{\omega}_{+,f}) + \sum_{f\in F} f^{-}(r^{\omega}_{-,f}) && && (1)\\
\text{s.t.} \quad & \sum_{i\in I} y_{f,i} = 1 && \forall f \in F && (2)\\
& \sum_{f\in F(i)} y_{f,i} = 1 && \forall i \in I && (3)\\
& r^{\omega}_{+,f} \geq t_i - T^{\omega}_{f} - M(1 - y_{f,i}) && \forall f \in F, i \in I && (4)\\
& r^{\omega}_{-,f} \geq T^{\omega}_{f} - t_i - M(1 - y_{f,i}) && \forall f \in F, i \in I && (5)\\
& \mathbf{r}^{\omega}_{+}, \mathbf{r}^{\omega}_{-} \in \mathcal{R}_{+}, \mathbf{y} \in \mathcal{B}
\end{aligned}
$$

The objective in stage 2 minimizes the cost of deviating from scheduled arrival/departure time. A flight can only be assigned to one operation (2) and an operation can only be associated with one flight (3). The delay and early arrival is calculated in (4) and (5) respectively.

Stochastic Two-Stage Model – 2nd Stage

- **Objective:**
  - Assign individual flights to the optimum sequence such that the resulting assignment minimizes total cost, after the uncertainty in event times are realized
- **Assumptions:**
  - Let G'(N',A') be a bipartite graph such that N1 contains a node for each aircraft that is scheduled to arrive/depart, N2 contains a node for each aircraft class/event type in the optimum sequence
  - Let A' contain an arc for each feasible assignment of flights to the slots in the sequence
  - Let f be the fuel/delay cost function if flight i is assigned to slot j in the optimum sequence
- **Approach**
  - The solution of the Assignment Problem on G' is a minimum cost feasible schedule

Stochastic Two-Stage Model – 2nd Stage

- **Given the following sets, parameters and variables:**

Sets:

I:	set of operations, defined with direction (arrival/departure) and aircraft class (H,7,L,S)
F:	set of flights
$F(i)$:	set of flights of operation type i
Ω:	set of scenarios

Parameters:

T_f^ω:	scheduled arrival/departure time for flight f in scenario ω
t_i:	time of arrival/departure for operation i

Variables:

$r_{+,f}^\omega$	late time for flight f in scenario ω
$r_{-,f}^\omega$	early time for flight f in scenario ω
$y_{f,i}^\omega$	1 if flight f is assigned to operation i in scenario ω, 0 otherwise

Stochastic Two-Stage Model – 2nd Stage

- **The model can now be formulated as:**

$$
\begin{aligned}
\min \quad & \sum_{f \in F} f^{+}(r^{\omega}_{+,f}) + \sum_{f \in F} f^{-}(r^{\omega}_{-,f}) && && (1)\\
\text{s.t.} \quad & \sum_{i \in I} y_{f,i} = 1 && \forall f \in F && (2)\\
& \sum_{f \in F(i)} y_{f,i} = 1 && \forall i \in I && (3)\\
& r^{\omega}_{+,f} \geq t_i - T^{\omega}_{f} - M(1 - y_{f,i}) && \forall f \in F, i \in I && (4)\\
& r^{\omega}_{-,f} \geq T^{\omega}_{f} - t_i - M(1 - y_{f,i}) && \forall f \in F, i \in I && (5)\\
& \mathbf{r}^{\omega}_{+}, \mathbf{r}^{\omega}_{-} \in \mathcal{R}_{+}, \mathbf{y} \in \mathcal{B}
\end{aligned}
$$

The objective in stage 2 minimizes the cost of deviating from scheduled arrival/departure time. A flight can only be assigned to one operation (2) and an operation can only be associated with one flight (3). The delay and early arrival is calculated in (4) and (5) respectively.

Stochastic Two-Stage Model

- **With the sets and parameters:**

Ω:	set of scenarios
p^ω:	probability of scenario $\omega \in \Omega$
$\mathbf{c}$:	vector representing cost in stage 1
$\mathbf{d}^\omega$:	vector representing cost in stage 2 for scenario $\omega \in \Omega$
$\mathbf{A}$:	matrix representing constraints in stage 1
$\mathbf{B}^\omega$:	matrix representing constraints in stage 2 for scenario $\omega \in \Omega$
$\mathbf{b}$:	right hand side value

- **The stochastic program can be formulated as:**

$$\min \quad \mathbf{c}^T\mathbf{x} + \sum_{\omega\in\Omega} p^\omega \mathbf{d}^{\omega T}\mathbf{r}^\omega$$

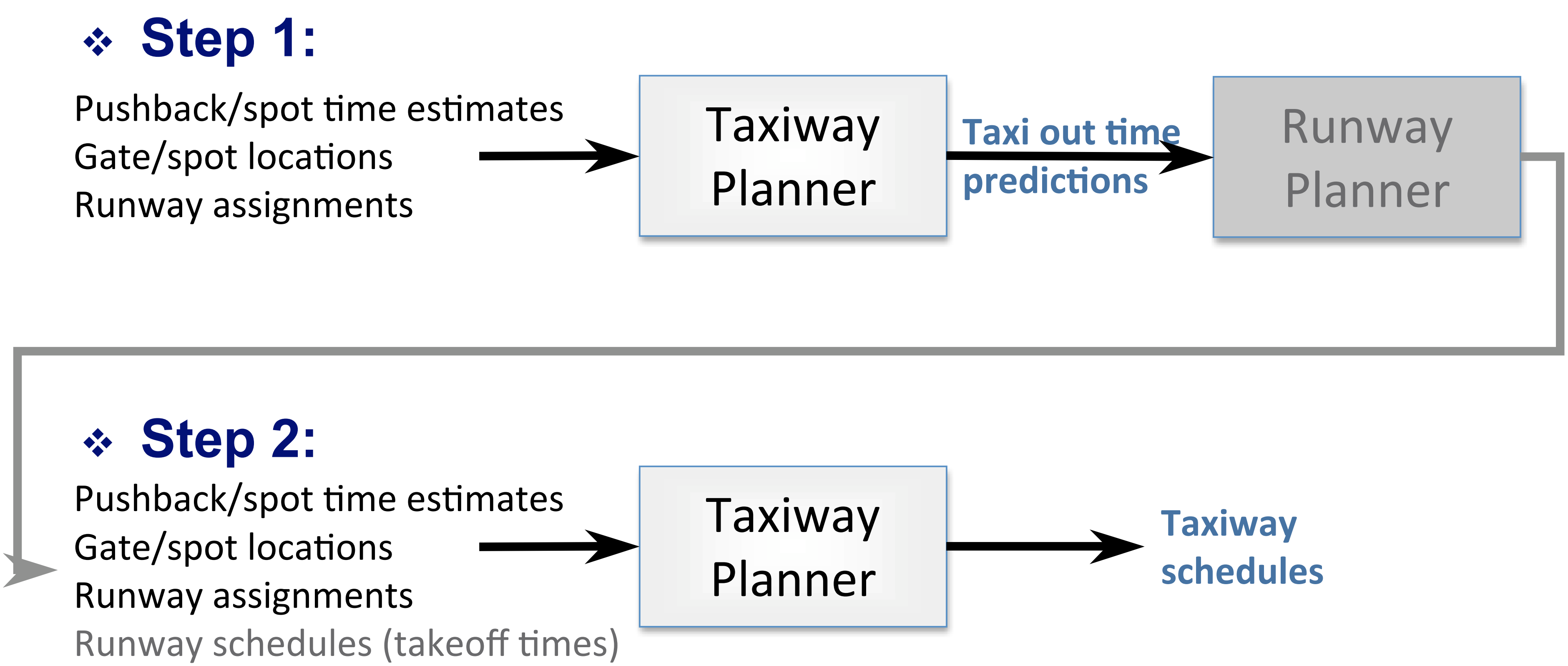
$$\text{s.t.} \quad \mathbf{A}\begin{bmatrix}\mathbf{x}\\ \mathbf{t}\end{bmatrix} + \mathbf{B}^\omega \begin{bmatrix}\mathbf{y}\\ \mathbf{r}\\ \mathbf{t}\end{bmatrix} = \mathbf{b} \qquad \forall \omega \in \Omega$$

$$\mathbf{x}, \mathbf{y} \in \{0,1\} \quad \mathbf{t}, \mathbf{r} \geq 0$$

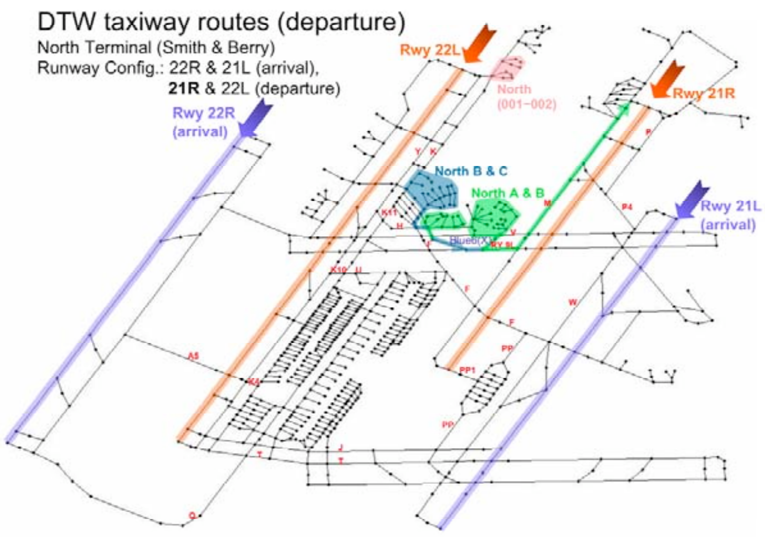
Taxiway Operations Planner

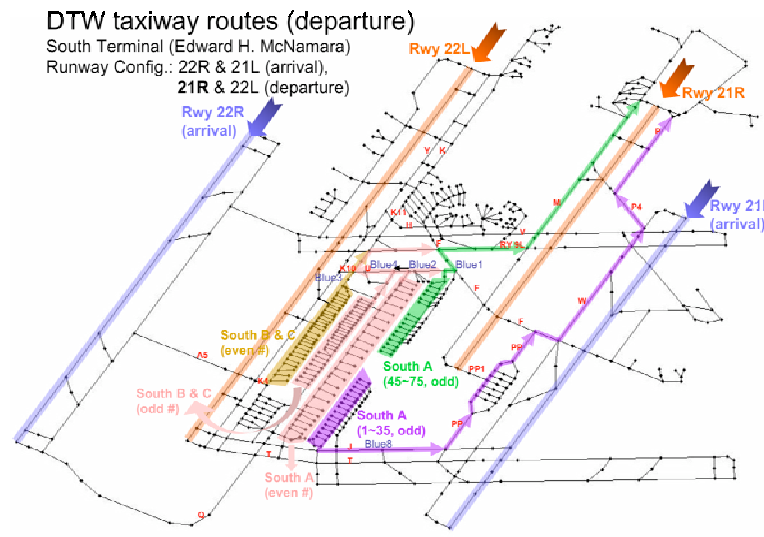
Hanbong Lee, Hamsa Balakrishnan (MIT)

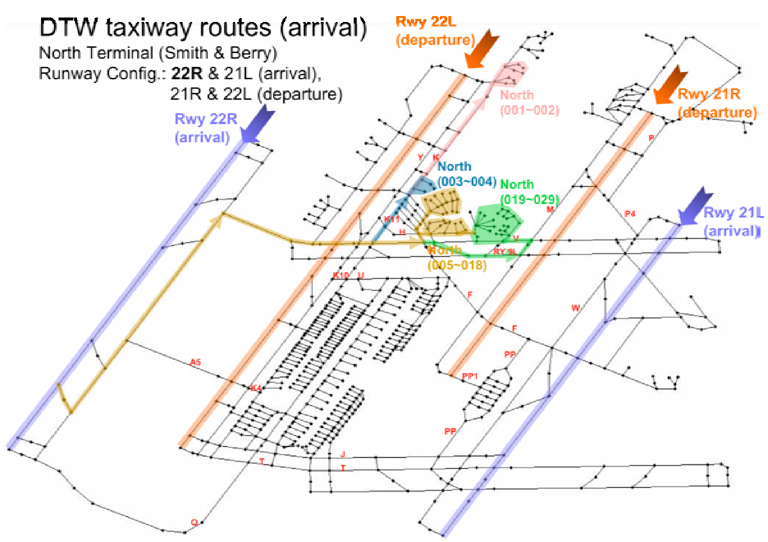
Taxiway Operations Planner

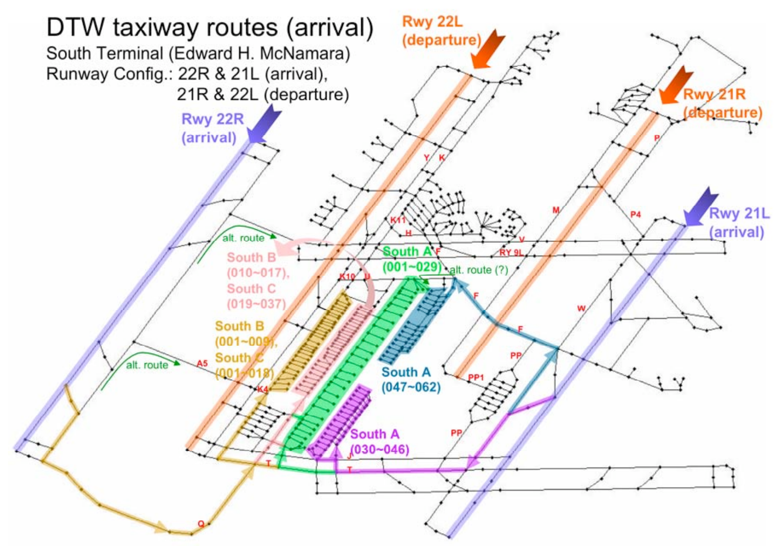


Sample DTW Taxi Routes

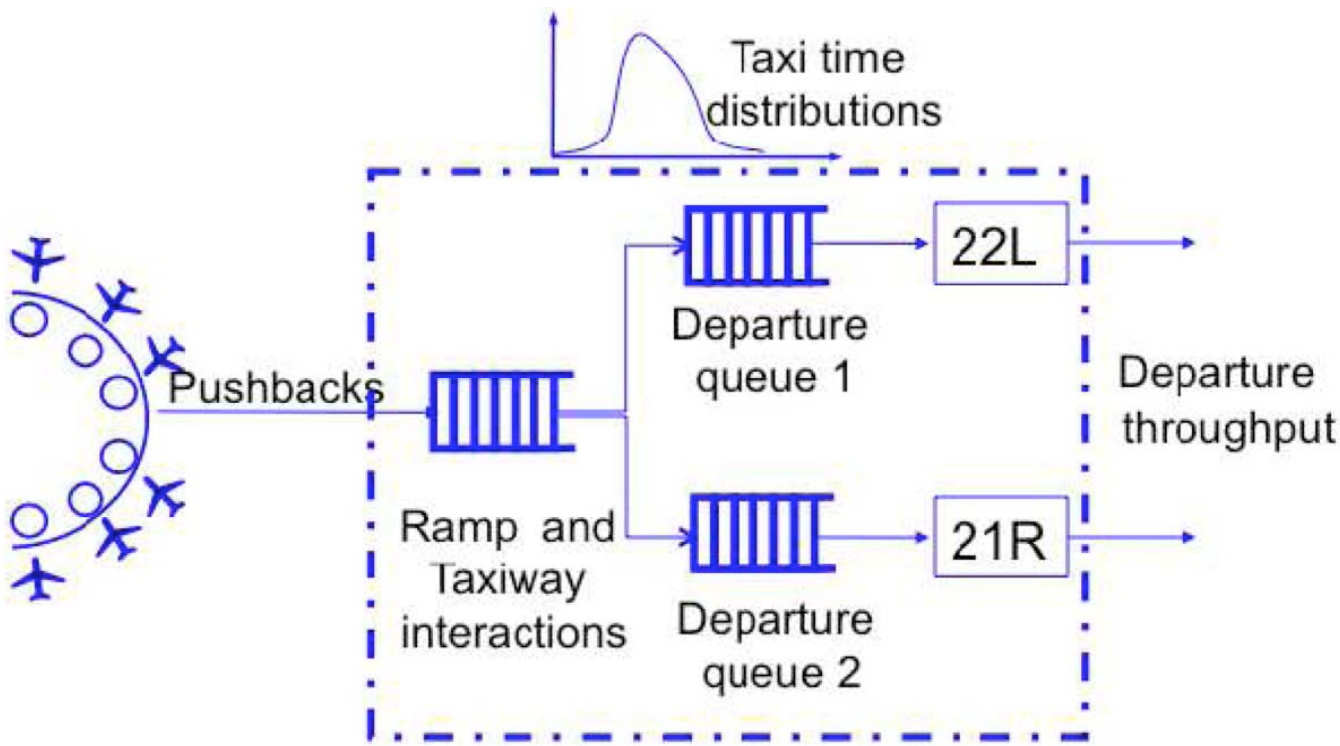




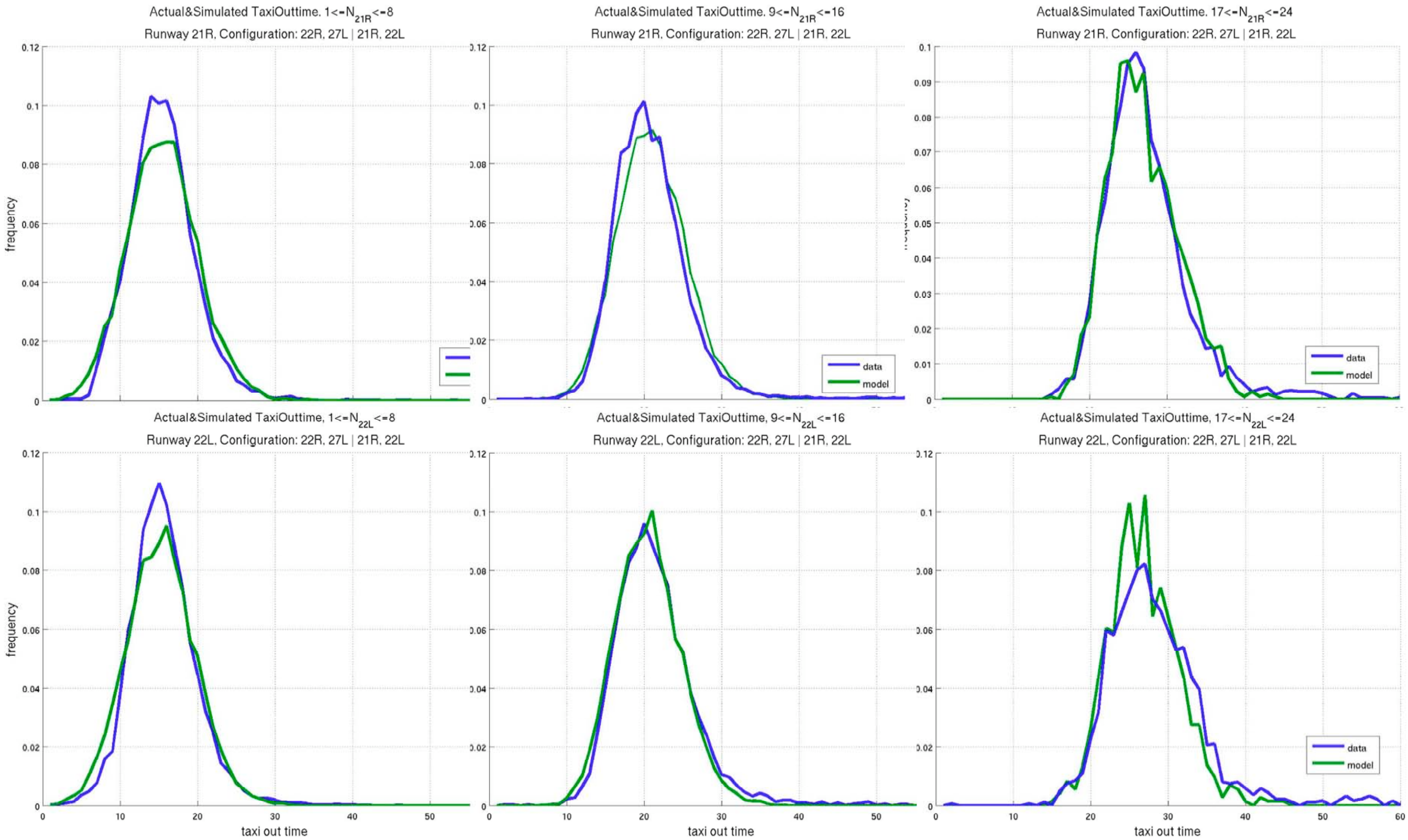




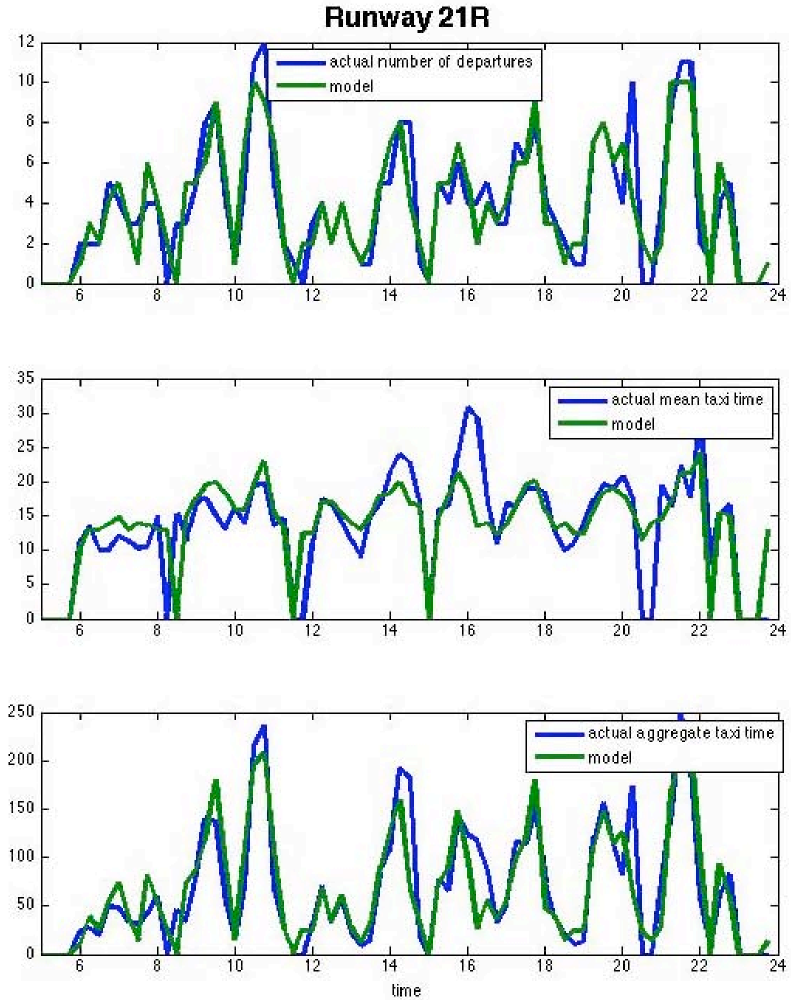
Runway Arrival Time Estimator

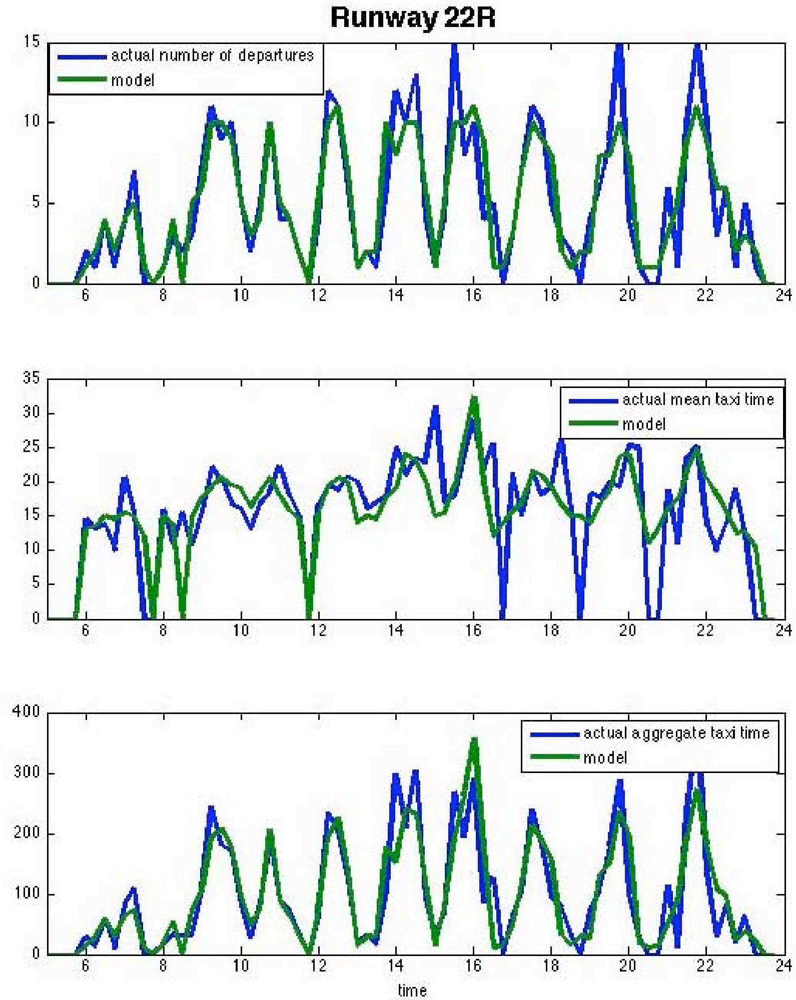


Modeled v. Actual Taxi-Out Time



Modeled v. Actual Departure Statistics





Optimization of taxiway schedules

- **Minimize total taxi time**
  - Time between pushback and wheels-off for departures
  - Time between wheels-on and gate arrival for arrivals
  - Currently associate twice the cost per unit delay for arrivals as compared to departures
  - Large penalty associated with not meeting runway schedule
- **Model two modes of operation:**
  - Only deconflict trajectories through speed advisories along links; no gate or spot hold assigned
  - Assign gate/spot hold times, that is, control the time at which aircraft enter taxiway system

Optimization of taxiway schedules

- **Integer program to compute optimum pushback times and surface trajectories, given gate (or spot) and runway assignments, and earliest possible pushback time**
- **Solved using AMPL/CPLEX**
- **Runway schedules (required time of arrival at runway for departures) set by enforcing wake-vortex separation requirements on the predicted arrival times at the runway**
- **Parameters tuned such that the baseline case (with no gate or spot hold) are consistent with current operations**
  - Maximum speed on taxiways: 15 knots
  - Maximum speed in ramp area: 7 knots

Georgia Tech Air Transportation Laboratory

Initial Results

Optimization Results (1)

Time Window	Departures			Arrivals	
	Number of flights	Avg. gate holding time (min)	Avg. taxi time (min)	Number of flights	Avg. taxi time (min)
12:00AM ~ 12:15AM	0	-	-	0	-
12:15AM ~ 12:30AM	0	-	-	0	-
12:30AM ~ 12:45AM	0	-	-	0	-
12:45AM ~ 1:00AM	0	-	-	0	-
1:00AM ~ 1:15AM	0	-	-	0	-
1:15AM ~ 1:30AM	0	-	-	0	-
1:30AM ~ 1:45AM	0	-	-	0	-
1:45AM ~ 2:00AM	0	-	-	0	-
2:00AM ~ 2:15AM	4	5.5	10.5	0	-
2:15AM ~ 2:30AM	19	7.9	10.3	0	-
2:30AM ~ 2:45AM	23	9.7	9.9	2	8.5
2:45AM ~ 3:00AM	12	8.6	9.3	0	-
3:00AM ~ 3:15AM	7	8.8	6.6	8	8.8
3:15AM ~ 3:30AM	3	7.6	7.3	0	-
3:30AM ~ 3:45AM	3	8.6	4.8	2	7.8
3:45AM ~ 4:00AM	1	5.8	6.2	1	6.0
4:00AM ~ 4:15AM	12	8.3	8.2	5	7.5
4:15AM ~ 4:30AM	17	9.3	10.0	7	9.0
4:30AM ~ 4:45AM	26	11.1	10.4	3	11.2
4:45AM ~ 5:00AM	12	13.7	11.4	7	7.3
5:00AM ~ 5:15AM	5	9.2	7.9	4	8.9
5:15AM ~ 5:30AM	5	7.0	8.8	3	7.2
5:30AM ~ 5:45AM	8	7.5	9.2	2	7.5
5:45AM ~ 6:00AM	4	7.7	6.6	2	5.6
6:00AM ~ 6:15AM	2	7.8	6.4	2	9.4
6:15AM ~ 6:30AM	2	7.6	4.9	3	10.7
6:30AM ~ 6:45AM	0	-	-	4	7.1
6:45AM ~ 7:00AM	0	-	-	0	-
7:00AM ~ 7:15AM	0	-	-	2	4.8
7:15AM ~ 7:30AM	0	-	-	0	-
7:30AM ~ 7:45AM	0	-	-	1	7.5
7:45AM ~ 8:00AM	0	-	-	1	9.0

Optimization Results (2)

Time Window	Departures			Arrivals	
	Number of flights	Avg. gate holding time (min)	Avg. taxi time (min)	Number of flights	Avg. taxi time (min)
8:00AM ~ 8:15AM	0	-	-	0	-
8:15AM ~ 8:30AM	0	-	-	0	-
8:30AM ~ 8:45AM	0	-	-	0	-
8:45AM ~ 9:00AM	0	-	-	2	8.3
9:00AM ~ 9:15AM	0	-	-	1	10.3
9:15AM ~ 9:30AM	1	11.1	1.7	0	-
9:30AM ~ 9:45AM	0	-	-	0	-
9:45AM ~ 10:00AM	1	11.0	1.8	0	-
10:00AM ~ 10:15AM	1	5.8	6.3	1	4.6
10:15AM ~ 10:30AM	0	-	-	0	-
10:30AM ~ 10:45AM	2	11.5	1.8	0	-
10:45AM ~ 11:00AM	0	-	-	0	-
11:00AM ~ 11:15AM	0	-	-	1	7.1
11:15AM ~ 11:30AM	0	-	-	0	-
11:30AM ~ 11:45AM	0	-	-	0	-
11:45AM ~ 12:00PM	0	-	-	0	-
12:00PM ~ 12:15PM	0	-	-	5	7.0
12:15PM ~ 12:30PM	0	-	-	6	8.7
12:30PM ~ 12:45PM	0	-	-	3	6.3
12:45PM ~ 1:00PM	0	-	-	2	6.5
1:00PM ~ 1:15PM	1	5.3	6.6	3	9.8
1:15PM ~ 1:30PM	5	6.6	6.7	1	5.6
1:30PM ~ 1:45PM	7	7.0	7.1	0	-
1:45PM ~ 2:00PM	5	7.8	6.9	1	10.2
2:00PM ~ 2:15PM	8	6.8	9.0	4	9.4
2:15PM ~ 2:30PM	9	9.7	7.2	12	9.4
2:30PM ~ 2:45PM	2	11.0	7.9	15	7.9
2:45PM ~ 3:00PM	6	12.8	7.6	15	9.4
3:00PM ~ 3:15PM	4	13.6	10.1	12	8.7
3:15PM ~ 3:30PM	4	6.8	7.9	8	6.9
3:30PM ~ 3:45PM	5	7.3	6.3	3	8.7
3:45PM ~ 4:00PM	3	8.1	7.8	13	9.5

Optimization Results (3)

Time Window	Departures			Arrivals	
	Number of flights	Avg. gate holding time (min)	Avg. taxi time (min)	Number of flights	Avg. taxi time (min)
4:00PM ~ 4:15PM	13	13.0	10.2	12	9.0
4:15PM ~ 4:30PM	15	14.9	13.7	11	9.7
4:30PM ~ 4:45PM	23	14.3	13.9	8	10.4
4:45PM ~ 5:00PM	19	12.5	13.1	7	6.4
5:00PM ~ 5:15PM	7	9.7	11.3	6	7.8
5:15PM ~ 5:30PM	13	8.2	9.5	10	9.0
5:30PM ~ 5:45PM	14	10.6	9.7	11	8.6
5:45PM ~ 6:00PM	15	13.3	12.8	9	7.4
6:00PM ~ 6:15PM	11	13.8	11.9	14	8.8
6:15PM ~ 6:30PM	5	11.2	8.2	7	9.8
6:30PM ~ 6:45PM	1	5.4	7.0	5	7.8
6:45PM ~ 7:00PM	4	5.6	9.7	2	8.0
7:00PM ~ 7:15PM	10	7.9	9.4	11	8.7
7:15PM ~ 7:30PM	5	10.2	10.3	9	8.3
7:30PM ~ 7:45PM	15	14.8	16.7	14	9.9
7:45PM ~ 8:00PM	14	15.0	17.6	20	8.9
8:00PM ~ 8:15PM	8	12.9	17.7	16	8.4
8:15PM ~ 8:30PM	3	9.6	4.4	2	10.7
8:30PM ~ 8:45PM	5	5.9	10.2	9	6.7
8:45PM ~ 9:00PM	14	10.7	10.3	15	8.6
9:00PM ~ 9:15PM	11	13.4	11.0	6	7.8
9:15PM ~ 9:30PM	16	15.0	15.5	13	9.3
9:30PM ~ 9:45PM	15	14.5	23.9	17	10.0
9:45PM ~ 10:00PM	12	12.9	17.8	10	8.7
10:00PM ~ 10:15PM	12	10.1	20.1	3	7.9
10:15PM ~ 10:30PM	12	7.1	9.2	9	5.8
10:30PM ~ 10:45PM	21	11.5	9.8	0	-
10:45PM ~ 11:00PM	34	14.7	11.9	0	-
	Total: 576	**Average: 11.1 min**	**Average: 11.4 min**	**Total: 423**	**Average: 8.6 min**

Optimization Results (4)

- **Between 4:15PM and 4:30PM on 9/26/2006**
  - Number of frozen flights (from the previous time intervals): 26
  - Number of departures optimized: 20
  - Number of arrivals optimized: 9
  - Average (optimized) taxi-out time: 587.0 sec (versus 1275.5 sec)
  - Average gate-hold time: 688.5 sec
  - Average taxi-in time: 603.3 sec
- **Between 4:30PM and 4:45PM on 9/26/2006**
  - Number of frozen flights (from the previous time intervals): 21
  - Number of departures optimized: 6
  - Number of arrivals optimized: 10
  - Average (optimized) taxi-out time: 706.7 sec (versus 1265.8 sec)
  - Average gate-hold time: 559.2 sec
  - Average taxi-in time: 699.5 sec

Runway Configuration Planner

Leihong Li and John-Paul Clarke (Georgia Tech)