

Development of Methods of Increasing Terminal Flexibility and Control Authority

NASA Contract: NNA14AC42C

Option Year 1 Final Presentation

September 30, 2016

Version #1

Architecture Technology Corporation



Outline



- Background and Overview of Departure Management What-if Analysis
- Option Year 1 Objectives and Accomplishments
- What-if Analysis Tool Enhancements
- Traffic and Weather Scenarios
- What-if Analysis Tool Verification
- What-if Evaluation Metrics
- What-if Evaluation Example
- What-if Analysis Tool Demonstration
- Recommendations



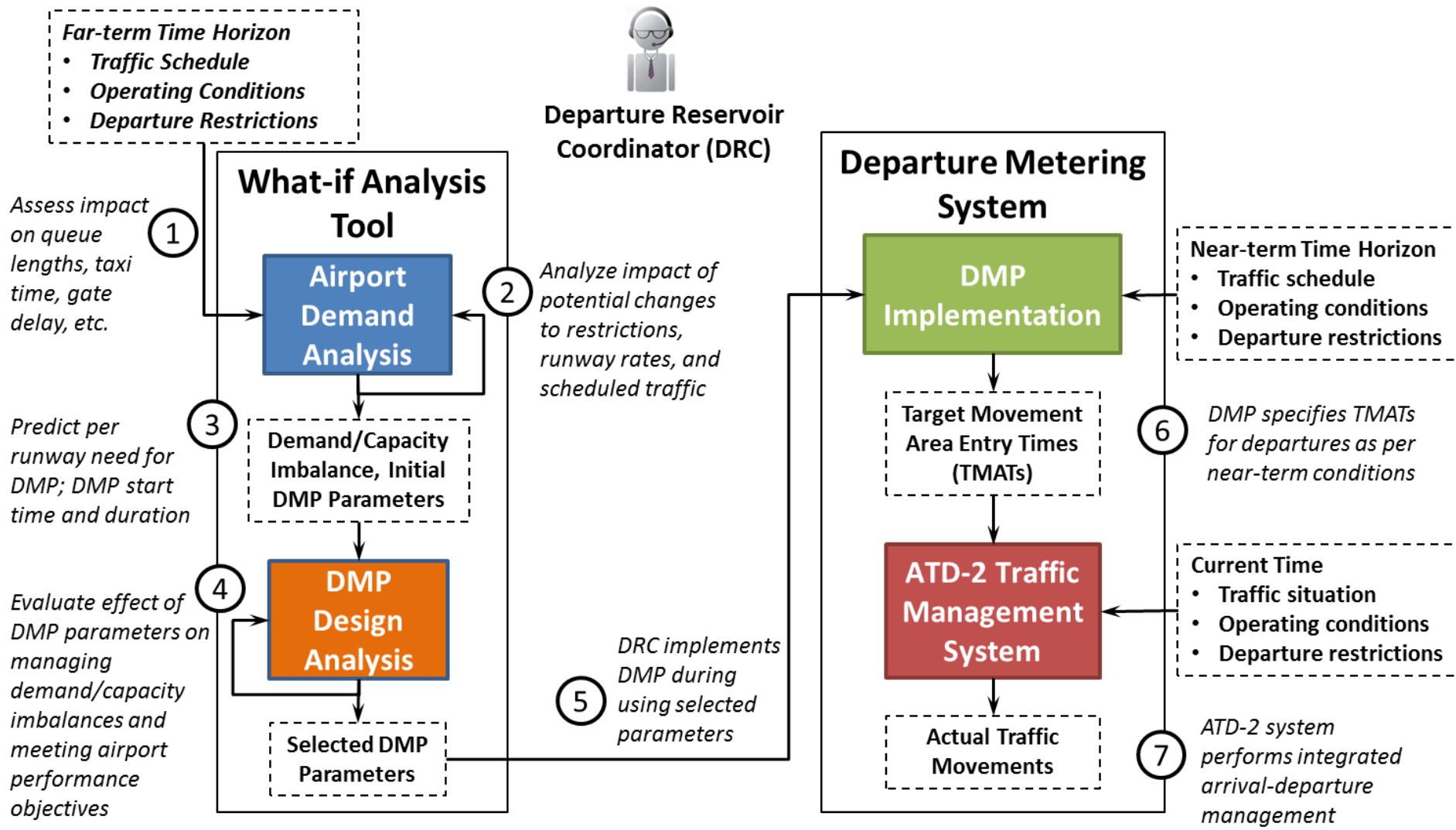
What-if Analysis Tool Background



- NASA Airspace Technology Demonstration 2 (ATD-2)
 - Integrated arrival-departure-surface traffic management tools and operations enable ideal trajectories for departures
 - Delay at gate, unimpeded taxi on the airport surface, minimum time in departure runway queue, and continuous climb to cruise altitude
- FAA Surface Collaborative Decision Making (CDM) Concept of Operations
 - Departure Management Programs (DMPs) to provide strategic Target Movement Area Entry Times (TMATs) to control surface traffic levels
- Interfaces of NASA ATD-2 with FAA Surface CDM
 - Interface between Spot and Runway Departure Advisor (SARDA) runway takeoff and spot release sequence & schedule and DMP TMATs
 - Ramp control to meet strategic TMATs
- What-if analysis
 - Strategic planning of DMPs to mitigate effects of demand/capacity imbalances at airport under forecast operating conditions



Departure Metering What-if Analysis Concept Overview





Option Year 1 Objectives

SOW



- Develop and refine the what-if capability
 - Airport surface
 - Terminal airspace
 - Metrics and interfaces
 - Traffic and weather scenarios
 - DMP parameters and scope
- Use what-if analysis capability
 - Specify DMP parameters for CLT under different traffic and weather conditions impacting departure traffic flow
 - Evaluate effectiveness of DMPs in mitigating impacts of traffic flow inefficiencies
 - E.g., reducing delays during surface taxi & airborne transit



Option Year 1 Accomplishments



Objective	Accomplishments
Airport surface	<ul style="list-style-type: none">• Investigated and documented CLT surface operations• Implemented node-link modeling of airport runways, spots and terminal gates for different configurations• Specified modeling parameters from CLT operations data and references, Base Year analyses• Verified implementation of models, compared simulation results to FAA ASPM• Developed detailed models of traffic flow interactions of runways, taxiways, non-movement area
Terminal airspace	<ul style="list-style-type: none">• Implemented and verified modeling of time period miles-in-trail restrictions for departure fixes• Implemented and verified miles-in-trail restrictions for departure runways to meet fix restrictions• Modeled link transit times from Base Year high-fidelity departure simulation data
Metrics & interfaces	<ul style="list-style-type: none">• Implemented metrics and interfaces for DRC to assess airport departure and arrival traffic flow and design DMPs• Implemented interfaces to configure and conduct What-if analysis and assess results
DMP parameters & scope	<ul style="list-style-type: none">• Summarized specifications for DMPs from FAA Surface Collaborative Decision Making ConOps• Implemented explicit control of Target Departure Queue Length for individual departure runways• Implemented methods to accommodate multiple flow restrictions on departures• Implemented automatic DMP start & end times from runway queue data
Traffic & weather scenarios	<ul style="list-style-type: none">• Identified recent operational days for idealized traffic schedule and traffic “disturbance” scenarios• Created input files for What-if Tool from traffic and restrictions data for those days
DMP Evaluations	<ul style="list-style-type: none">• Used What-if analysis tool to conduct demand analysis and DMP implementation for different historical and notional traffic & weather scenarios• Documented results & developed demonstrations



What-if Analysis Tool Capabilities



- Adapt to changes in airport and airspace operating conditions
 - Runway configurations & rates
 - Traffic levels & airport/airspace resource utilizations
 - Departure fix restrictions
- Design & emulate Departure Management Program
 - Scheduling of gate pushback times & TMATs
 - Meter flights to control runway queue length
 - Account for per-runway departure rates & multiple departure restrictions
- Rapidly evaluate airport traffic performance
 - Evaluate variety of operating and DMP alternatives and uncertainty
 - DMP go-no go screening, start & end times, particular runways
- Present key departure and arrival performance metrics for detailed and aggregate performance assessment
 - Metrics important to airport operations
 - Nature of demand characteristics and airport traffic response
 - Time period- and runway-based assessment for detailed understanding
 - Aggregate assessment for comprehensive overview



CLT Airport Modeling Enhancements



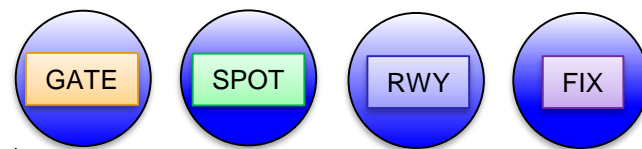
- Node-link modeling of airport and airspace
 - Synthesized from gate/spot/runway/fix routes of flights in traffic file
 - Provides modeling flexibility to balance fidelity with simulation time

• Nodes

- Queueing points where congestion occurs
- Nodes
 - Gates, spots, runways, arrival and departure fixes abstracted as nodes
- Parameters
 - Aircraft service time, T_s
 - Maximum queue size, Q_{max}
- First in first out at specified service rate
- Traffic in-flow versus out-flow determines flight delay

• Links

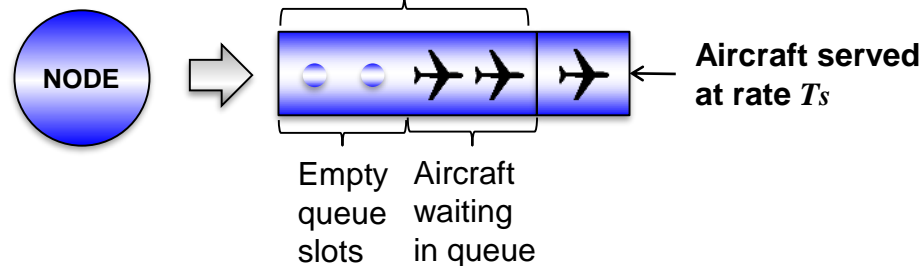
- Transit segments between nodes
- Parameter
 - Transit Time T_T



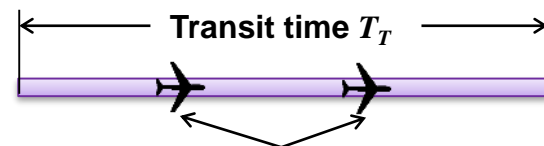
Entities modeled as nodes

Elements of node

Node Model

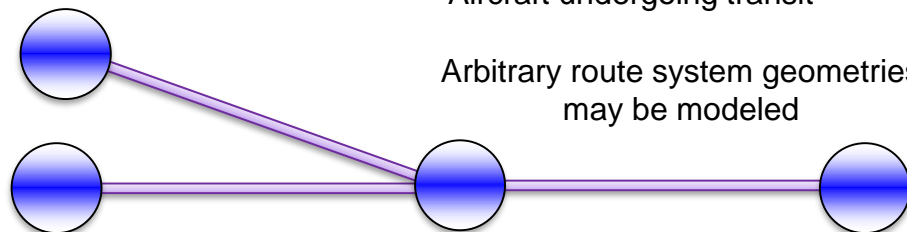


Link Model



Aircraft undergoing transit

Arbitrary route system geometries may be modeled

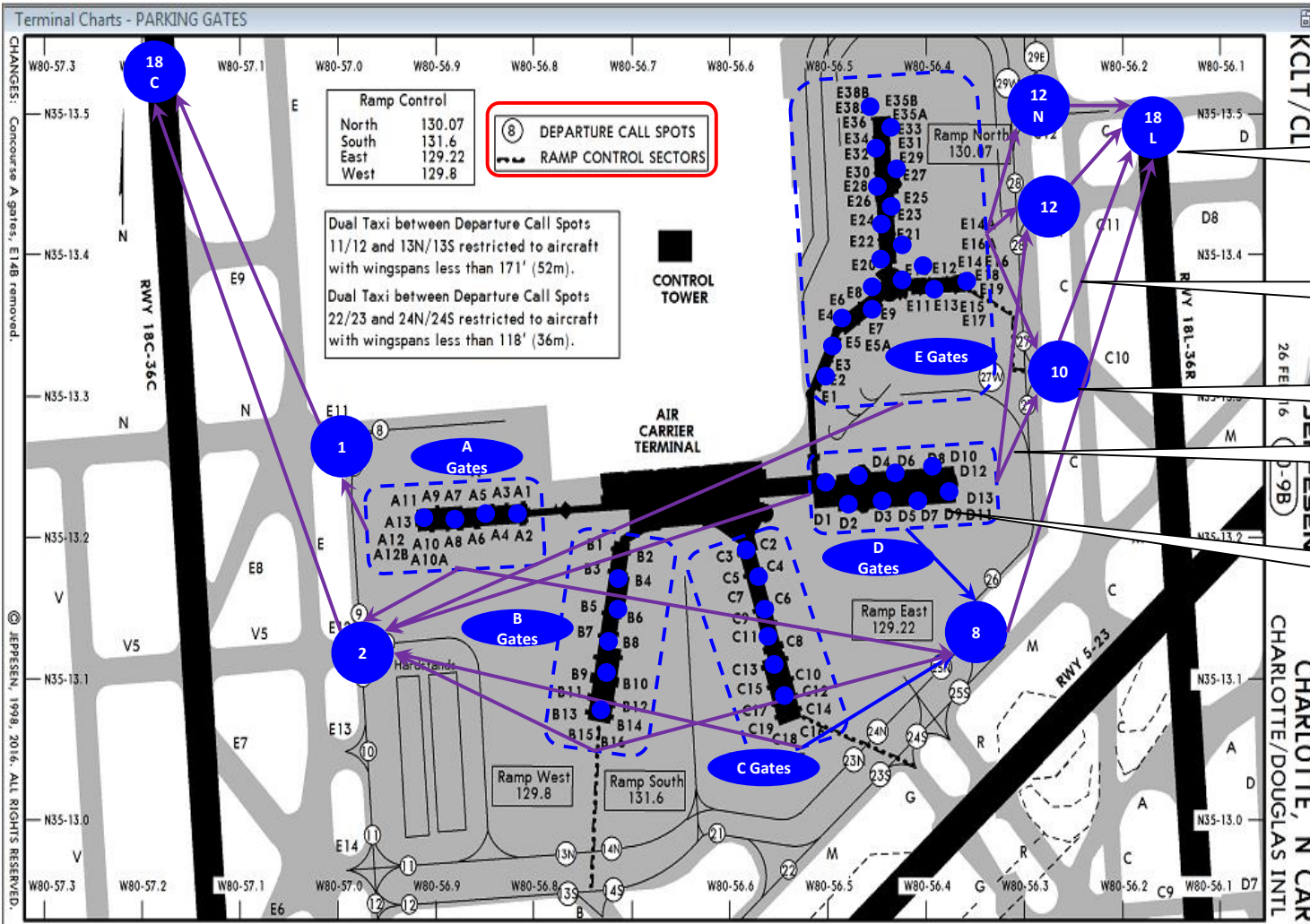




CLT Airport Surface Departure Modeling Example



Node-link modeling of gate-spot-runway routes



- Runway node
- Spot-runway link
- Spot node
- Gate-spot link
- Gate nodes

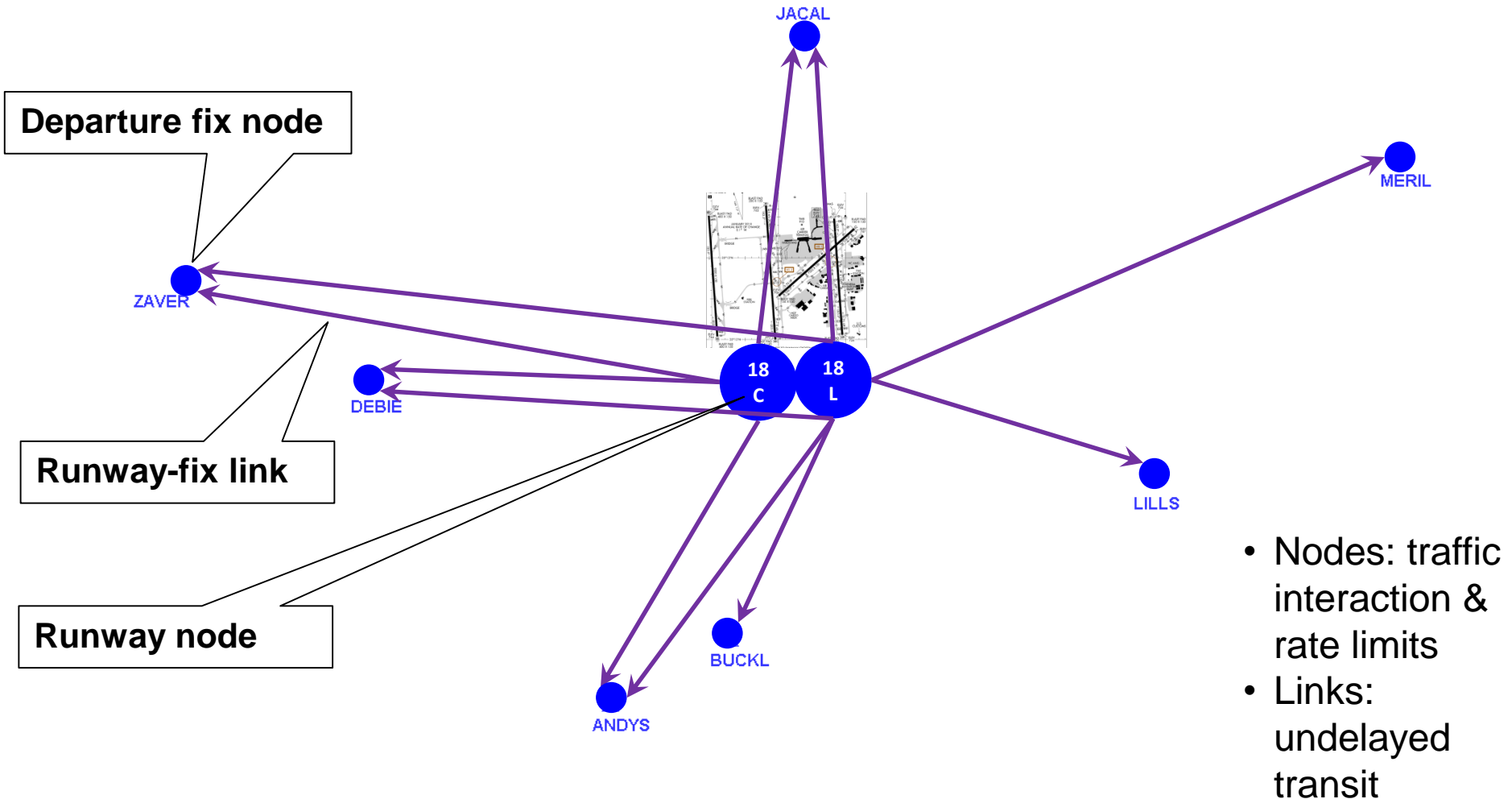
- Nodes: traffic interaction & rate limits
- Links: undelayed transit



CLT Terminal Airspace Departure Modeling Example



Node-link modeling of runway-fix routes



- Nodes: traffic interaction & rate limits
- Links: undelayed transit



CLT Node & Link

Parameters/Attributes/Behavior



Node type	Service time, Minutes	Size limit, aircraft	Data source
Gate	30.0	1	Estimation
Spot	1.0	N/A	Estimation
Runway	2.0	N/A	30 aircraft/hour
Fix	1.7	1	SME-specified 7 miles @ 250 knots

Link type	Transit time, minutes	Data source
Gate-spot	4.0	SOSS simulation of CLT
Spot-runway	2.0	SOSS simulation of CLT
Runway-fix	14.0	Flight simulations of MERIL departures

- **Service time:** Minimum time to process aircraft, models rate limit of traffic passing through node, e.g., time interval of runway departure rate, in-trail spacing of departures crossing fix
- **Size limit:** Number of aircraft that can be waiting for service, e.g., number of departures that taxiway can fit, number of aircraft that can occupy terminal gate
- **Transit time:** Undelayed transit time between nodes



CLT Specialized Node Models



- Runway nodes
 - Node exit time for departures as per
 - Node service time
 - Service time for miles-in-trail restrictions at departure fix

Fix	Miles In Trail	Time Start, Min	Time End, Min
MERIL	20	50	150
BUCKL	15	75	200

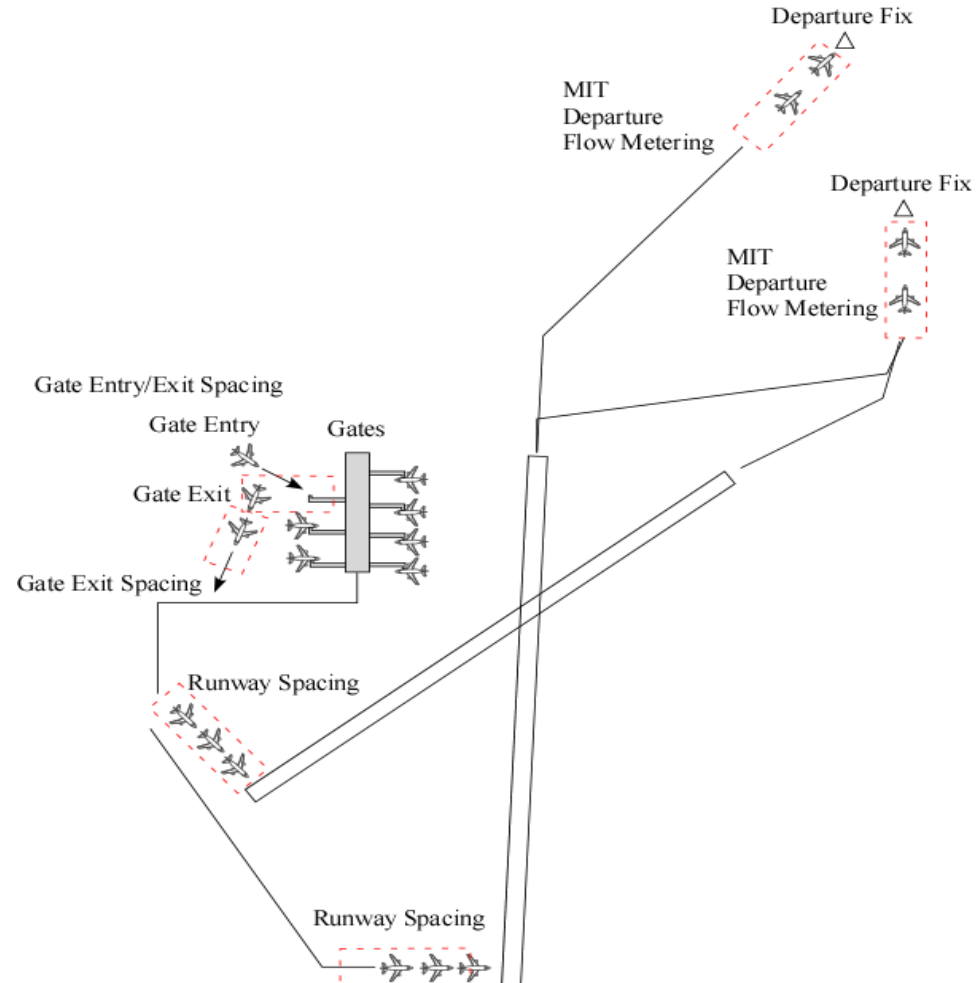
- Gate nodes
 - Departure entry/exit times fixed
 - Entry at scheduled gate entry time
 - Exit at gate occupancy time or DMP-scheduled pushback time
 - Arrivals delayed entry to gate until occupancy time window is available



What-if Tool Enhancements DMP Emulation

Key Features

- Generates TMATs to absorb delay at the gate
- Satisfies multiple constraints
 - Minimum Gate Occupancy Spacing
 - Minimum Departure Spacing at Runways
 - Departure Fix Flow Restrictions
- Attempts to maintain a specified runway queue size

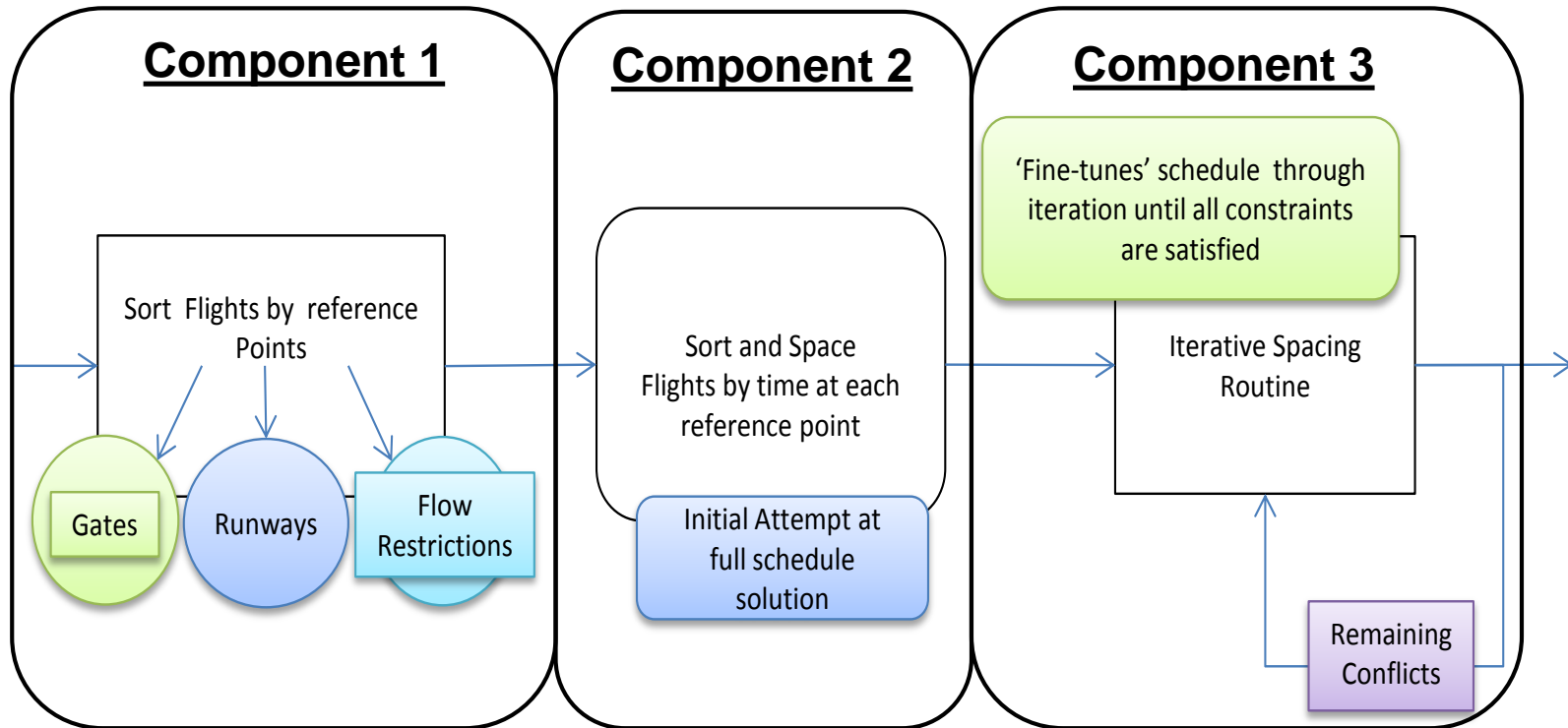




DMP Emulation Components



- High Level Functionality
 - Three main components



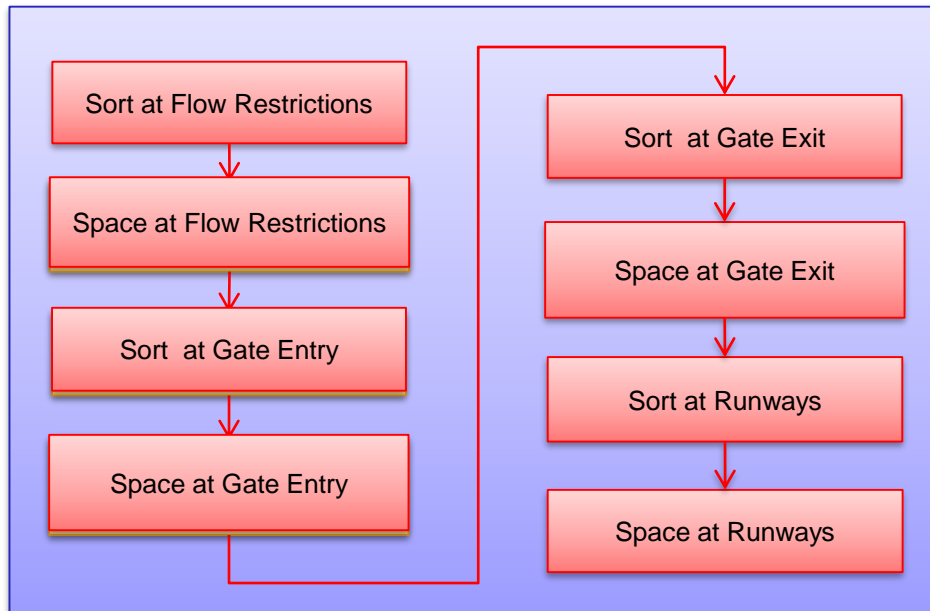


DMP Emulation Process Steps

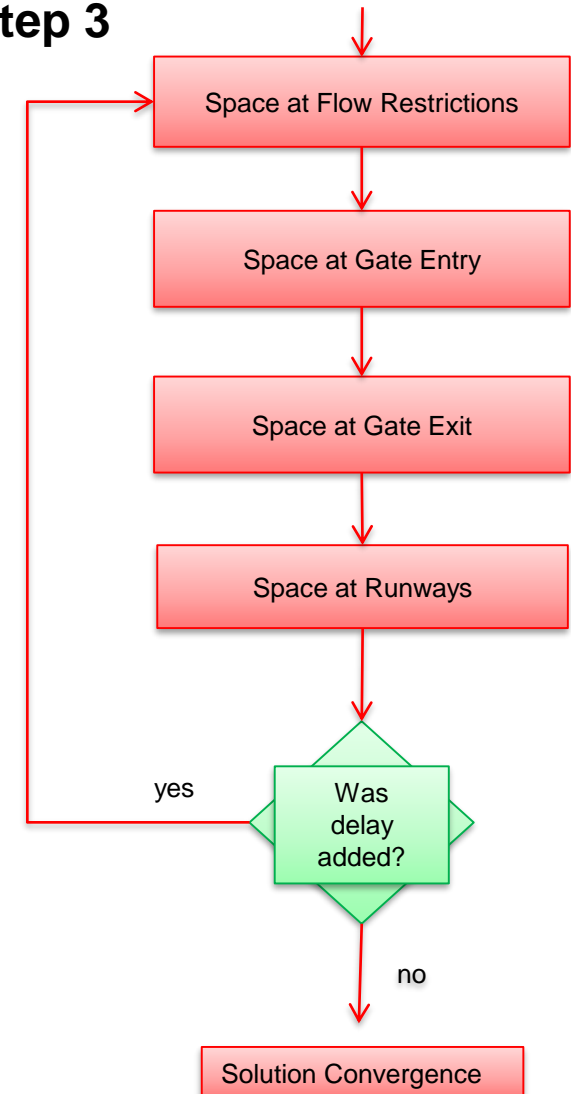


- Step 1: Sort by Reference Point
- Step 2: Initial Sorting and Spacing
- Step 3: Iterative solution for convergence

Step 2

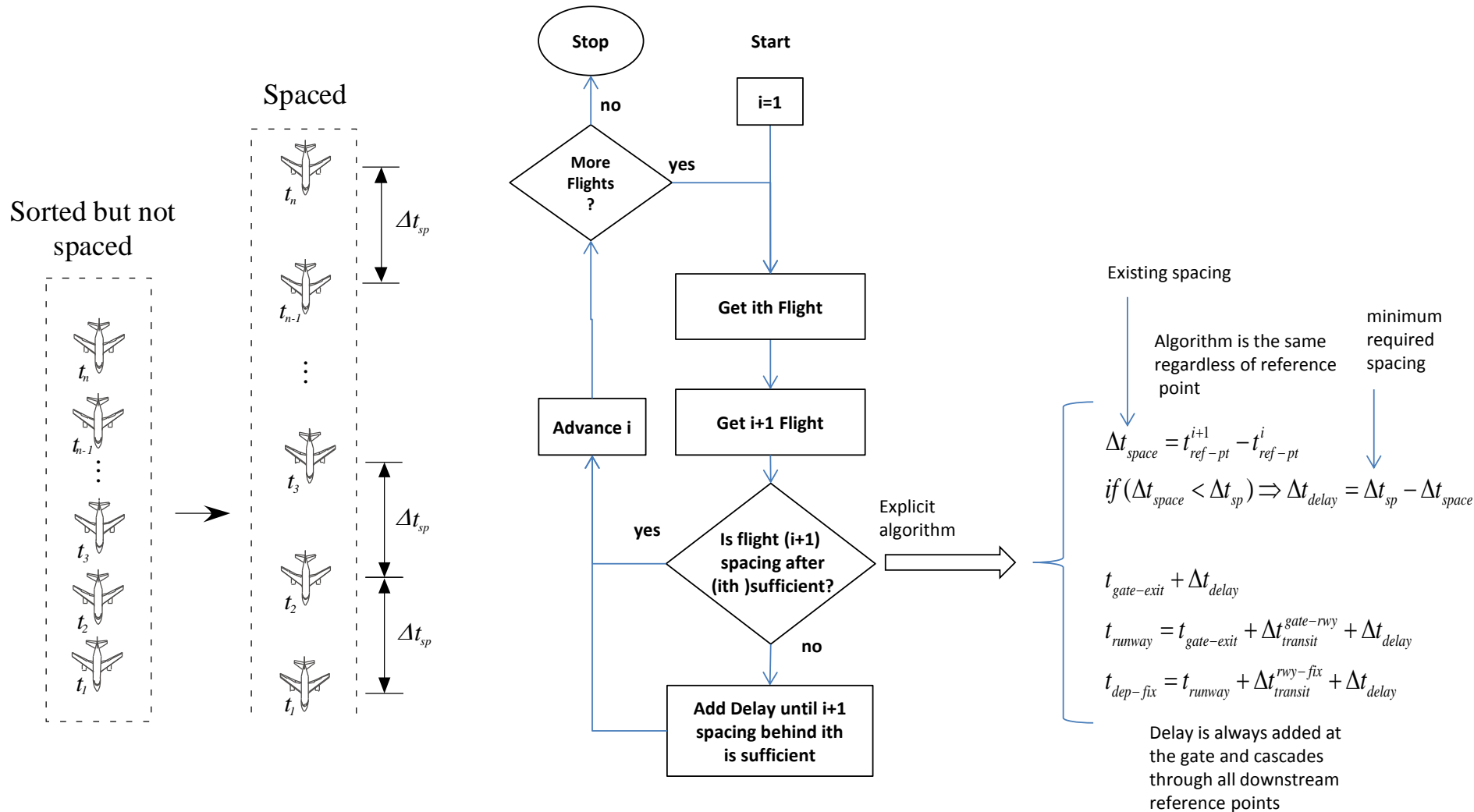


Step 3





DMP Emulation Aircraft Spacing Algorithm





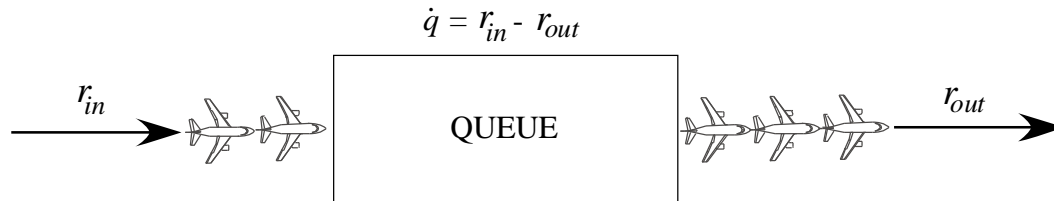
DMP Emulation



Runway Queue Size Control

$$r_{in} = \frac{1}{\Delta t_{sp_i}}$$

Aircraft supply rate & spacing



$$r_{out} = \frac{1}{\Delta t_{rwy}}$$

Aircraft service rate & spacing

Aircraft queue, q , forms when supply rate, r_{in} , exceeds service rate, r_{out}

Continuous

$$q = \int (r_{in} - r_{out}) dt$$

Discrete

$$q_{i+1} = q_i + (r_{in_i} - r_{out_i}) \Delta t_i$$

Supply & service rates r_{in} & r_{out} as inter-flight times Δt_{sp} & Δt_{rwy}

$$q_{i+1} = q_i + \left(1 - \frac{1}{\Delta t_{rwy}} \right) \Delta t_{sp_i}$$

Queue size, q_i , feedback control of supply rate/spacing, Δt_{sp} , to meet target queue size, q_t

$$e_q = q_t - q_i$$

$$\Delta t_{sp_i} = \Delta t_{rwy} - K_q \Delta t_{rwy} \frac{e_q}{q_t} \quad q_i \geq 0$$

Delay aircraft queue entry time as needed to satisfy inter-aircraft supply spacing, Δt_{sp}

$$\Delta t_{spacing} = t_{runway}^{i+1} - t_{runway}^i$$

$$\text{if } (\Delta t_{spacing} < \Delta t_{sp_i}) \Rightarrow \Delta t_{delay} = \Delta t_{sp_i} - \Delta t_{spacing}$$



Traffic & Weather Scenarios Development Methods



- Information sources for scenario initialization
 - Weather Underground for historical weather to select scenario days
 - ASDI in-bound fix/TRACON entry fix position and time (ATA) data
 - Out/Off/On/In (OOOI) from a major CLT airline operator for August 2014*
 - NASA Restrictions May through Dec 2014
 - Expected Departure Clearance Time (EDCT)
 - Call for Release (CFR)
 - Miles in Trail (MIT): used fix location and miles spacing values
 - Ramp controller procedures to infer spot allocation
- Scenario preparation methodology
 - Capture all arrivals/departures from 5 AM to midnight
 - Infer tail number connectivity by associating scheduled gate IN-OUT times per gate and aircraft type
 - Start time for each departure based on IN time of associated arrival
 - Spot assignments from airport layout, gate/runway pairs and airline Standard Operating Procedures (SOP)

* Note: Boeing obtained Official Airline Guide (OAG) data for the 3rd quarter of 2014 as reported in the “Traffic and Weather Identification and Modeling Document (Contract CDRL 4.6). However, the team relied entirely on the out/off/on/in (OOOI) schedule data to build the scenario.



Traffic & Weather Scenarios

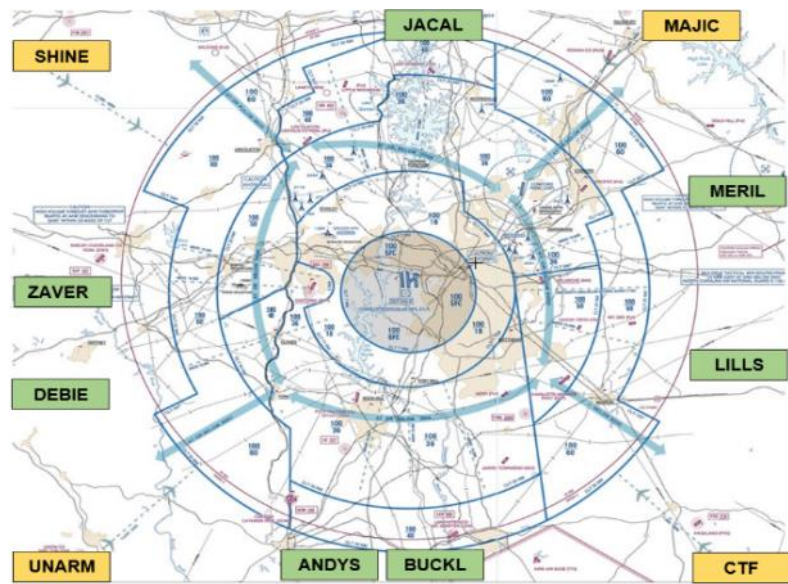
Reference Data For Days



Scenario Days

Type	Date in 2014	Weather at CLT	# of EDCT	# of CFR	# of MIT restrictions	Comment
Baseline (Good Weather)	August 8	Clear, visibility of 8 NM	4	25	42	Usual restrictions for CLT
Disruptive Events (Bad Weather)	August 11	Rainfall at CLT reduces visibility to 1 NM	1	25	45	Storm moving through CLT
	August 15	VMC/VFR conditions, no flow reversals	7	42	76	Weather near Atlanta with restrictions imposed by Atlanta ARTCC
	August 18		2	41	180	Heavy volume restrictions due to extreme rainfall in TN and NE Alabama

CLT Operational Constraints Arrival Flows & TRACON Fixes



Entry Fix

Exit Fix

Note: entry/exit fix positions are outside the diagram and are represented notionally



Weather and Traffic Scenarios

Departure Fix Restrictions



- CLT Departure Traffic With Restrictions for 8/18/2014
 - What-if tool models MIT restrictions

Fix	Miles In Trail	Time Start, Min	Time End, Min
MERIL	10	554	559
MERIL	15	570	732
MERIL	15	780	970
MERIL	20	970	1005
MERIL	25	1005	1090
MERIL	25	1139	1261
MERIL	10	475	505
MERIL	15	1100	1185

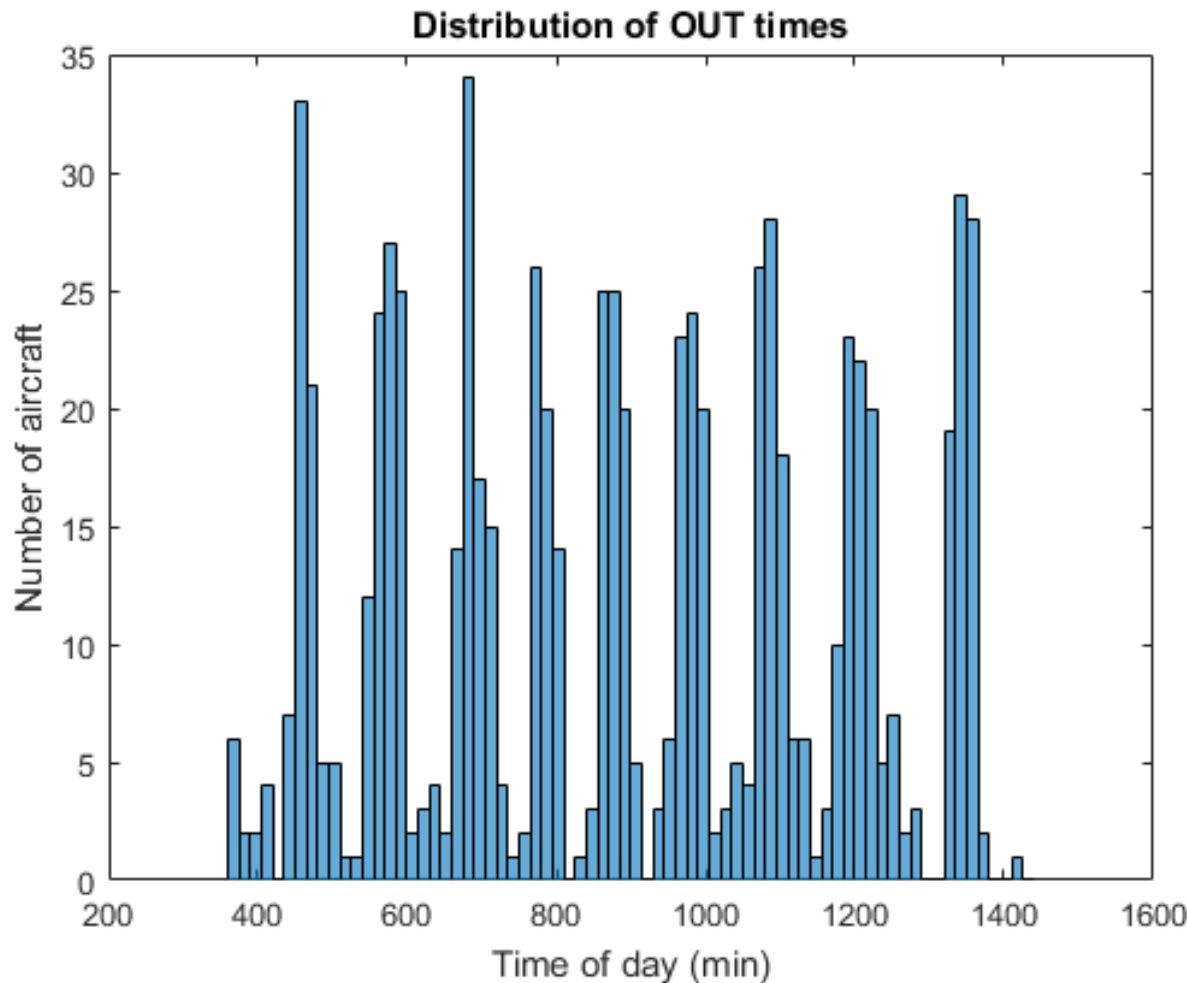


Weather and Traffic Scenarios



Baseline Scenario Surface Traffic Demand

Histogram of scheduled gate departure times for 8/8/2014 baseline traffic scenario



Histogram: number of scheduled departures by $\frac{1}{4}$ hour



What-if Analysis Tool Verification



- Traffic Simulation
 - Parameter adherence
 - Verified traffic flow adheres to link transit times, node service rates, node queue length limits, departure fix restriction spacing & time period
 - Comparison to FAA ASPM for 8 August 2014
 - Input traffic schedule
 - IN-OUT times differ from airline-scheduled times
 - Departure throughput & taxi-out times
 - Departure rates: Comparable maximum and total average, different hourly averages
 - Taxi-out times: Comparable hourly and total averages
 - Arrival throughput & taxi-in times
 - Arrival rates: Comparable maximum, hourly and total averages
 - Taxi-in times: Simulation higher due to gate occupancy and utilization modeling
- DMP Emulation
 - Parameter adherence
 - Verified scheduled departures adhere to runway rates, departure fix restrictions and gate occupancy restrictions
 - Traffic control
 - Verify metering meets traffic performance requirements



Airport Evaluation Metrics

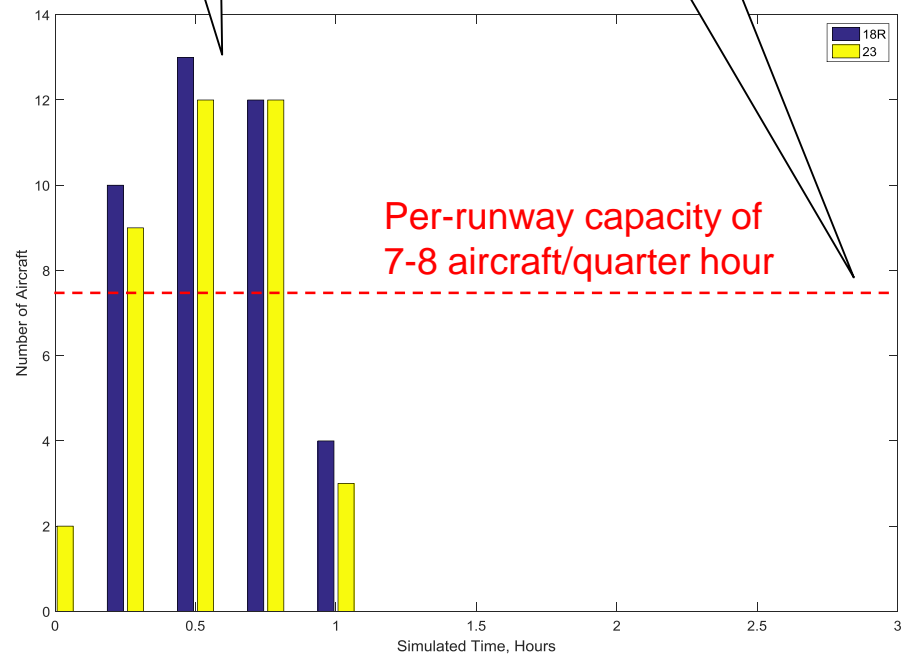
Runway Demand & Capacity



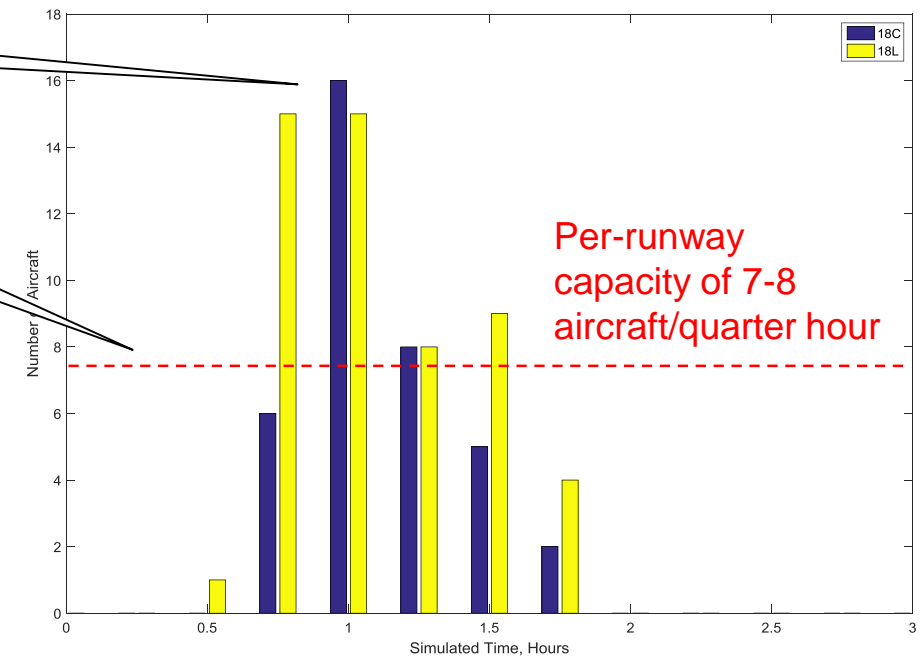
Time-bin traffic demand for each runway

Per-runway capacity

Arrivals



Departures





Airport Evaluation Metrics

Departure Performance



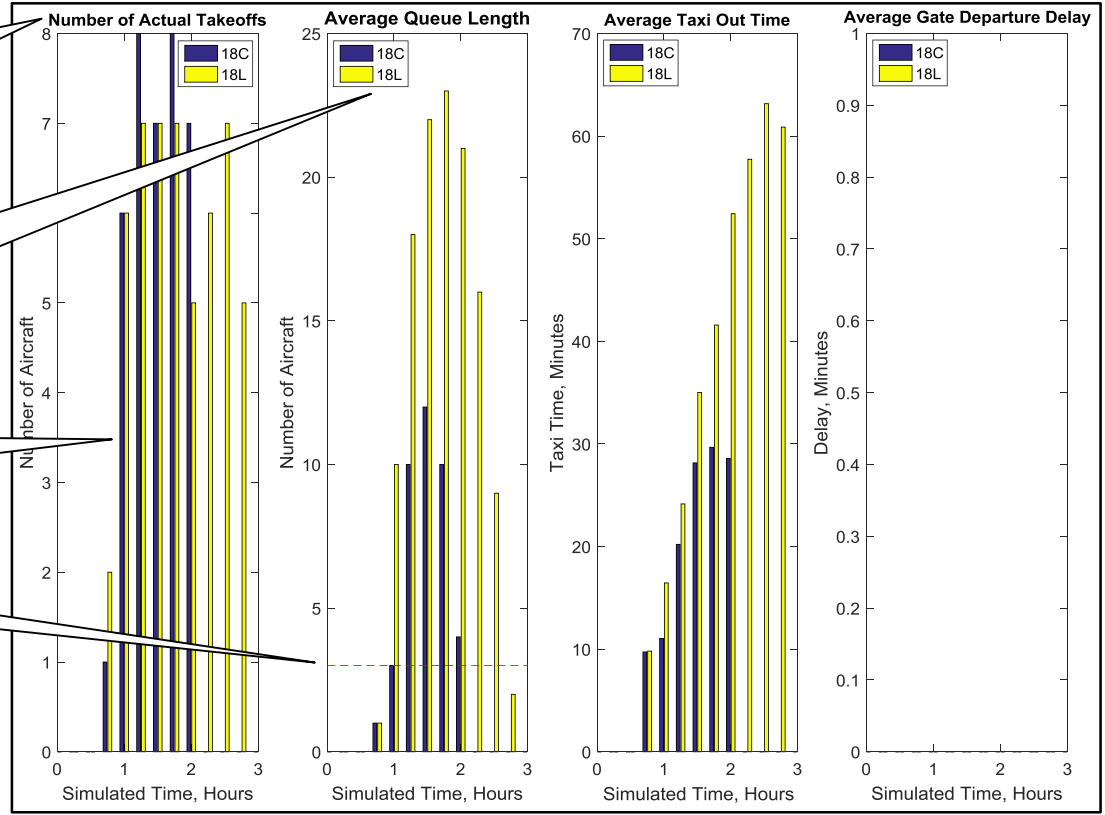
Key performance metrics of **throughput, congestion, taxi time and gate delay**

Airport runway traffic performance for detailed understanding of operations

Time-bin presentation to see trends & variability

Limits for comparison

Time period presentation to know total performance



Departure Runway	Average Throughput, Departures Per Hour	Average Queue Length, Departures	Maximum Queue Length, Departures	Minimum Queue Length, Departures	Average Taxi Out Time, Minutes	Average Gate Delay, Minutes
18C	29	3	12	0	23.6	0
18L	26	9	25	0	41.9	0



Airport Evaluation Metrics

Arrival Performance

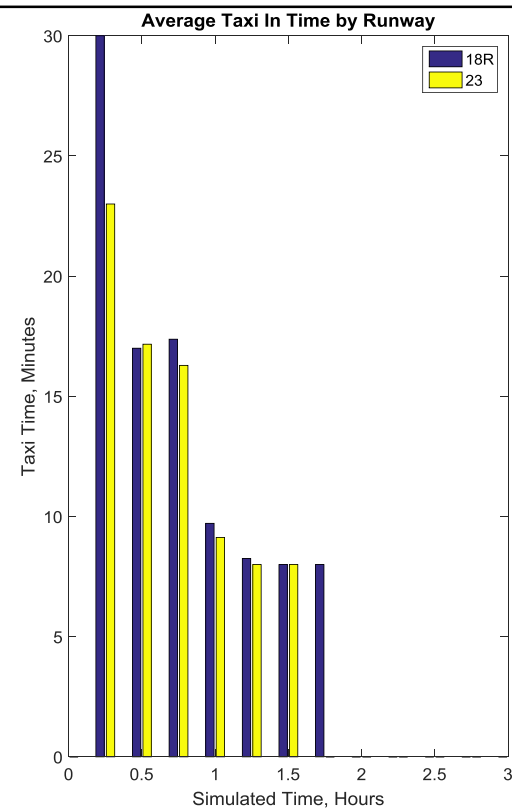
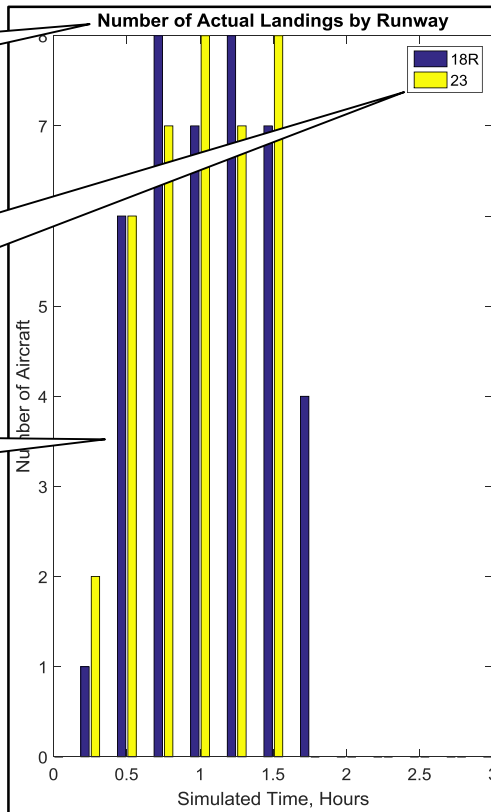


Key performance metrics of **throughput** and **taxi time**

Airport runway traffic performance for detailed understanding of operations

Time-bin presentation to see trends & variability

Time period presentation to know total performance



Arrival Runway	Average Throughput, Arrivals Per Hour	Average Taxi In Time, Minutes
18C	29	23.6
18L	26	41.9



What-if Analysis Tool

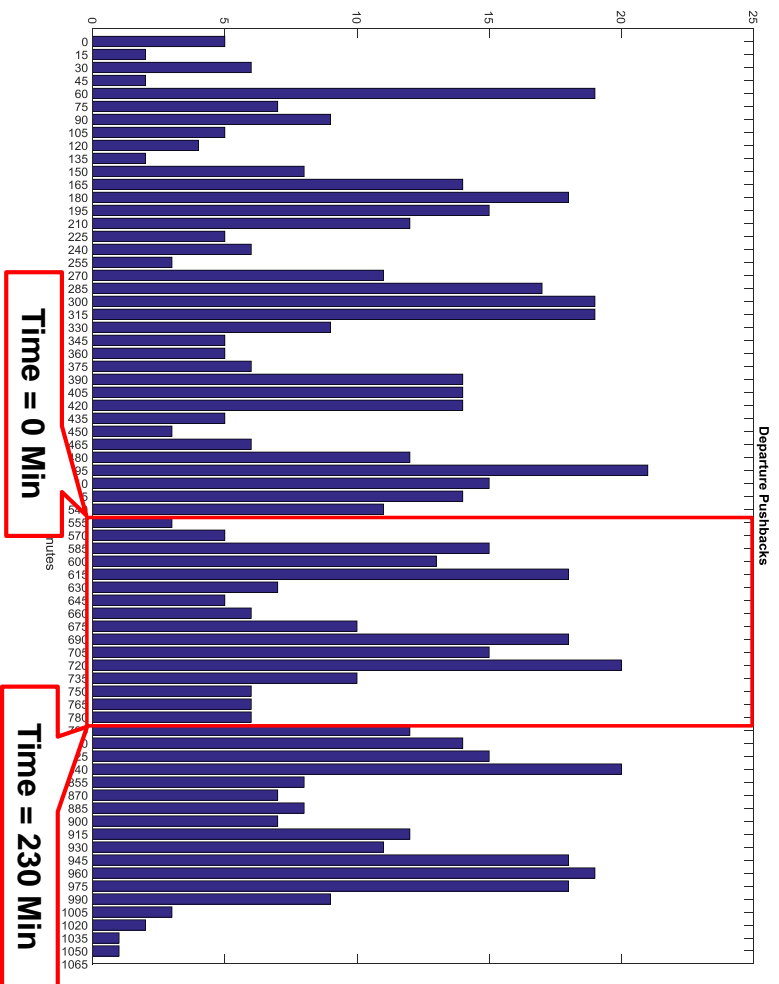
Example Evaluation



Traffic schedule

Scenario

- August 8, 2014, 2:08 p.m. to 5:58 p.m. local CLT time



	ANDYS	BUCKL	DEBIE	JACAL	LILLS	MERIL	NALEY	ZAVER
18C	1	2	7	2		4	33	27
18L	11	19	3	1	6	36	4	3

Departure restrictions

- Restrictions due to nearby rainstorms on August 18, 2014, 2:08 p.m. to 5:58 p.m. local CLT time

Fix	Miles In Trail	Time Start, Min	Time End, Min
MERIL	10	4	9
MERIL	15	20	182

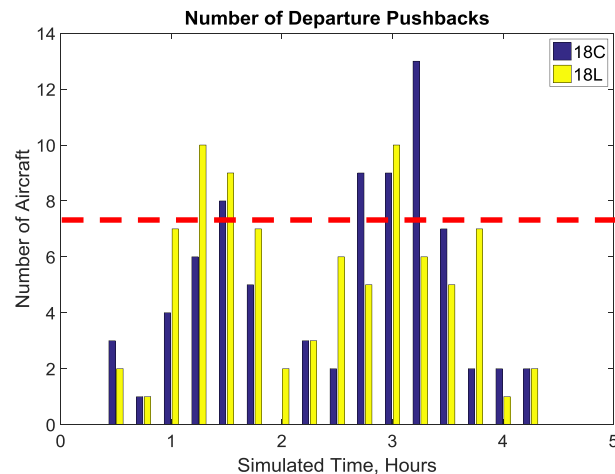


What-if Evaluation, Airport Demand Analysis



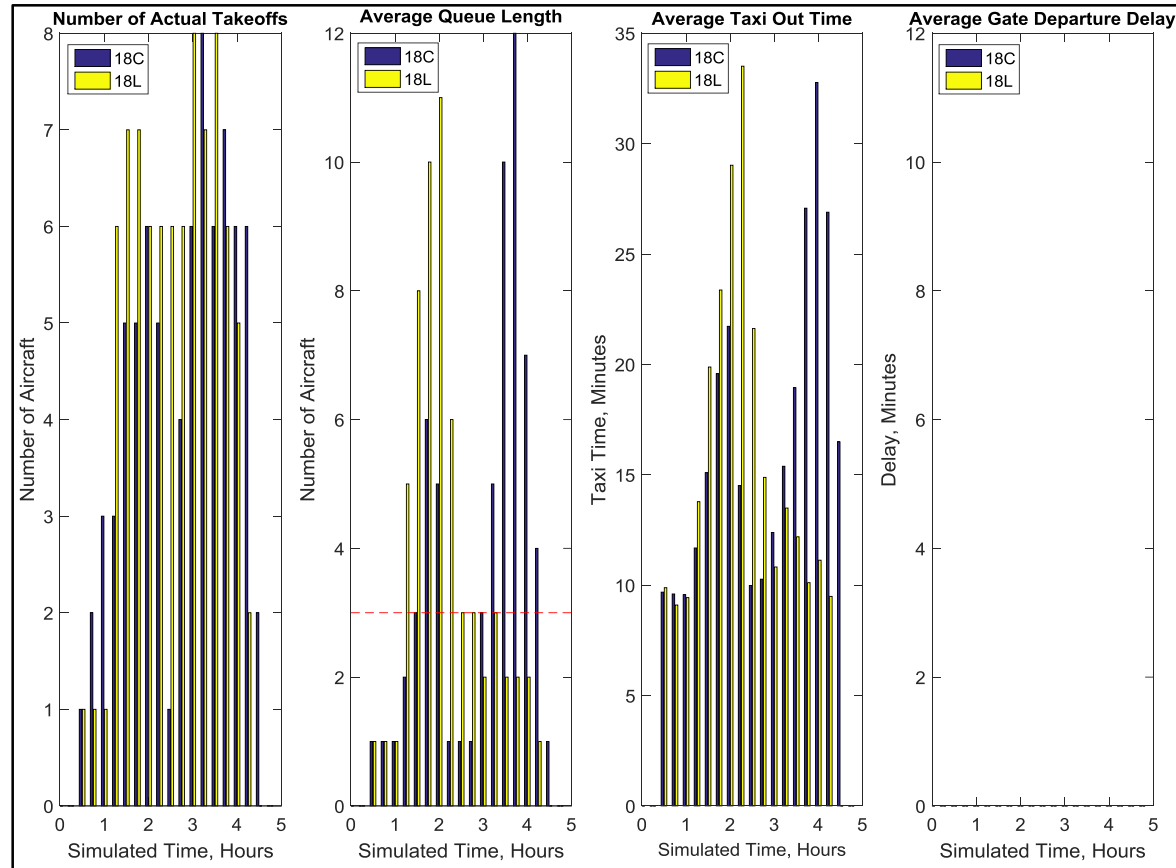
Departure Demand

Departures push back at
airline-scheduled times



Demand intermittently
exceeds **RDR of 7-8**
aircraft/quarter hour

Airport Departure Performance



- Runway throughput intermittently saturates
- Runway departure queues exceed target length
- Runway departures exhibit excessive taxi-out times



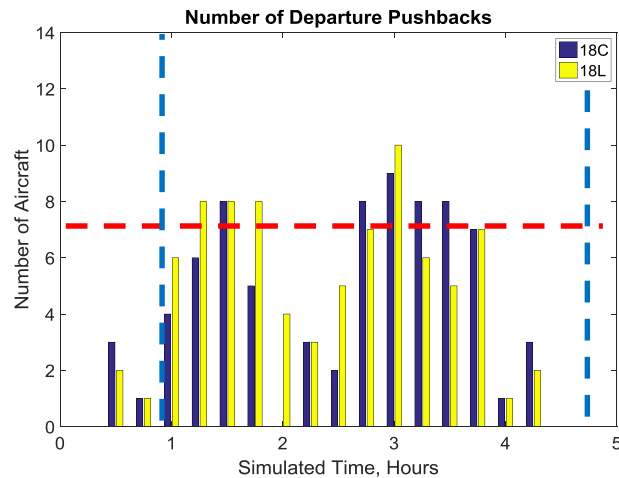
What-if Evaluation, DMP Analysis



Departure Demand

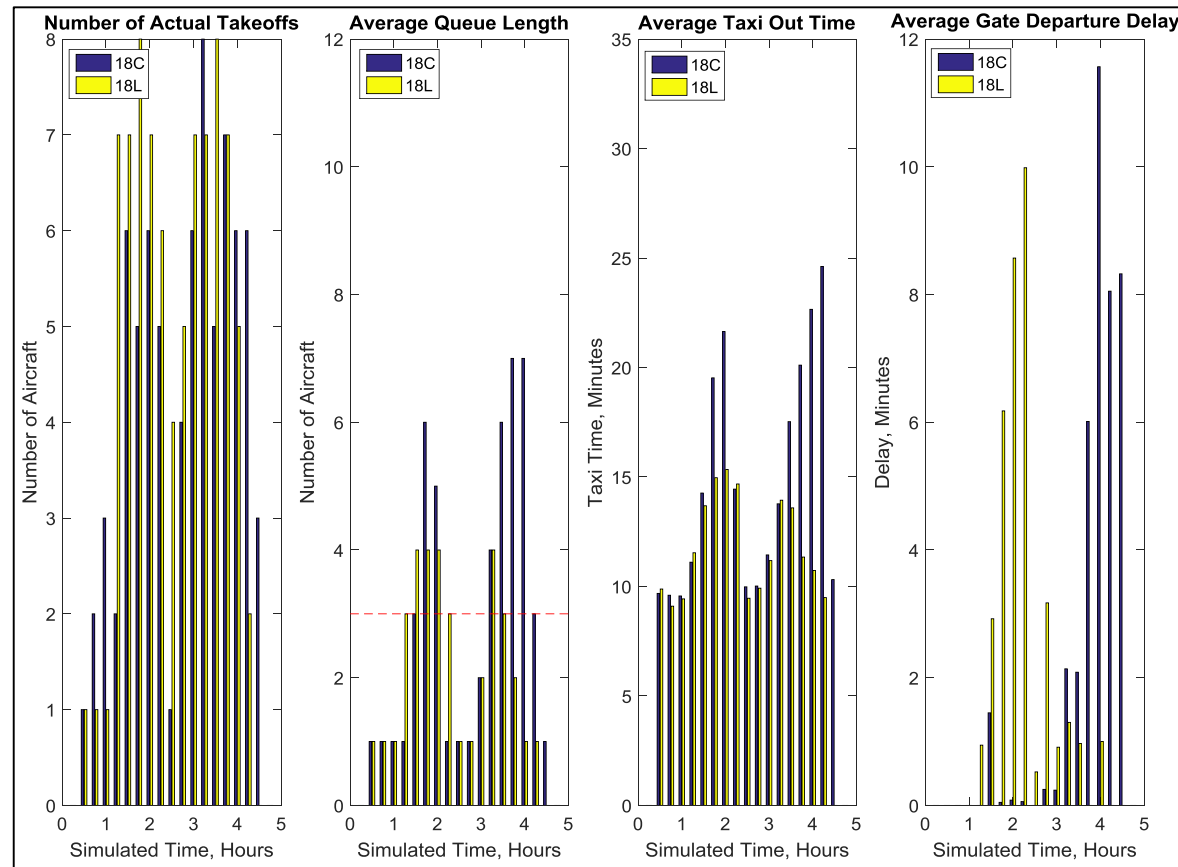
Departures push back at
DMP-scheduled times

- Start: 60 min
- End: 289 min



Demand more closely
complies with **RDR of 7-8**
aircraft/quarter hour

Airport Departure Performance

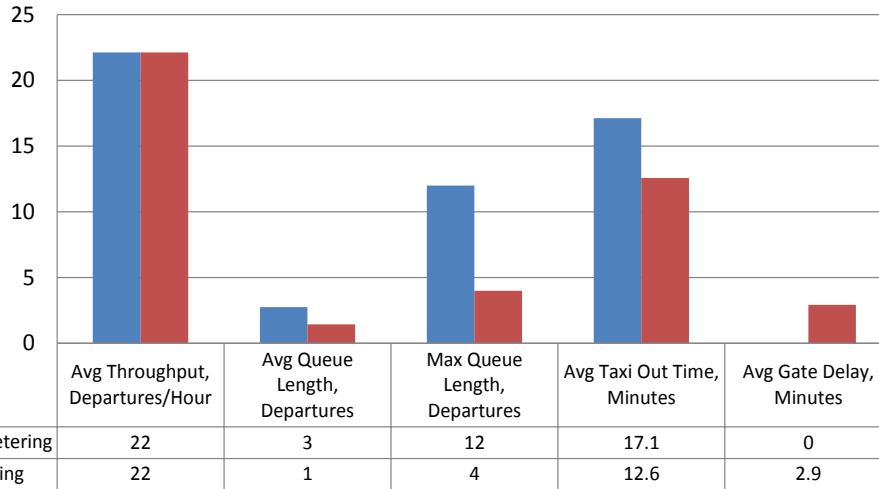


- Runway throughput maintained
- Runway departure queues closer to target length
- Average taxi-out times reduced
- Gate holding delay introduced

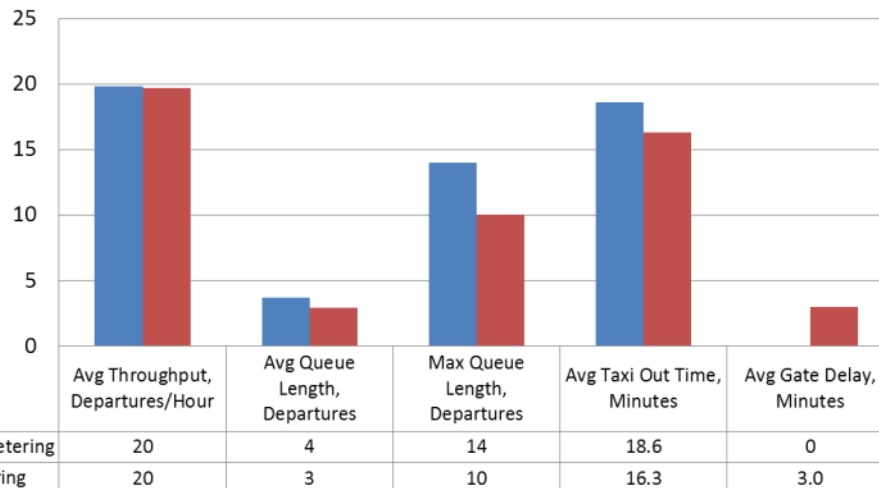


What-if Evaluation Comparison, Departures

CLT Departure Runway 18L



CLT Departure Runway 18C



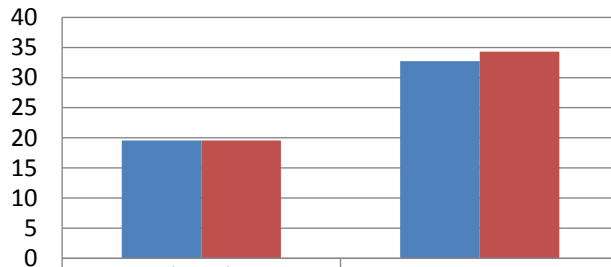
- Departure metering program effective
 - Runway departure throughput maintained
 - Runway queue lengths reduced
- More significant reductions for runway 18L departures
 - Arrivals to runway 18C interfering with planned runway departure rate
- Average taxi-out times reduced
 - More significant reduction of 4.5 minutes for departures from runway 18L
 - Arrivals to 18C impacting departure taxi-out delay



What-if Evaluation Comparison, Arrivals

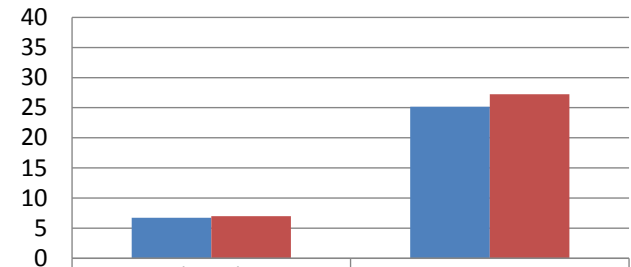


CLT Arrival Runway 18R



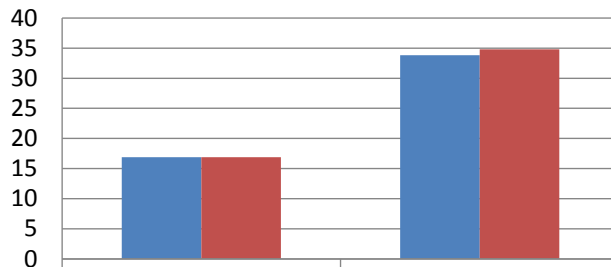
	avgThroughput, Arrivals/Hour	avg Taxi InTime, Minutes
Without Departure Metering	20	32.7
With Departure Metering	20	34.3

CLT Arrival Runway 18C



	avgThroughput, Arrivals/Hour	avg Taxi InTime, Minutes
Without Departure Metering	7	25.2
With Departure Metering	7	27.3

CLT Arrival Runway 23



	avgThroughput, Arrivals/Hour	avg Taxi InTime, Minutes
Without Departure Metering	17	33.8
With Departure Metering	17	34.8

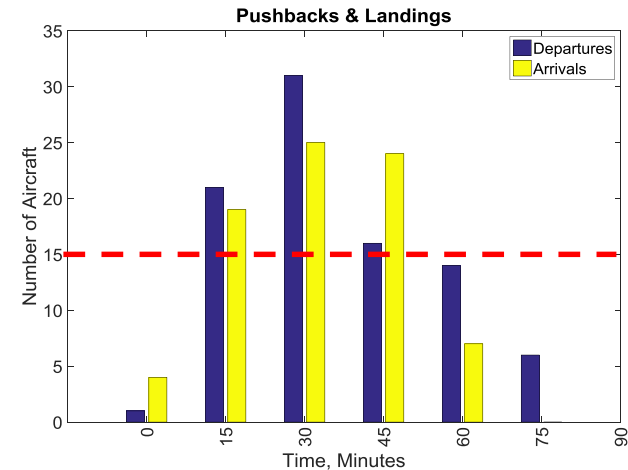
- Arrival taxi-in time increases due to departure gate holding
 - Average taxi-in delay increase due to increased gate occupancy of departures



Tool Demonstration



- Test case of delaying DMP start time
 - Traffic schedule
 - hitl6-training-advisory.list_data
 - CLT south flow
 - Departures: 52 from 18L, 37 from 18C
 - Arrivals: 41 from 18R, 38 from 23
 - Departure restrictions
 - TrafficFlowRestrictions.csv



Fix	Miles In Trail	Time Start, Min	Time End, Min
MERIL	20	50	150
BUCKL	15	75	200

- Departure management program
 - Start time, min: 60, 30



Summary



- Developed and demonstrated prototype What-if Analysis Tool for strategic assessment of airport traffic and planning of DMPs/TMATs
 - Adaptable to forecast airport operating conditions
 - Rapid evaluation of traffic
 - Emulation of DMP
 - Metrics & presentation to understand traffic behavior & assess airport performance
 - Supports exploring airport traffic behavior & DMP implementation
- Applied to realistic and notional traffic and weather scenarios
 - Effective in planning the management of departures & arrivals
 - Evaluating complicating factors of uncertainty in operating conditions



Conceptual User Interface



File View Window Help Current Time: 2045Z

RWY: 18L

Current Restrictions:

DEP STOP CLT 2045 - 2115 Z

Additional Modeled Restrictions: ALT PLAN A1

Model: Highlight: UT: 5 LT: 2 TQL: - - - 3 3 3 3 3 3 - -
 DMP - FIX MERIL 2115 - 2215 Z 30 MIT 2100 2200 2300

Model: Highlight: UT: 5 LT: 2 TQL: - - - 3 3 3 3 3 3 - -
 DMP - FIX LILLS 2115 - 2215 Z 30 MIT 2100 2200 2300

Model: Highlight: UT: 7 LT: 12 TQL: - - - 10 10 10 10 10 - -
 DMP - FIX ANDYS, BUCKL, J... 2115 - 2215 Z --- 2100 2200 2300

Optimize Preview Apply

Modeled Time Period:	Q Length Metric		OUT-OFF Metric		OFF Delay Metric	
	B	A1	B	A1	B	A1
Start (Z): 2115	Alt Plans		Alt Plans		Alt Plans	
End (Z): 2245	Avg Q length	26 16	Avg Off-Out (mins)	47 30	Avg Off delay (mins)	38 30
	Max Q length	30 16	Max Off-Out (mins)	55 34	Max Off delay (mins)	60 35
	Min Q length	17 16	Min Off-Out (mins)	31 26	Min Off delay (mins)	30 25





Recommendations What-if Operations



- Forecasting, what-if analysis and DMP implementation to proactively minimize the negative impact of changing weather, airport and traffic conditions
 - Forecasting traffic flow restrictions, traffic conditions, and airport operating conditions & estimating uncertainties of forecasts
 - What-if analysis tool and process to design DMPs to accommodate forecasts
 - Categorical (fix specific) DMPs along with other runway-specific DMPs or destination-specific TMIs for departures subject to particular restrictions
 - Collaboration of DRC with aircraft operators and other stakeholders in the what-if analysis and DMP implementation decision making



Recommendations

What-if Tool



- Airport & airspace modeling
 - Departure restrictions: other types, assignment to specific tail numbers
 - Surface traffic interaction points which impede flow
 - Gate modeling: assignment alternatives for arrivals, trail tracking for detailed impact on aircraft utilization
 - Variability in runway departure rates, transit times, gate occupancy times
 - Verification: flight taxi times as per OOOI data, use delay fields from SWIM/FIXM data as a source
- DMP emulation
 - Individual runways, departure runways shared with arrivals
 - Alternative implementation for distinct constraints
- Traffic & weather scenarios
 - Additional scenarios including Lower visibility weather conditions at CLT, North Flow runway operations, recovery from Ground Stop
 - Design around traffic patterns of interest



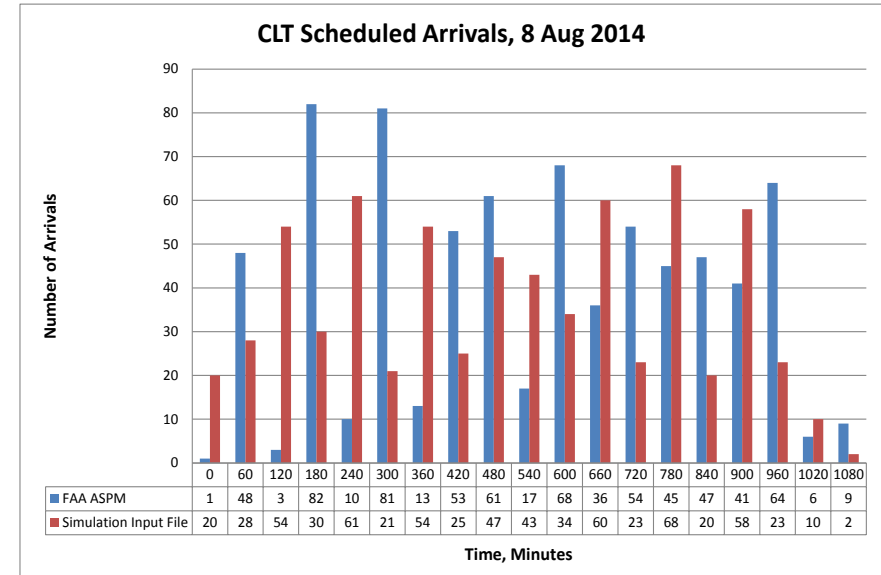
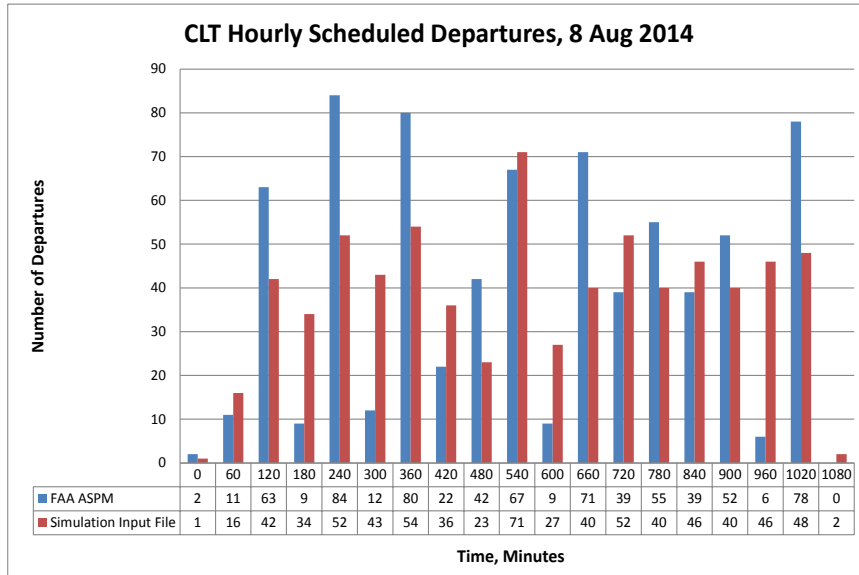
Backup





Verification Results

Traffic Input To Simulation



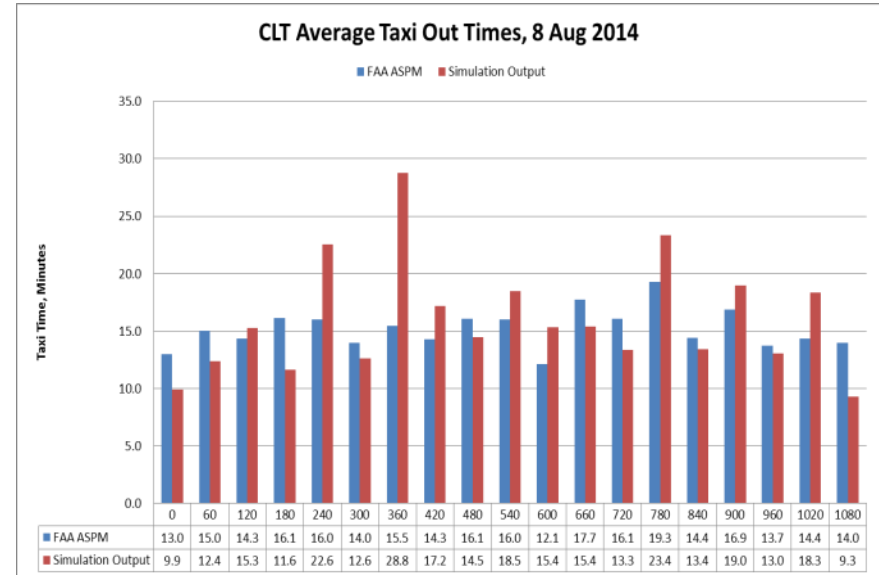
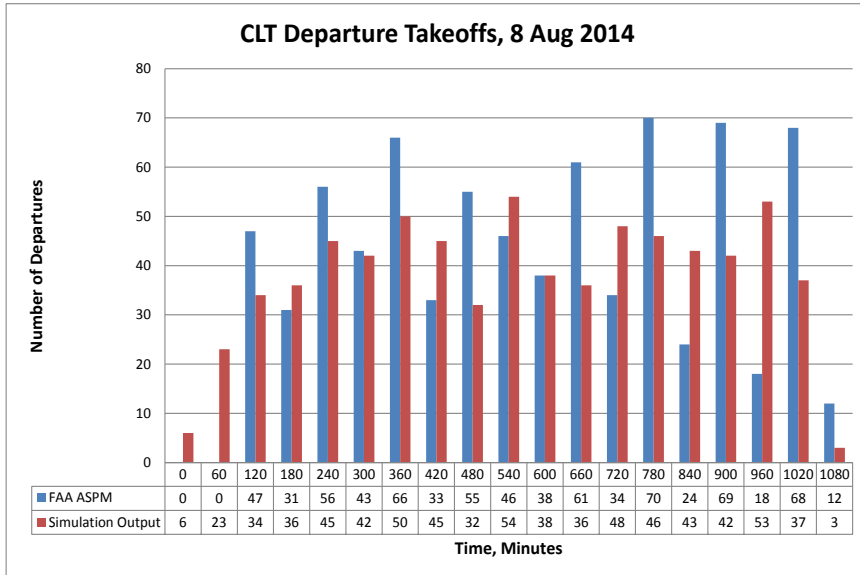
- Differences between hourly counts of scheduled arrivals & departures between FAA ASPM data and traffic schedule input to simulation
 - Traffic schedule input file derived from OOOI data, not schedule data
 - May impact comparison of hourly statistics computed from simulation output data



Verification Results



Traffic Output From Simulation



Simulated vs. FAA ASPM hourly takeoff rates differ significantly in many hours

Simulated vs. FAA ASPM hourly taxi-out times comparable in many hours

Source	Average Departure Throughput, Departures Per Hour	Average Taxi Out Time, Minutes
FAA ASPM, 8 August 2014	45	16.0
What-if Tool Traffic Simulation	36	15.9

- Simulated vs. FAA ASPM aggregate departure rates somewhat lower
- Simulated vs. FAA ASPM aggregate taxi-out times comparable

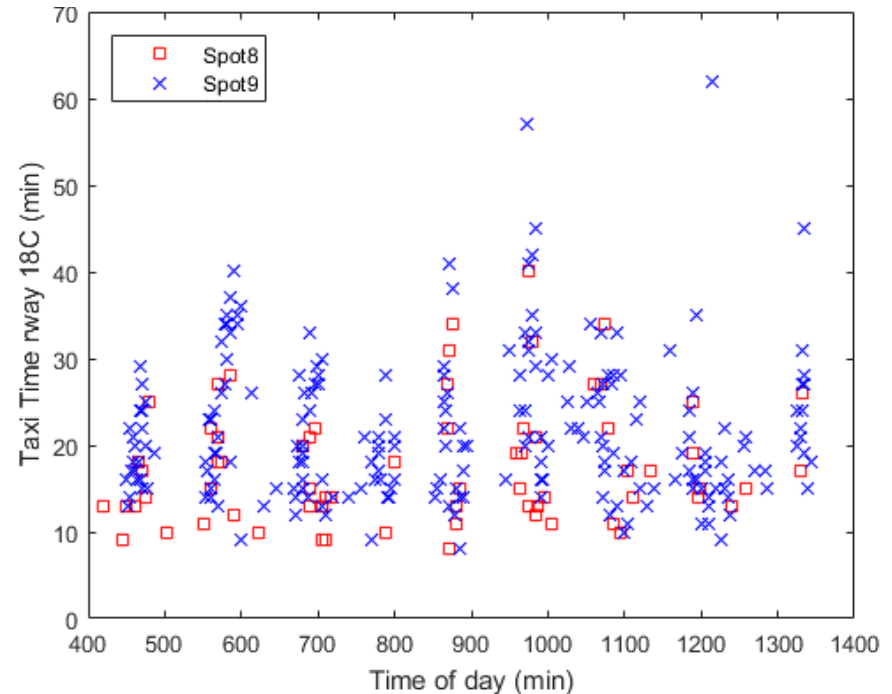
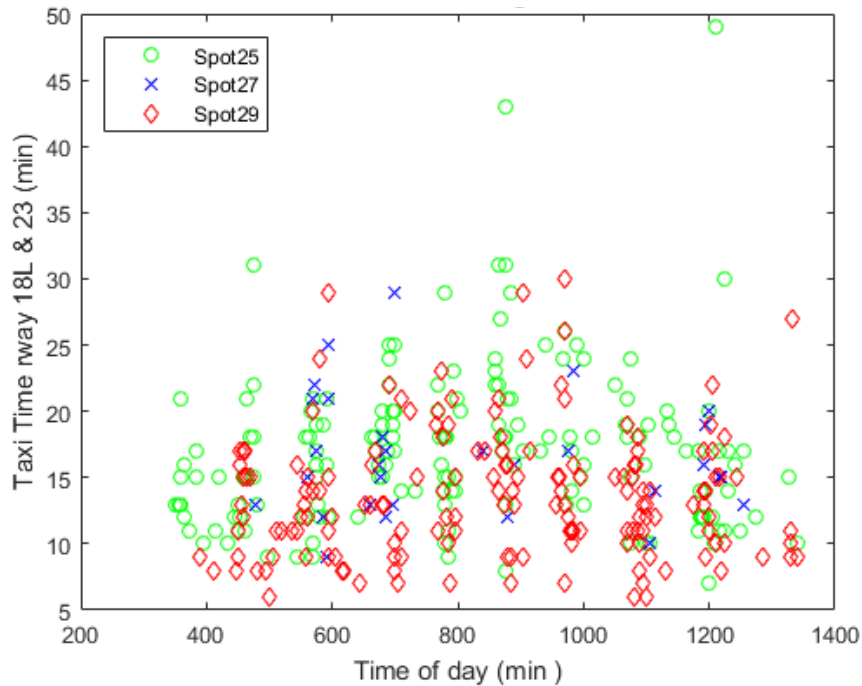


Traffic & Weather Scenarios



Baseline Scenario Surface Traffic

Scatter plot of actual departure taxi times by spot/runway assignment for 8/8/2014 baseline scenario



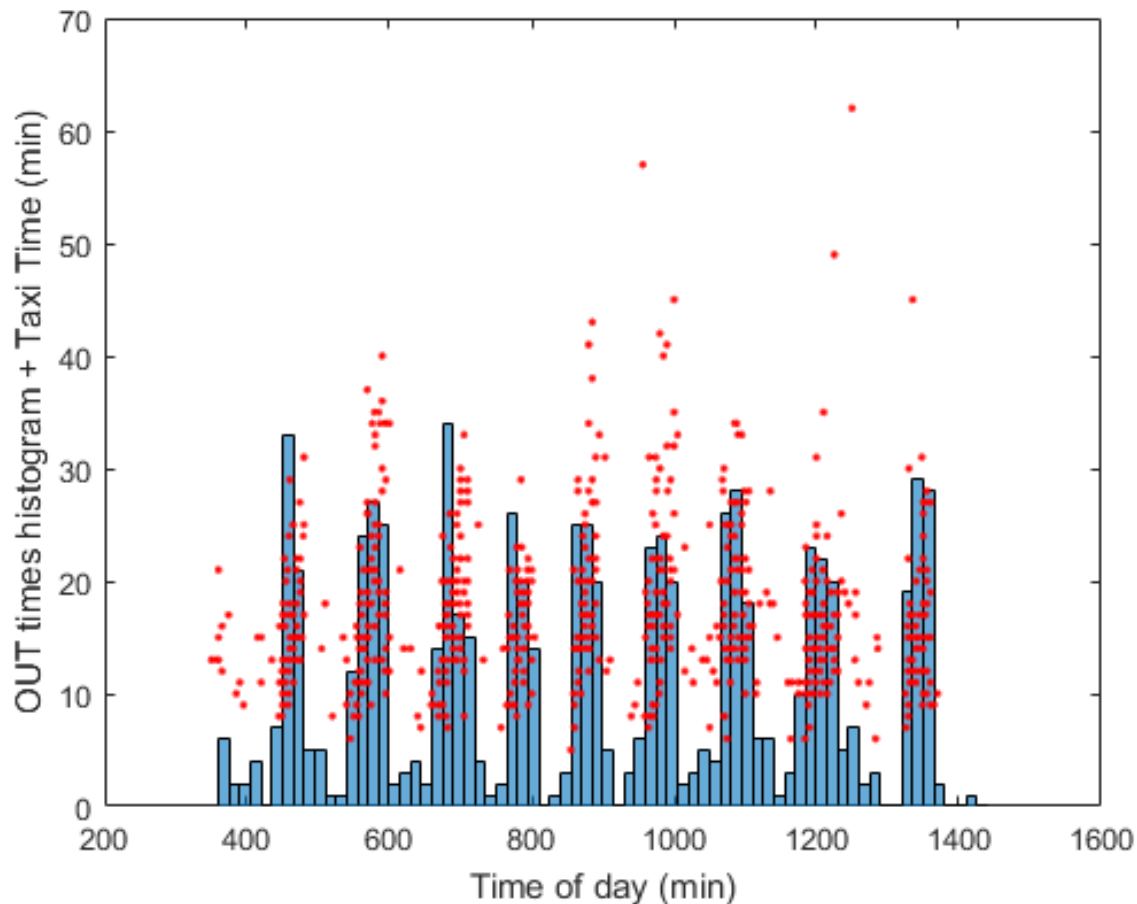


Traffic & Weather Scenarios



Baseline Scenario Surface Traffic

Scatter plot of actual departure taxi times overlaid onto histogram of gate scheduled departure times for 8/8/2014 baseline scenario

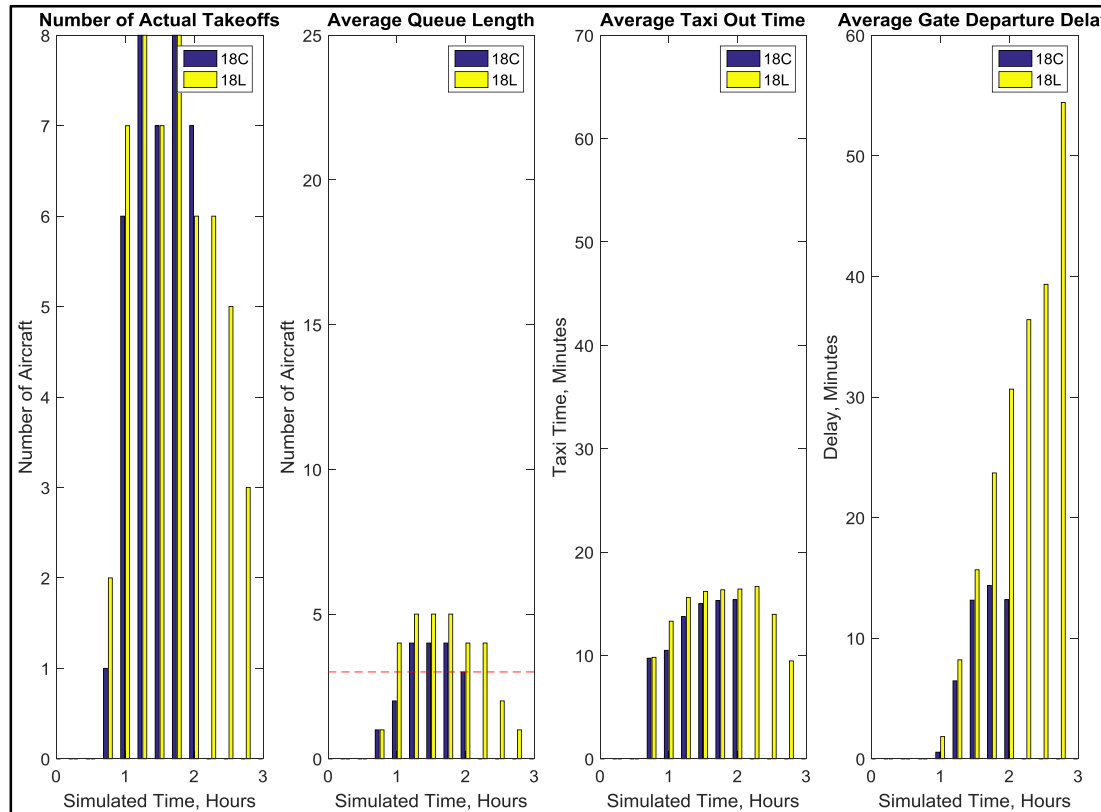


Histogram: number of scheduled departures by ¼ hour
Scatter Plot: departure taxi times for potential future analysis & comparison



Verification Results

DMP Implementation



- DMP results for simple test case *hitl6-training-advisory.list_data*
 - Throughput maintained
 - Runway queue lengths comply with the target of 3/+1-2 aircraft
 - Average quarter-hour taxi-out times departures are sharply reduced
 - Taxi-out delay shifted to gate



Current User Interface



Airport Demand Analysis

Airport Demand Analysis

Select initial scenario information

Traffic Schedule File: C:\Work\TerminalControl\What If OY1\ScenarioFiles\Sensitivity\hit6-training-advisor ...

Flow Restrictions File: inalControl\What If OY1\ScenarioFiles\Sensitivity\TrafficFlowRestrictionsShort.csv ...

Simulation & Results Configuration

Simulation Time Step (mins.) 1

Plot Time-Bin Size (mins.) 15

Choose airport/airspace parameter values for demand what-if analysis

Runway	Departure Rate	Departure Fix	MIT Restriction	Start Time	End Time
18C	30	MERIL6	20	50	100
18L	30	BUCKL7	15	75	135

Add Restriction Remove Restriction Analyze

Demand analysis results

Departure Runway	Ave Throughput	Ave Queue Length	Max Queue Length	Min Queue Length	Ave Taxi Out Time (min)	Ave Gate Delay (min)
18C	29.2105	2.9728	12	0	23.5761	8.6417e-16
18L	27.3684	9.0380	25	0	39.7462	1.0931e-15

Arrival Runway	Ave Throughput	Ave Taxi In Time (min)
18R	29.6386	12.0244
23	26.5116	12

Configure DMP

DMP Analysis

DMP Analysis

Choose parameters for DMP what-if analysis

Runway	Target Departure Queue Length	Start Time	Stop Time
18C	3	70	183
18L	3	59	183

Analyze

DMP what-if analysis results

Departure Runway	Ave Throughput	Ave Queue Length	Max Queue Length	Min Queue Length	Ave Taxi Out Time (min)	Ave Gate Delay (min)
18C	29.2105	1.7418	6	0	16.0840	7.4921
18L	27.8571	6.7857	15	0	31.3251	7.4979

Arrival Runway	Ave Throughput	Ave Taxi In Time (min)
18R	29.6386	15.7073
23	26.5116	15.7368