Development and Validation of an Automated Simulation Capability in Support of Integrated Demand Management

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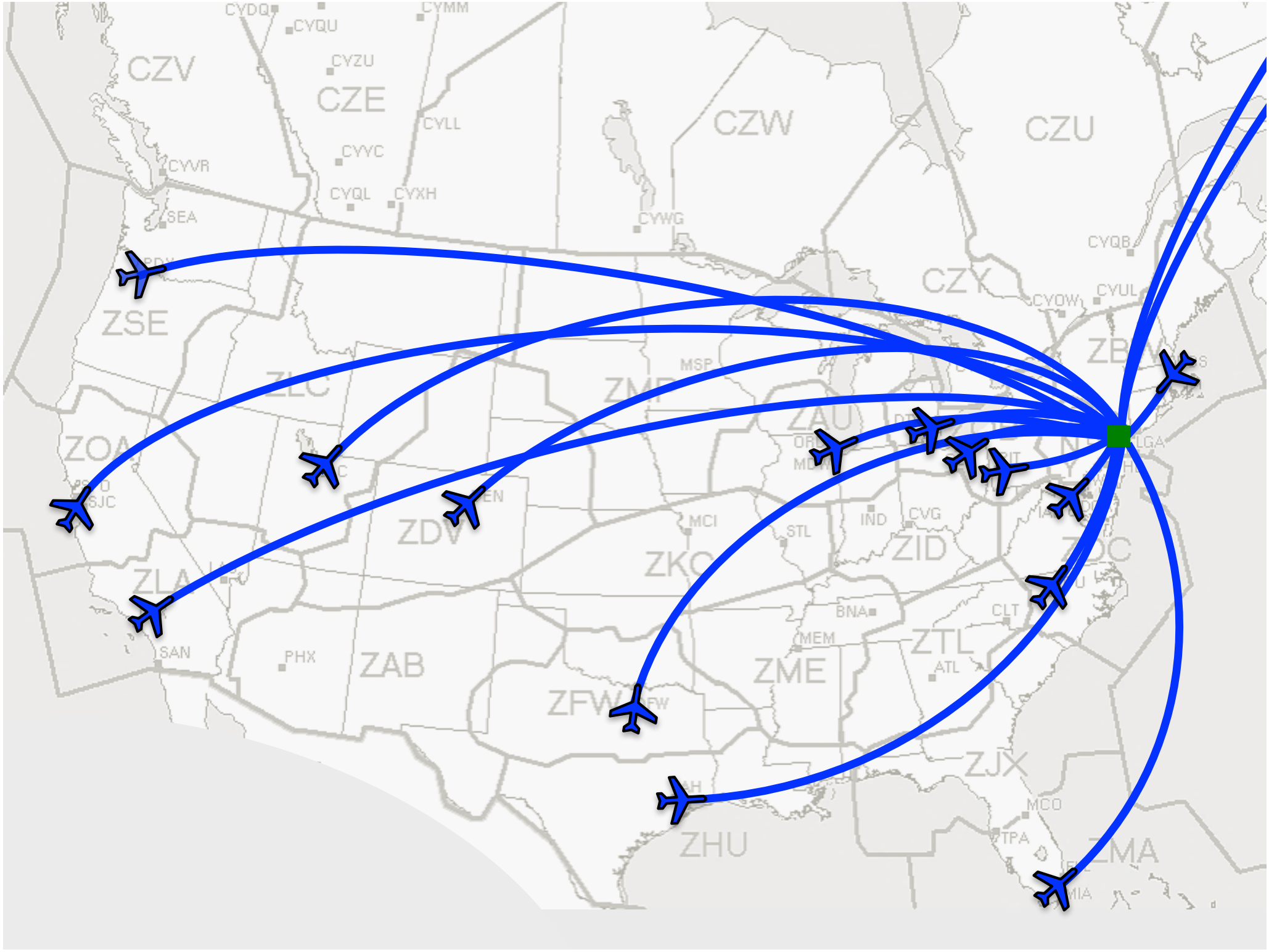
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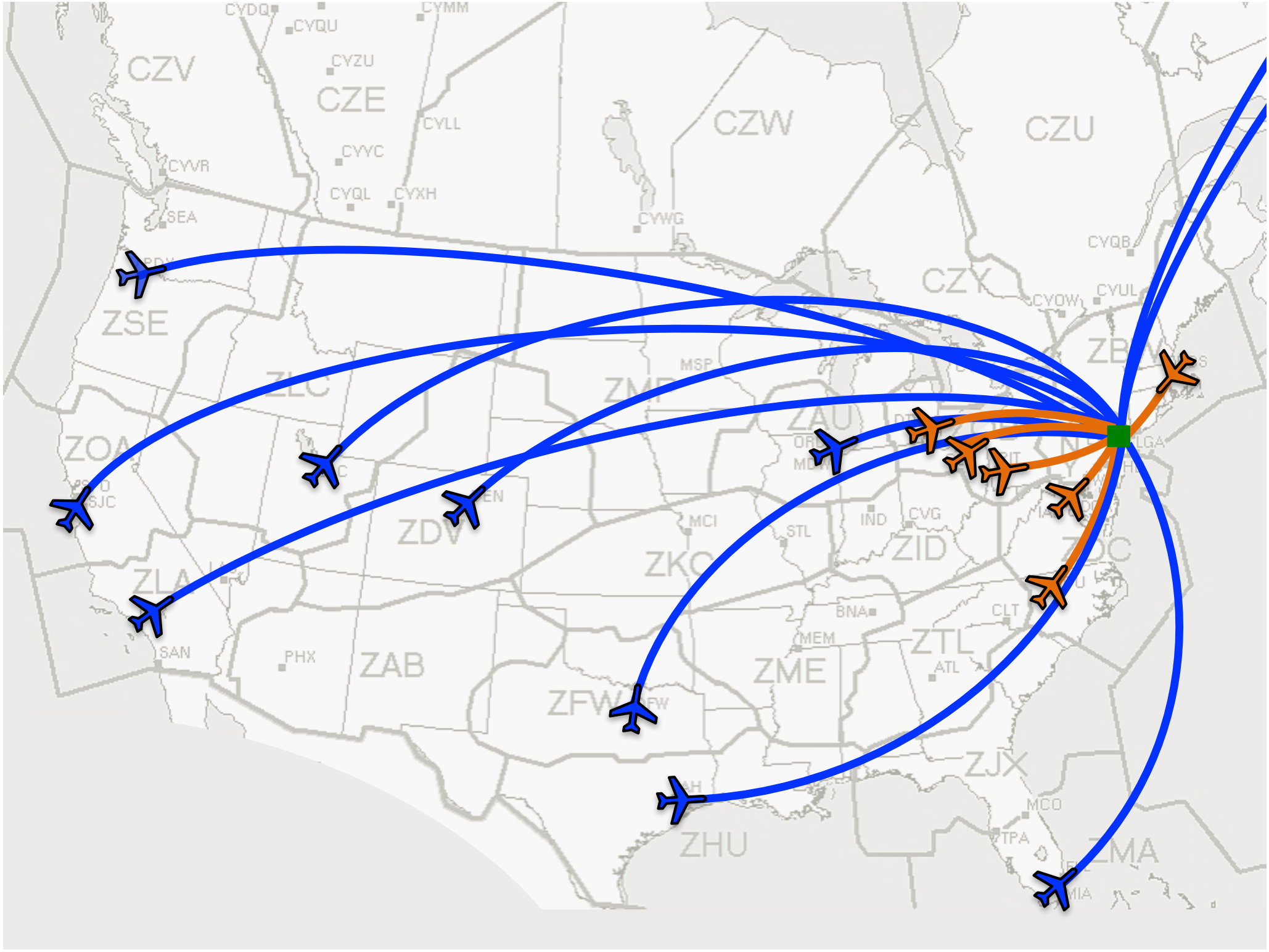
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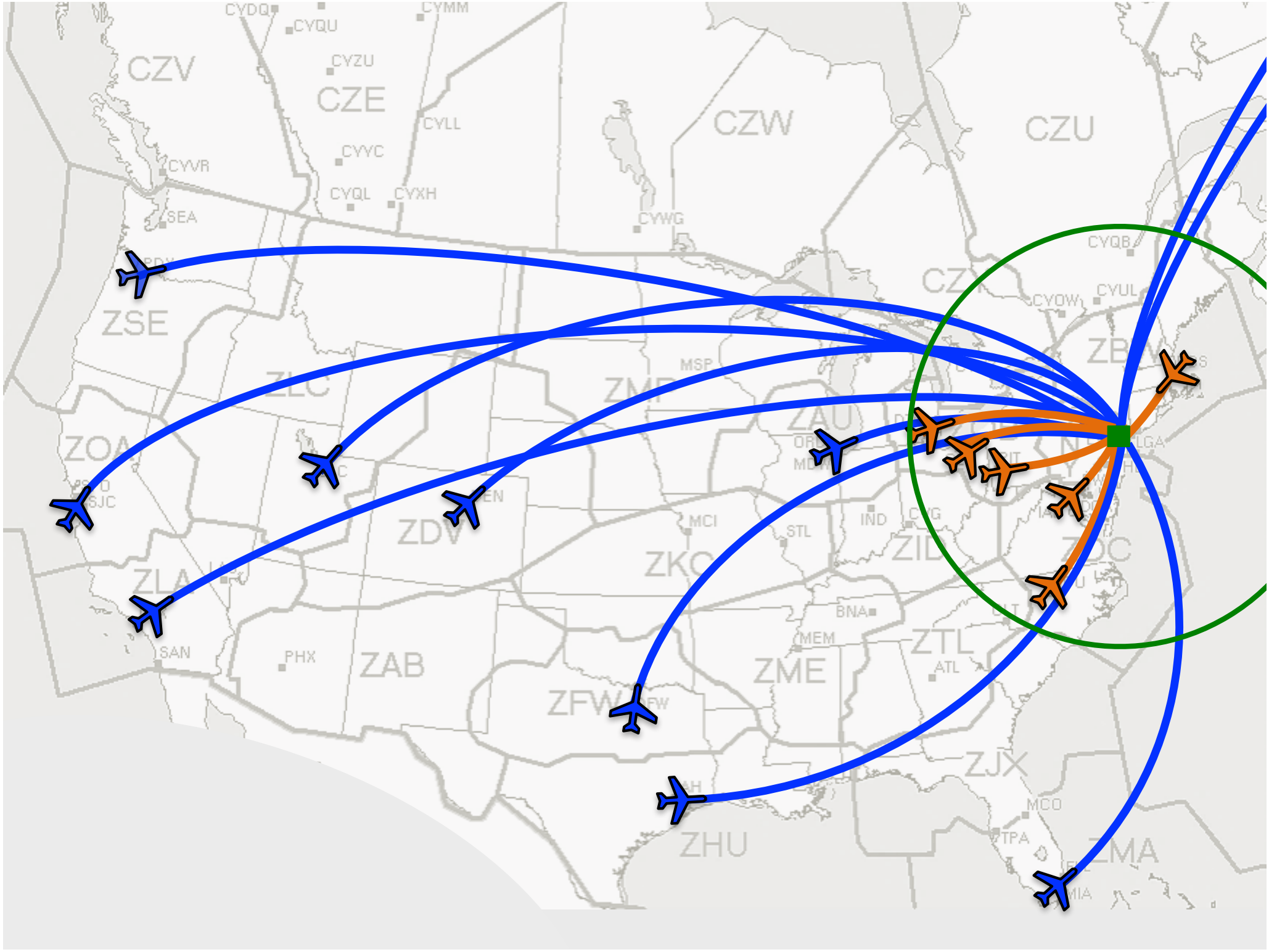
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Strategic Planning
Tactical Planning
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Human-in-the-loop (HITL) simulations

- Study integration of strategic and tactical planning tools
  - Strategic:
    - Pre-departure ground delay

    ⇨ Adjusts demand to roughly meet airport arrival constraint
  - Tactical:
    - Airborne delay near arrival airport
    - Pre-departure ground delay for short-haul flights

    ⇨ Delivers demand to actual arrival rate constraint
- Subject matter expert participants:
  - Air traffic controllers
  - Traffic flow managers

Challenges of HITL simulations

- Expensive
  - Subject matter expert participants
  - Simulation support staff
- Time consuming

  Minimum of 5 hours to capture long-haul flights pre-departure
- Limitations
  - Number of simulations executed
  - Number of airspace sectors that can be populated with traffic
  - Traffic volume

Motivation

- Evaluate over larger variation in parameters
- Simulate larger, more realistic traffic scenarios
- Augment HITL with automated background traffic

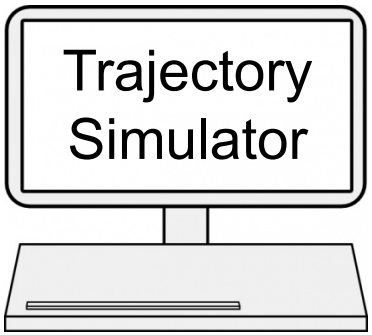
Objectives

- Automate HITL simulation
- Emulate HITL simulation results
- Maintain high fidelity trajectory simulation
- Incorporate updates to strategic planning tool

Outline

- Simulation structure
  - HITL simulation
  - HITL participant actions
  - Automated simulation capability
- Initial validation
- Conclusions and future work

Simulation structure



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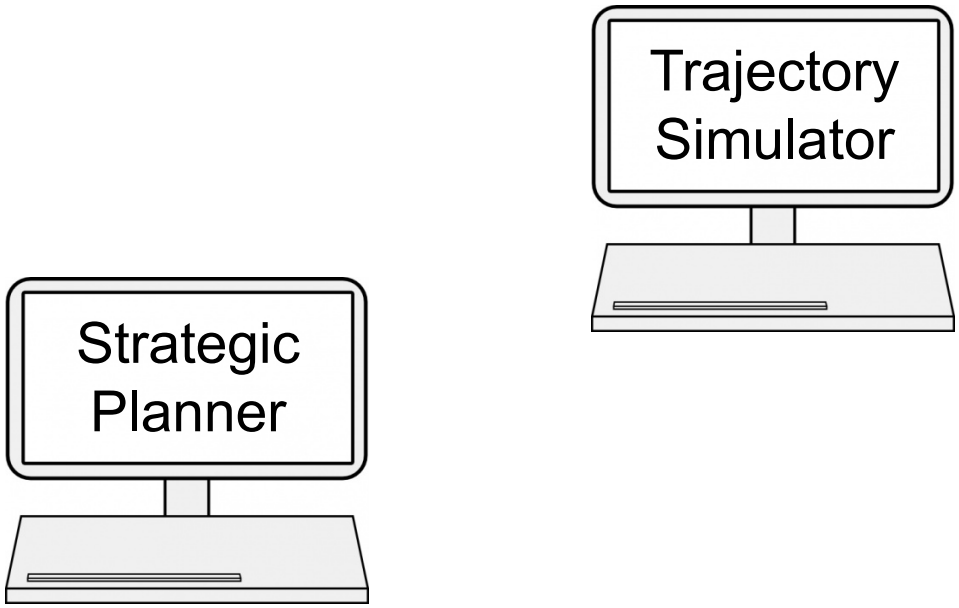

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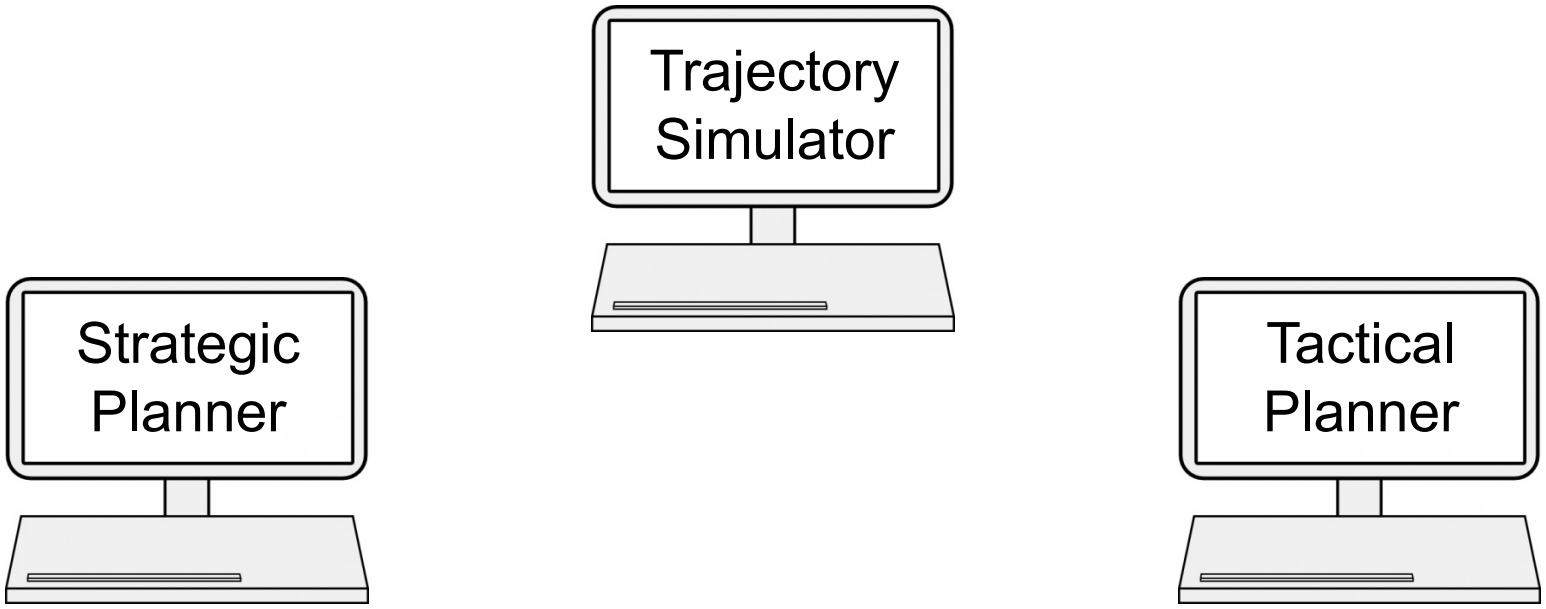
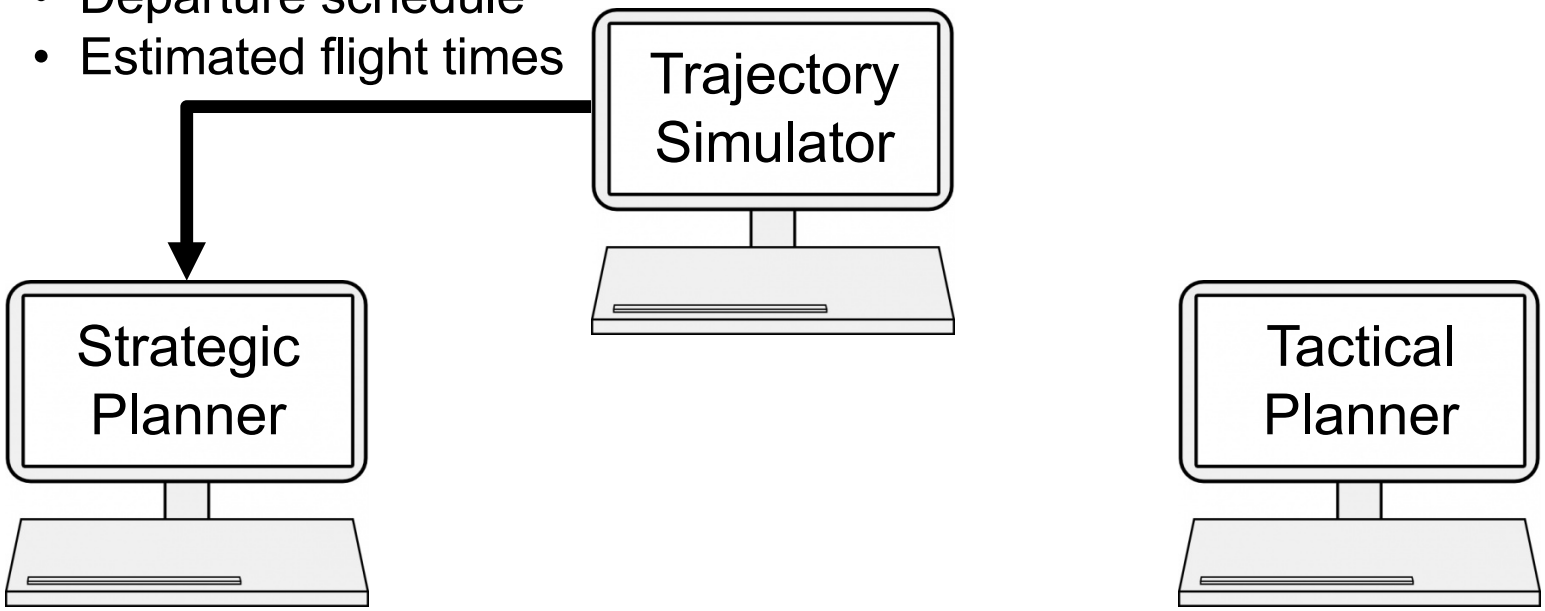


Simulation structure

- Departure schedule
- Estimated flight times



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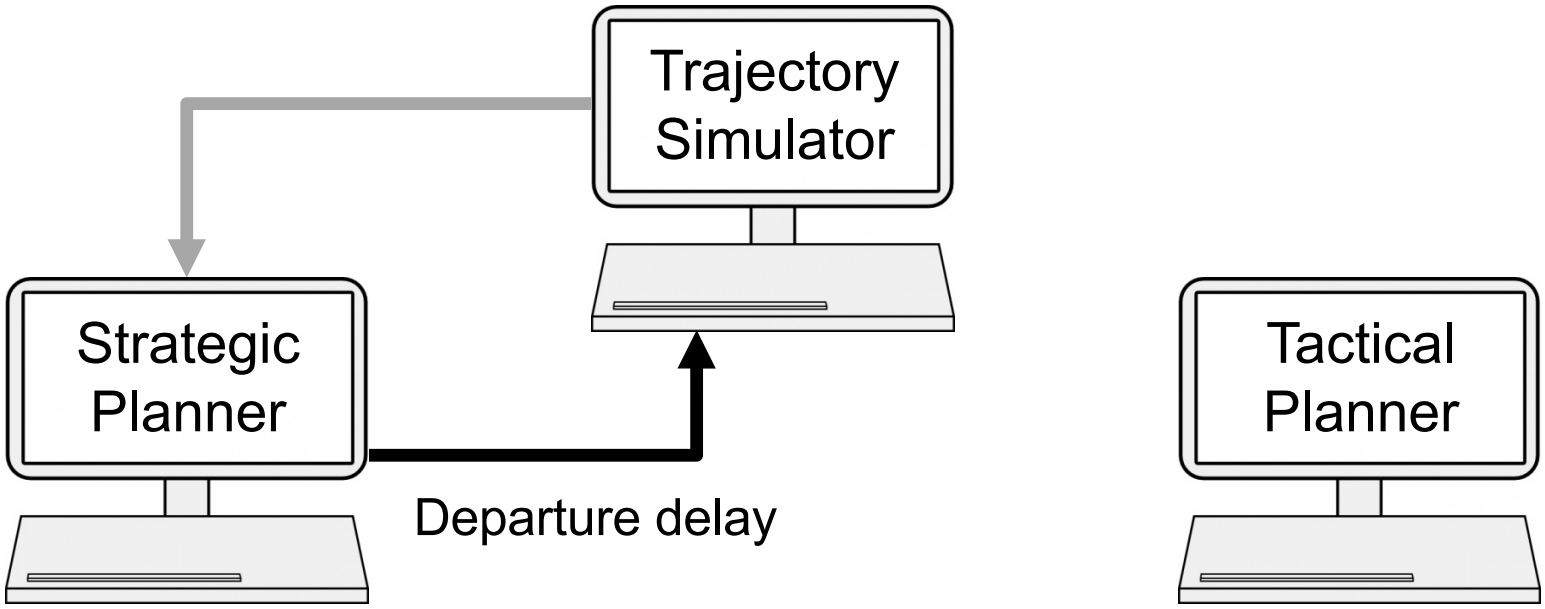

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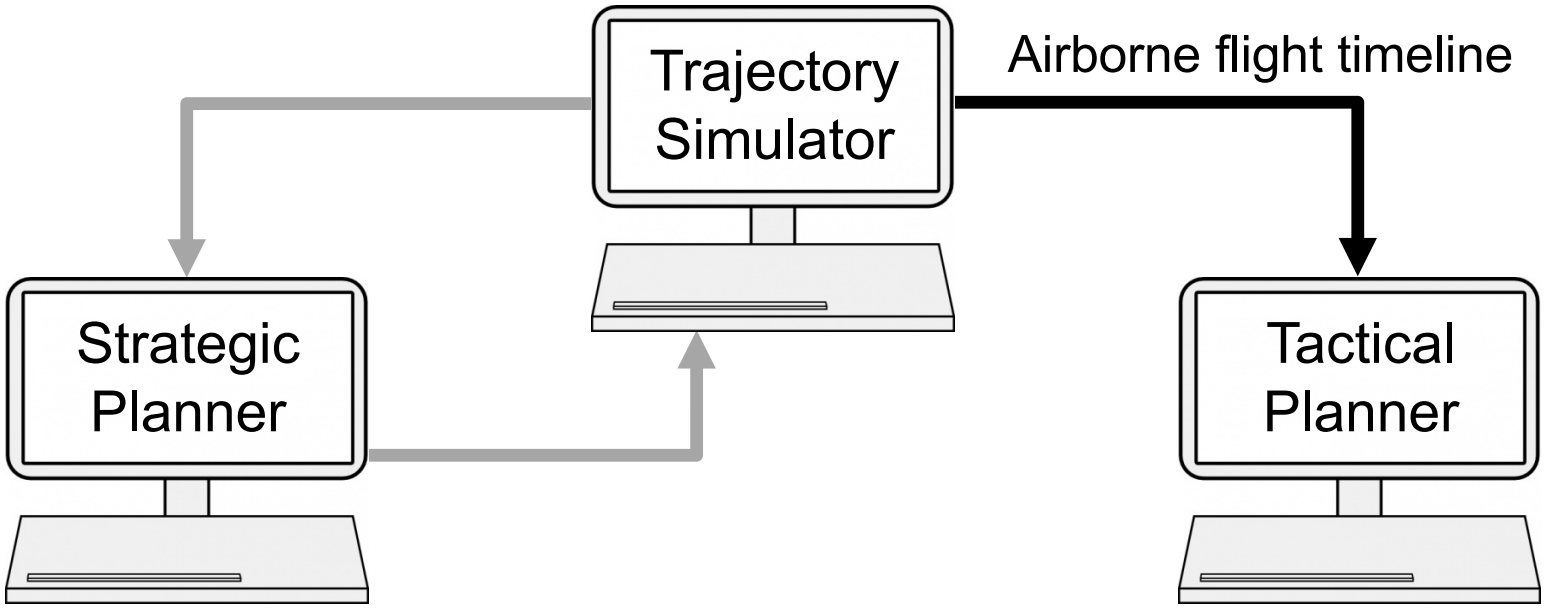

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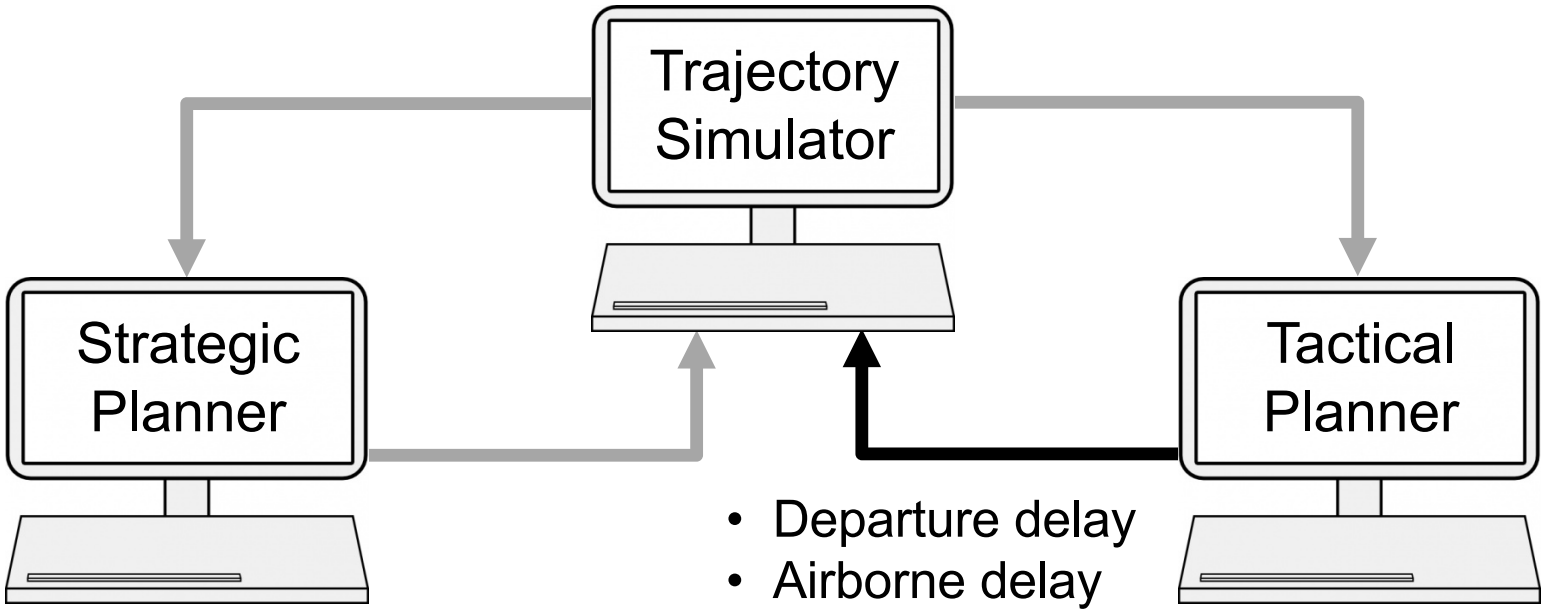

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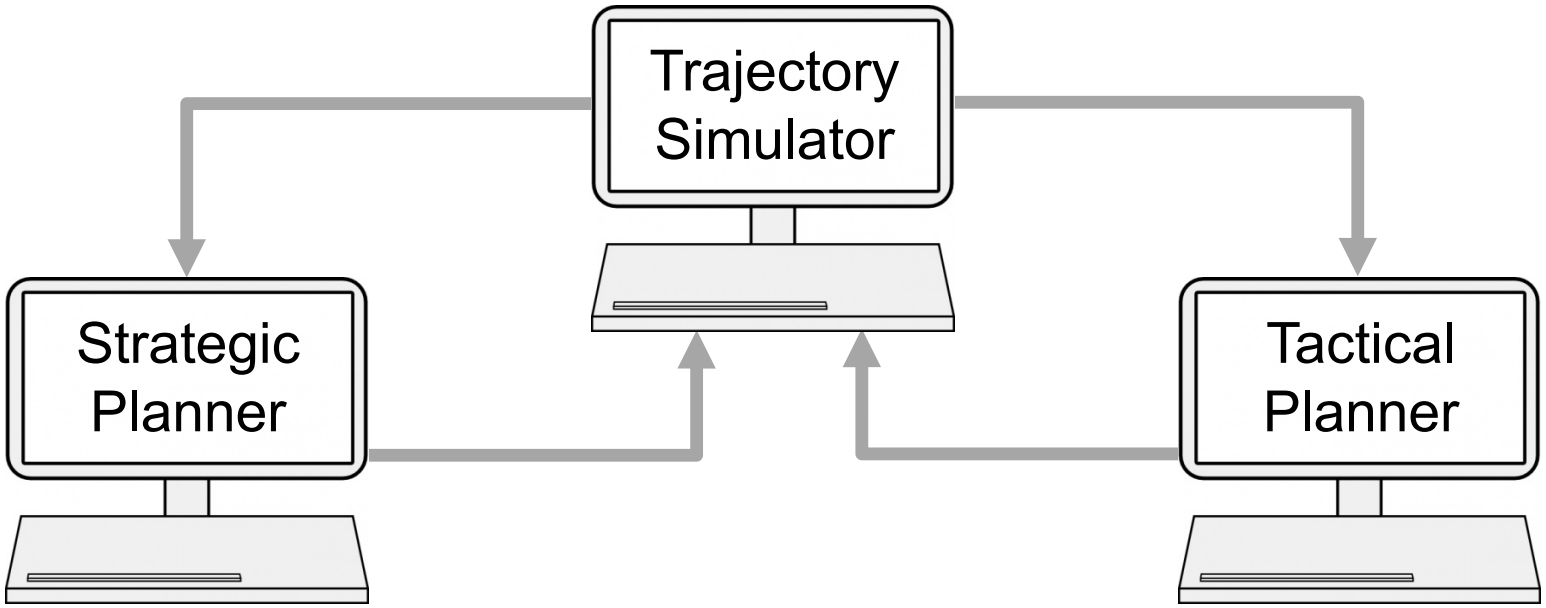

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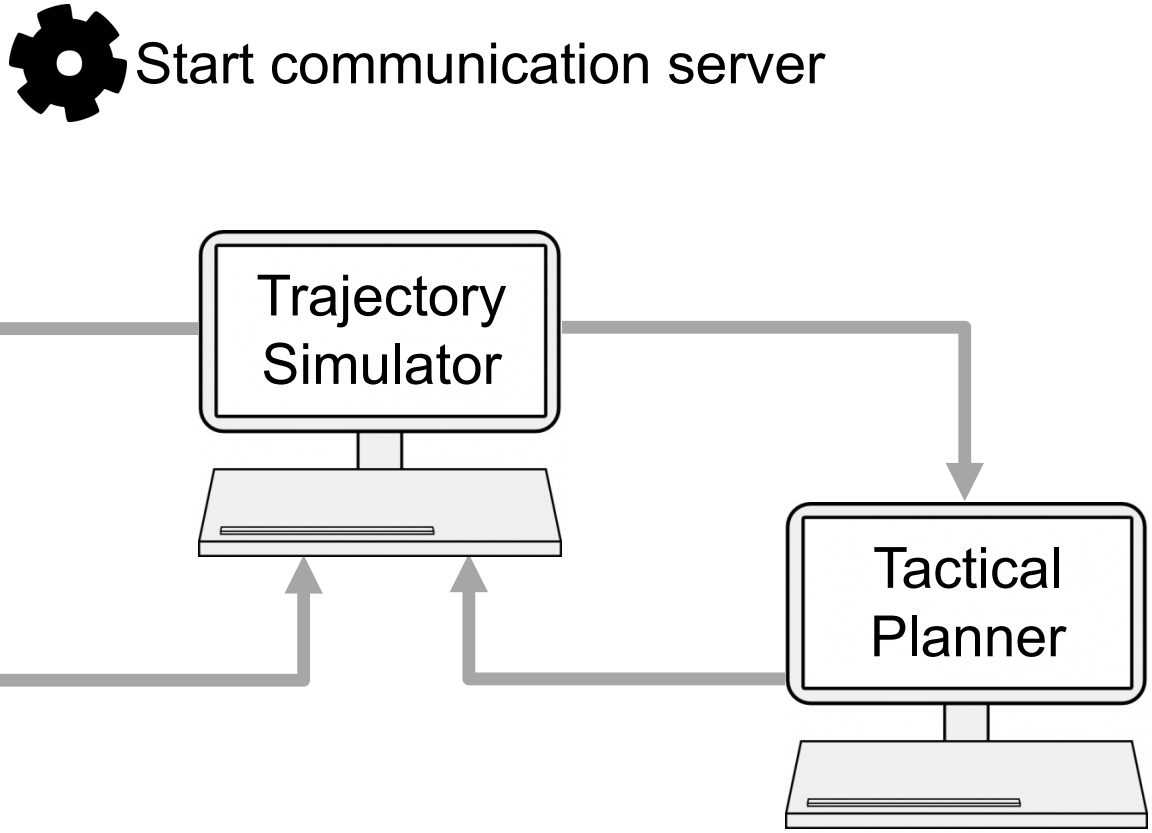

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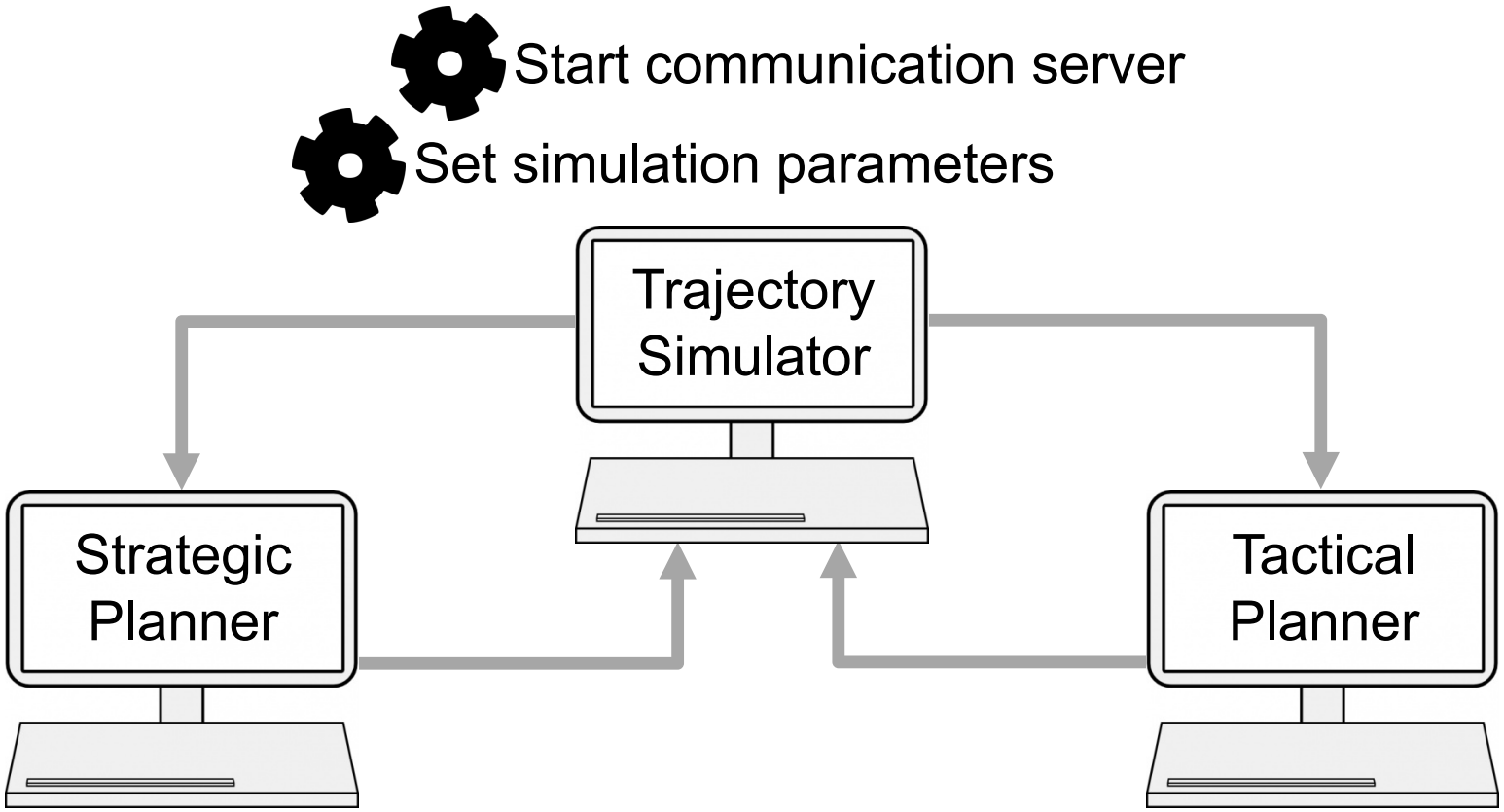

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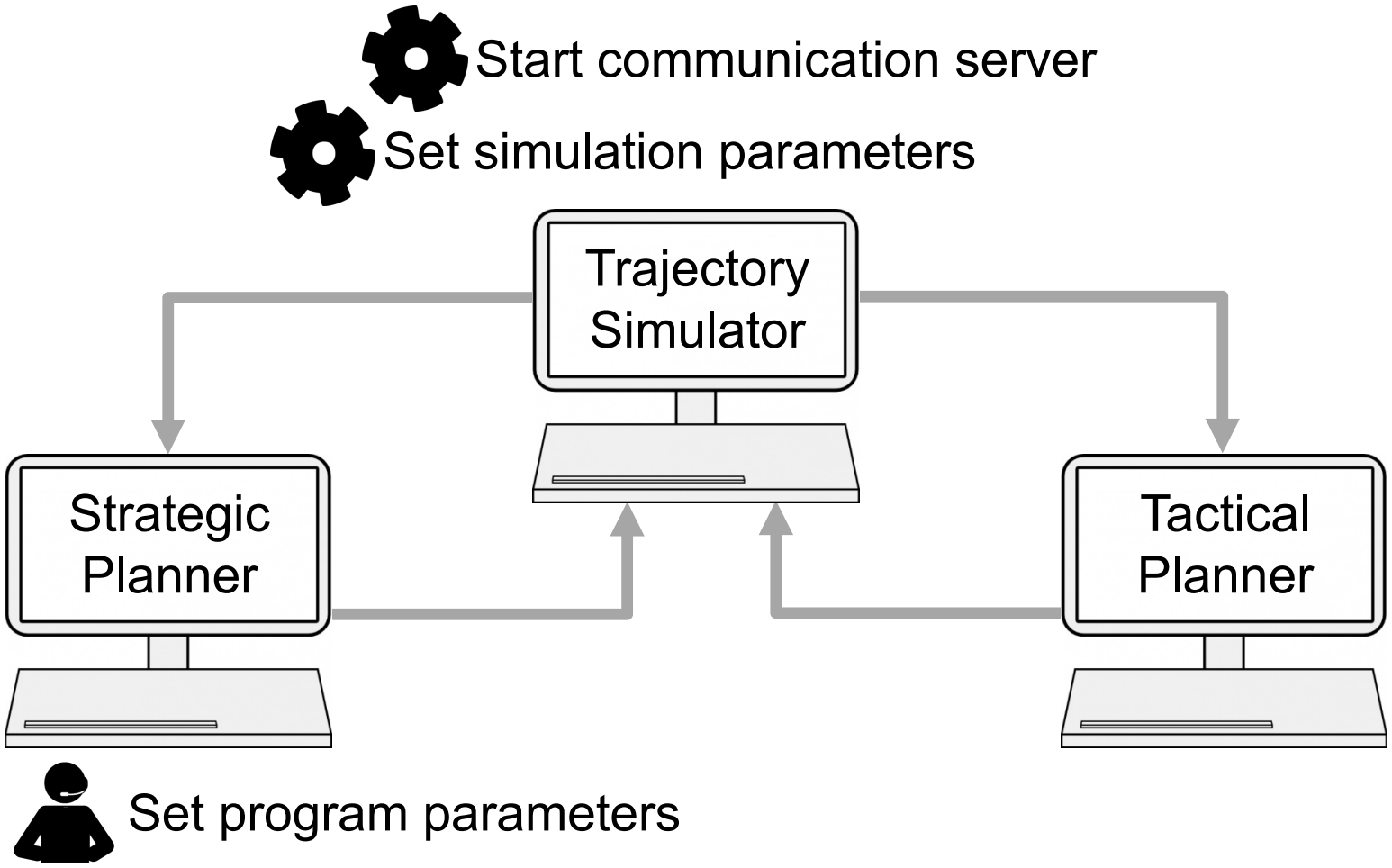

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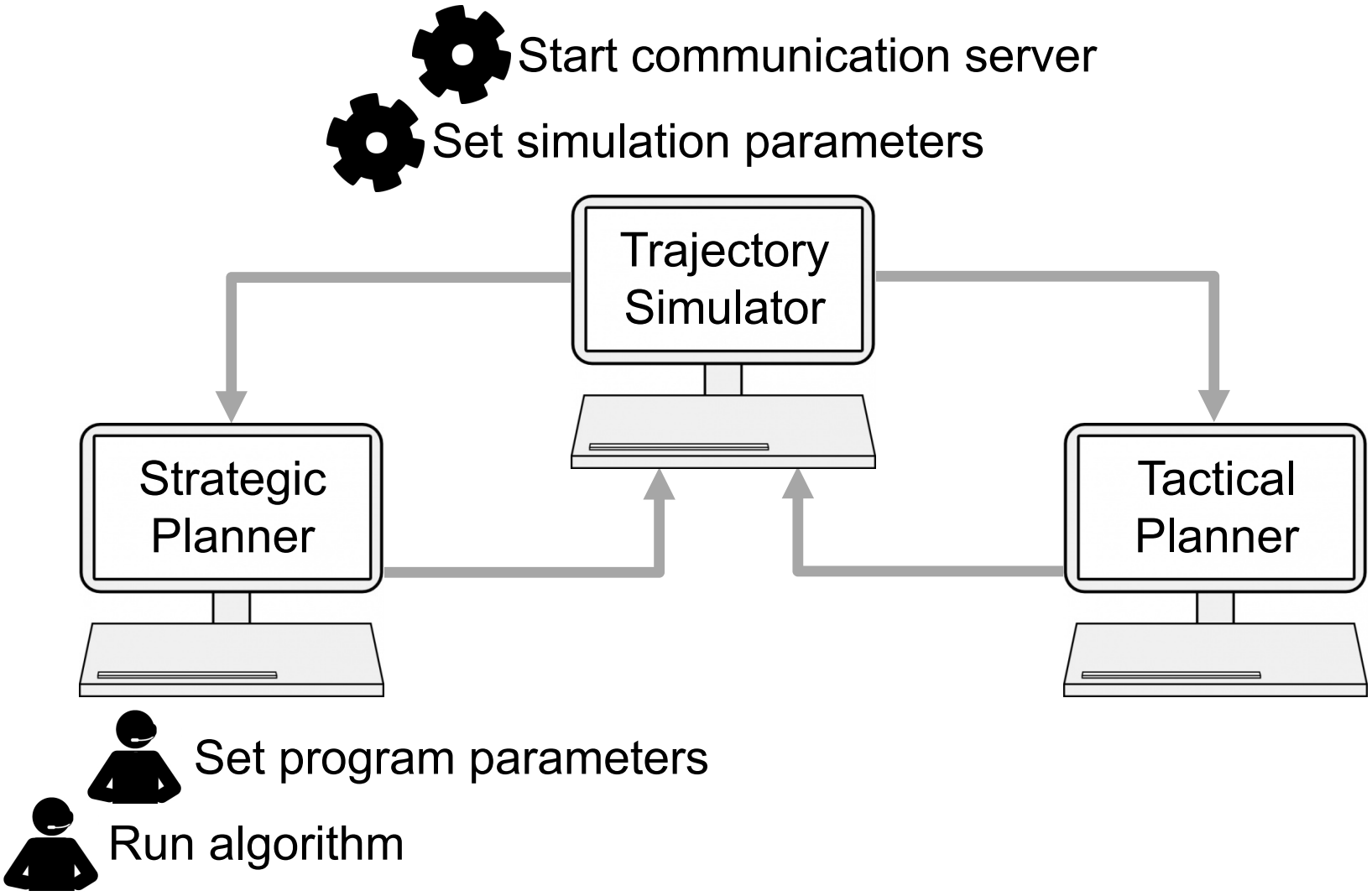

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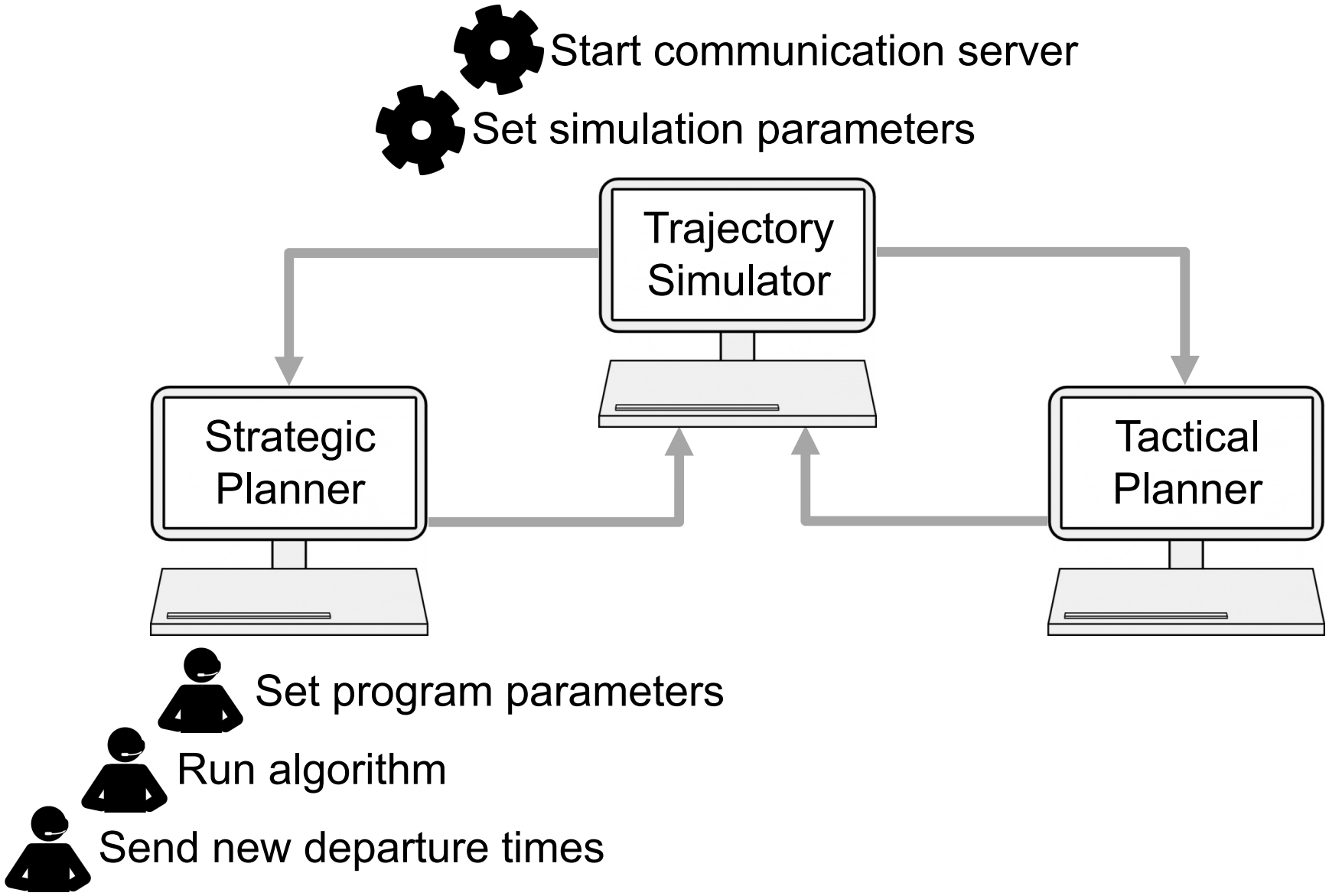

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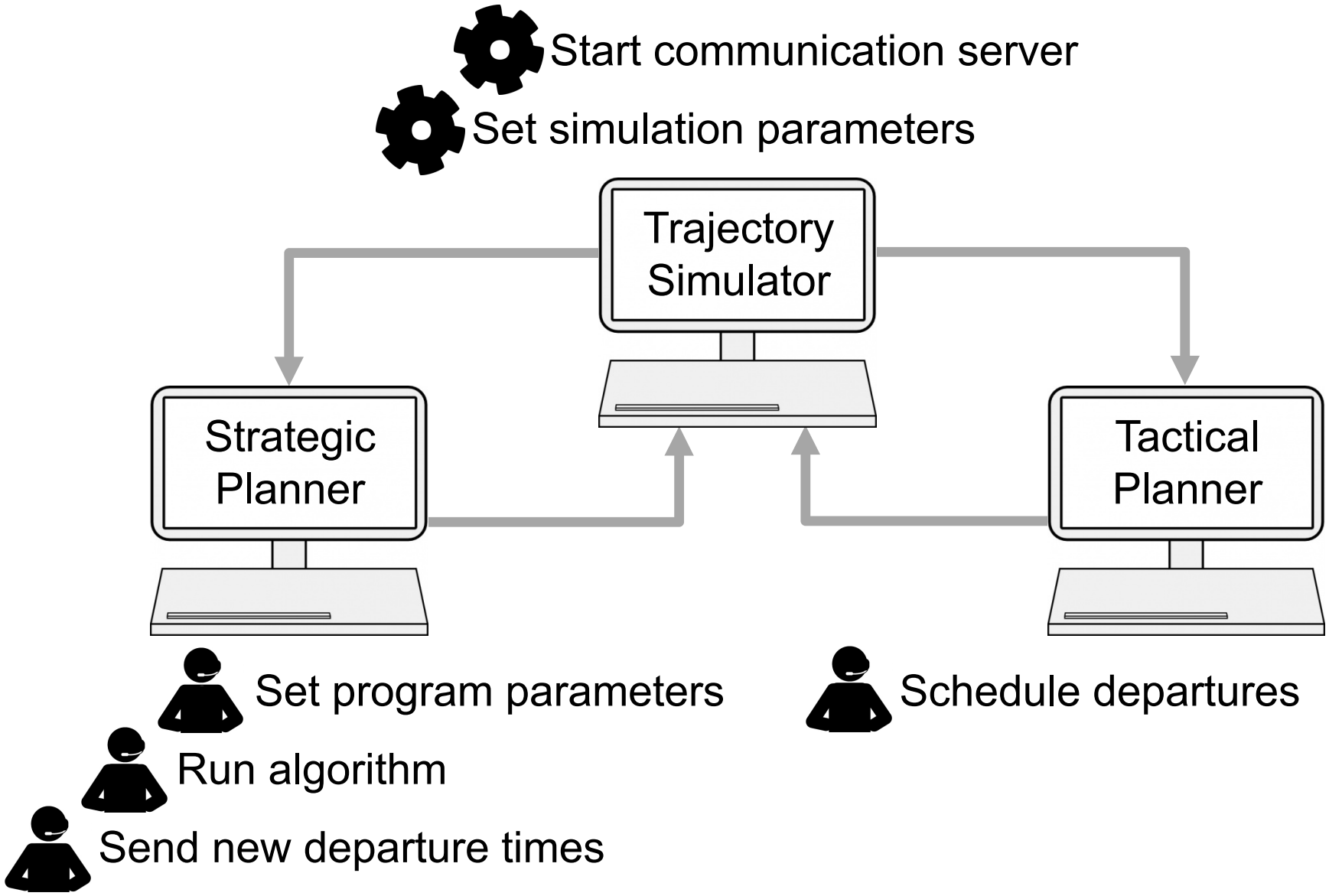

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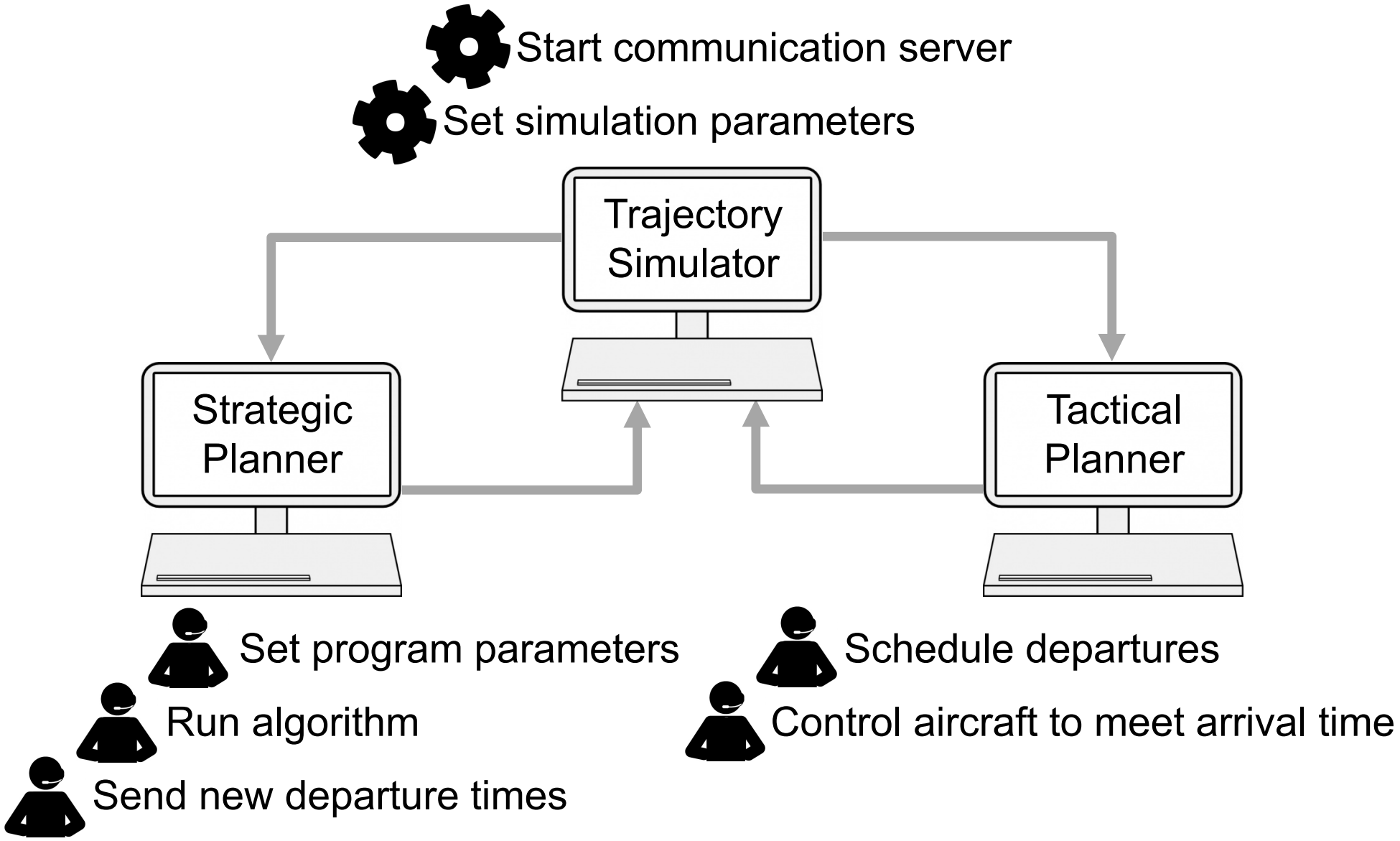

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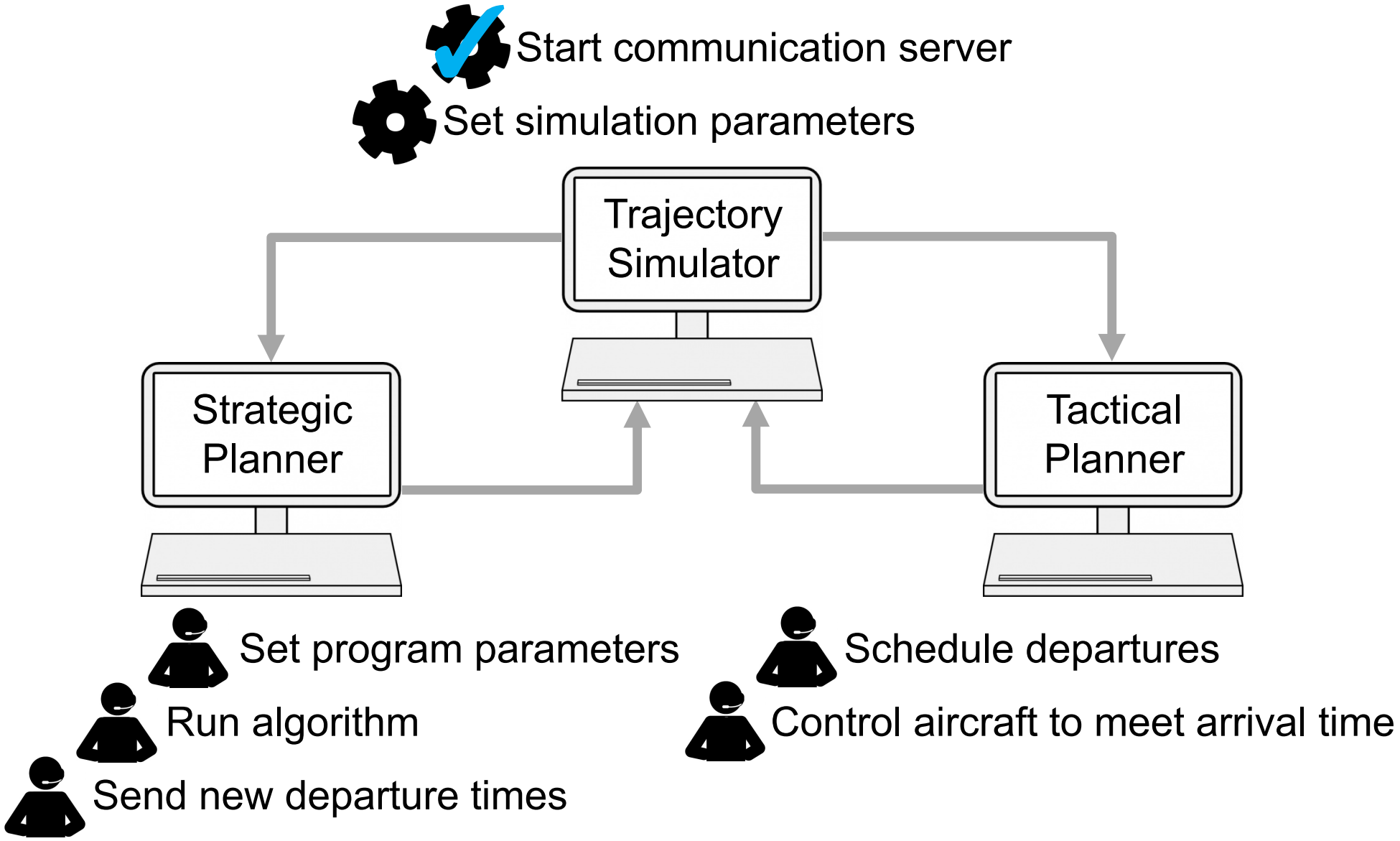

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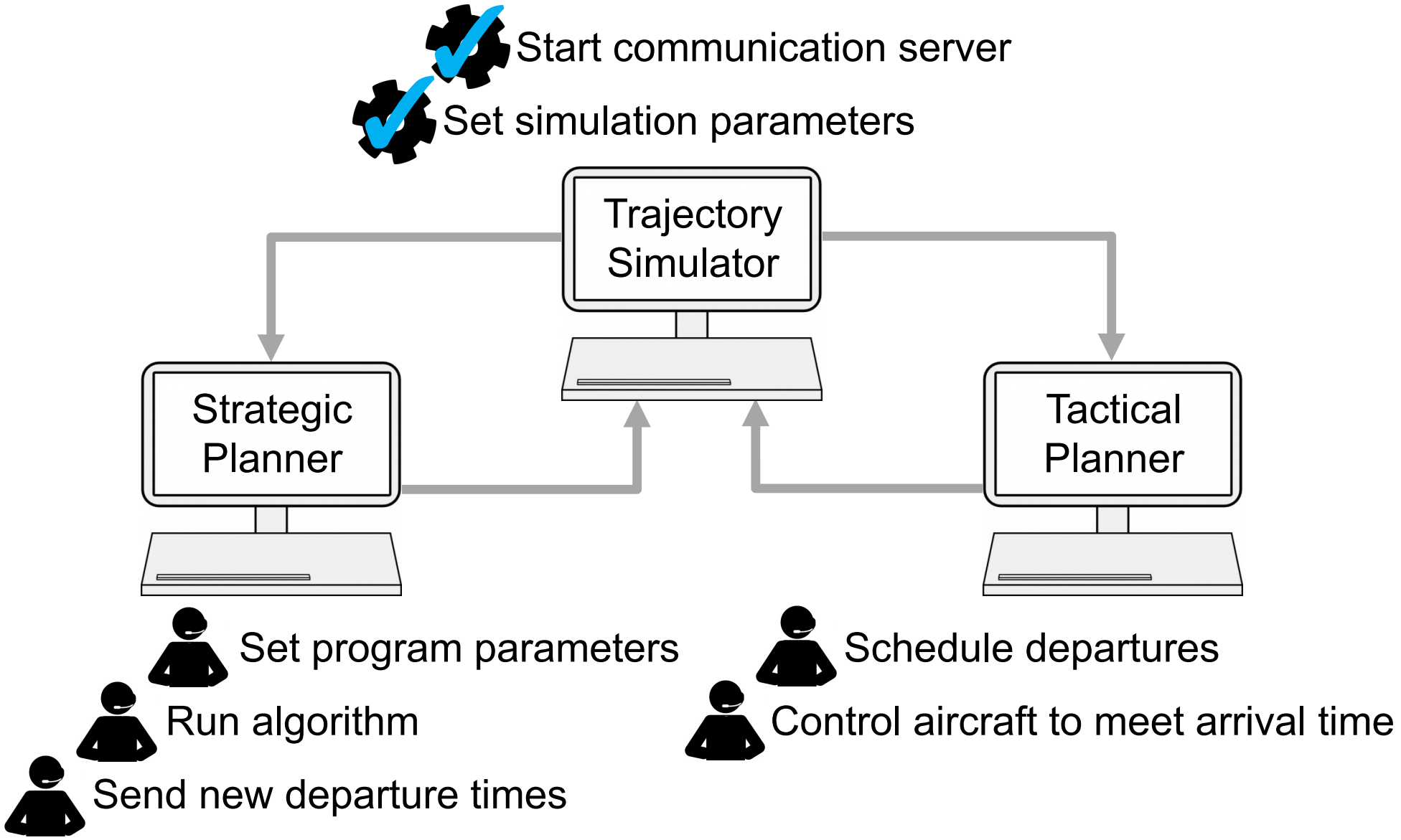

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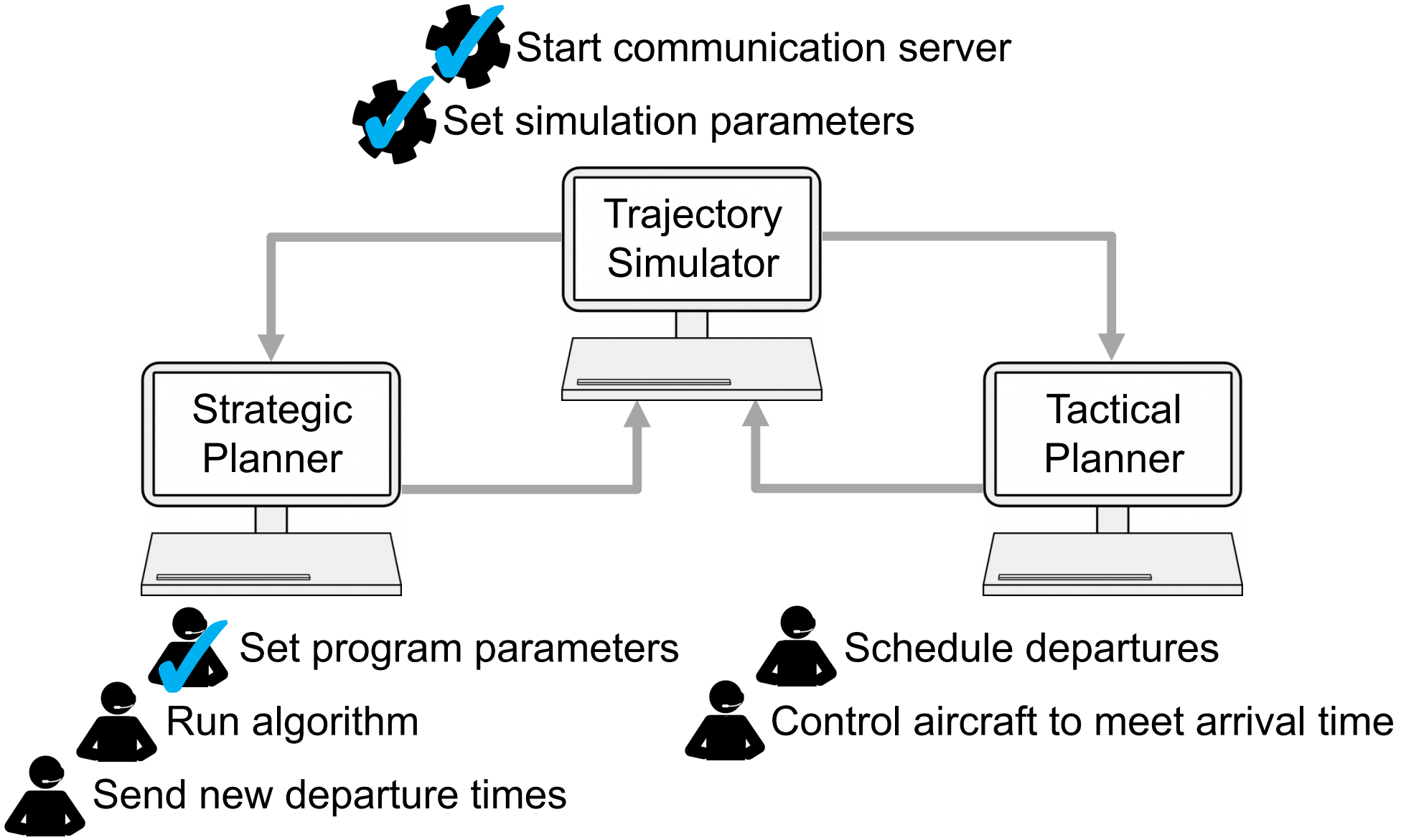

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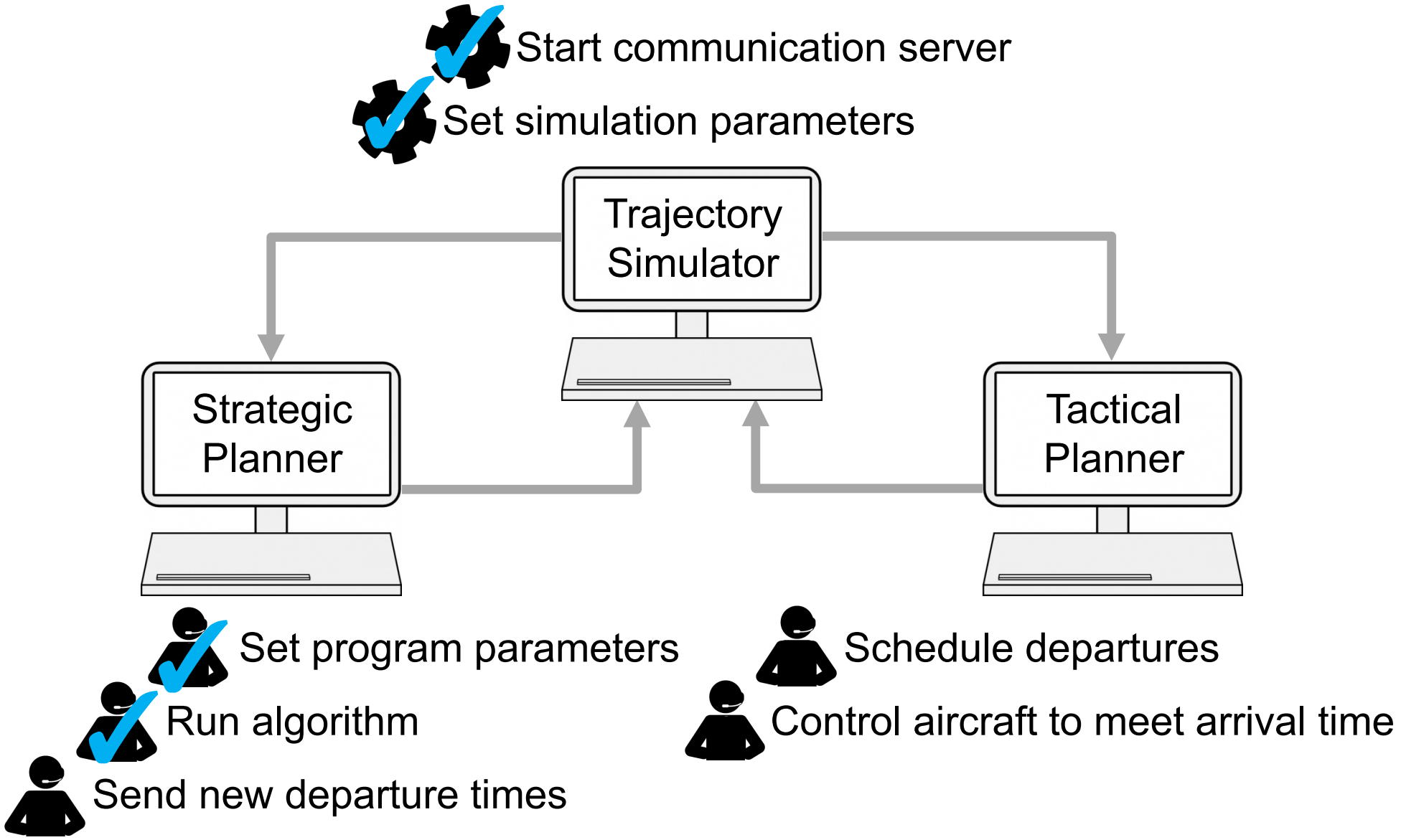

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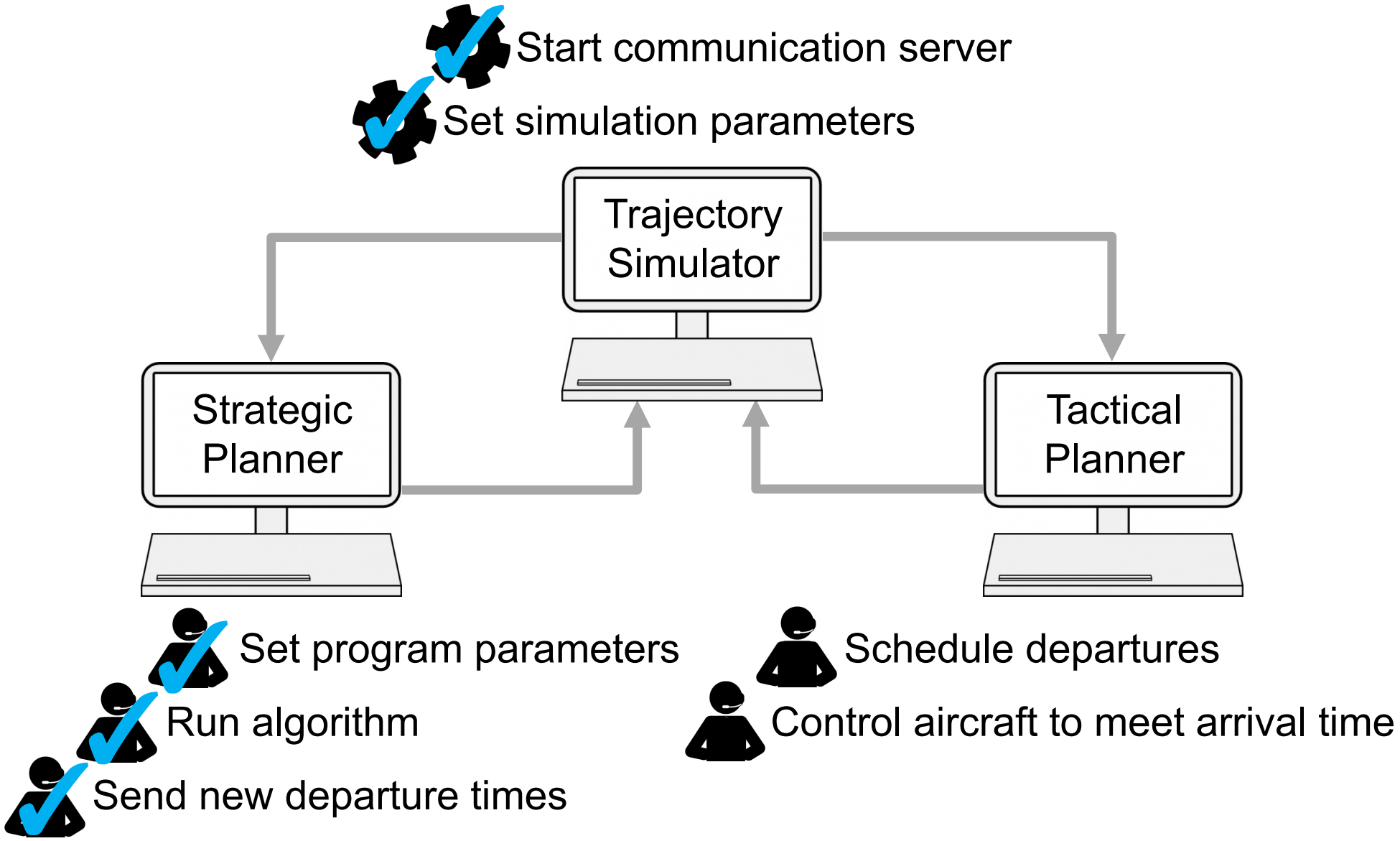

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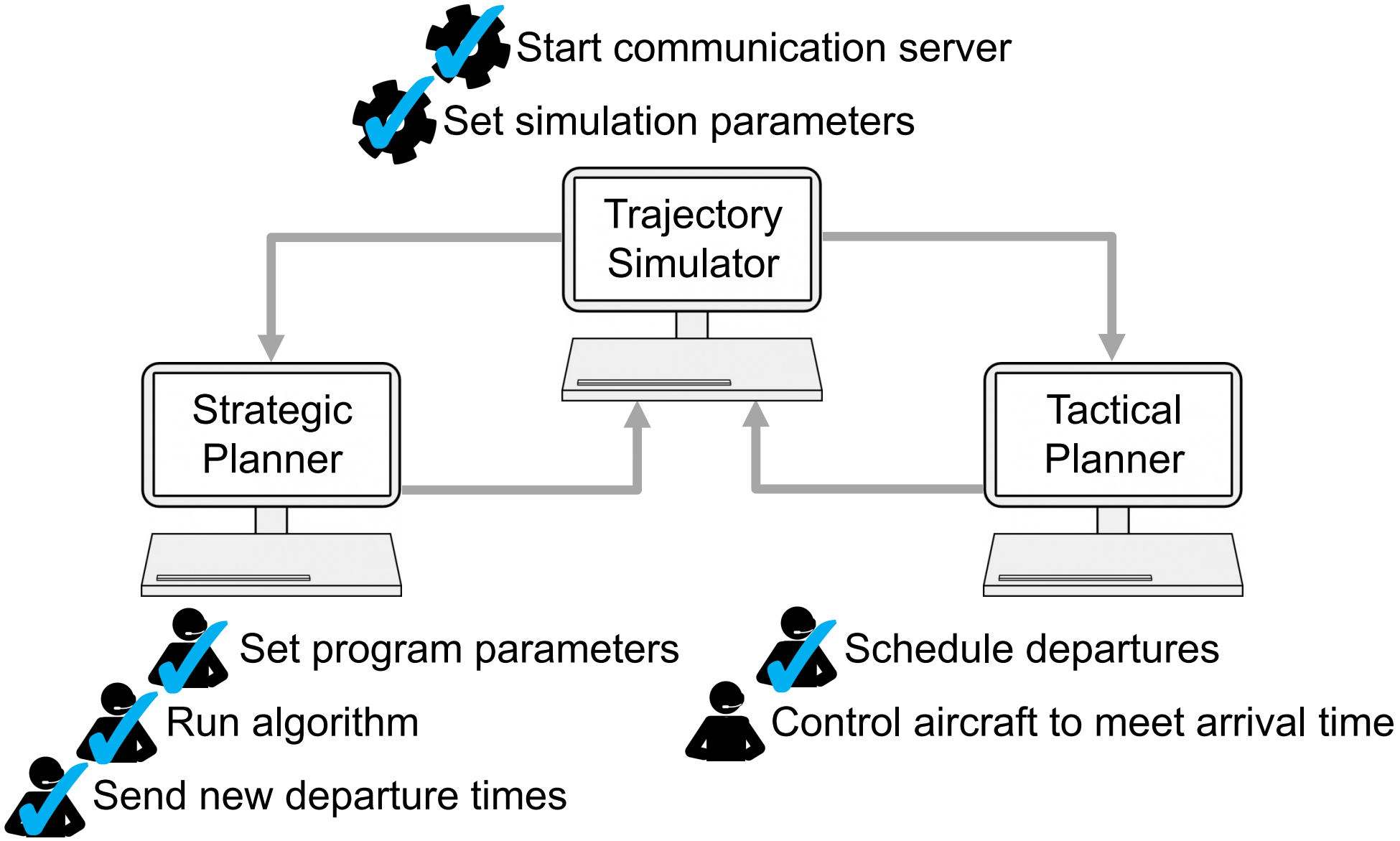

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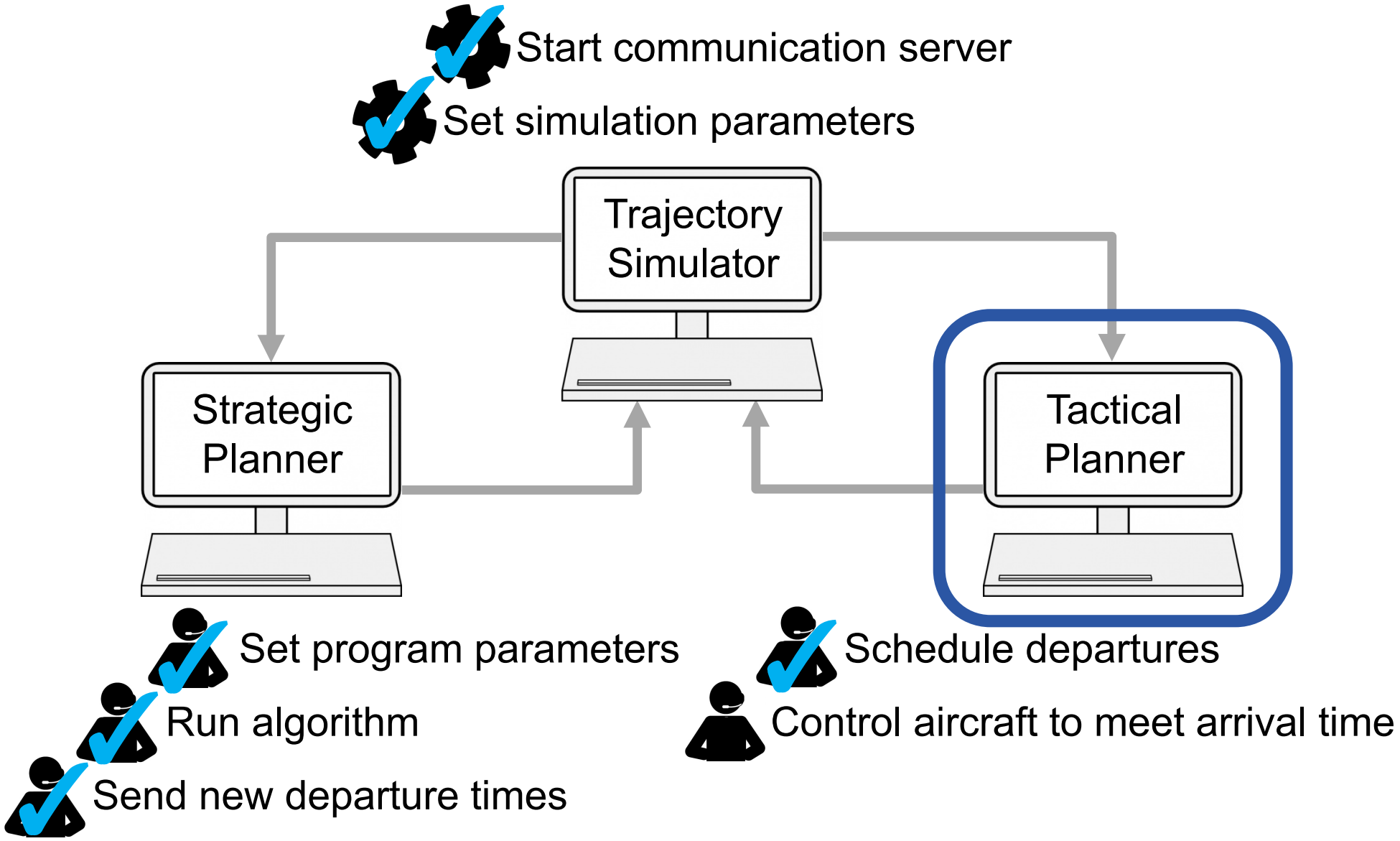
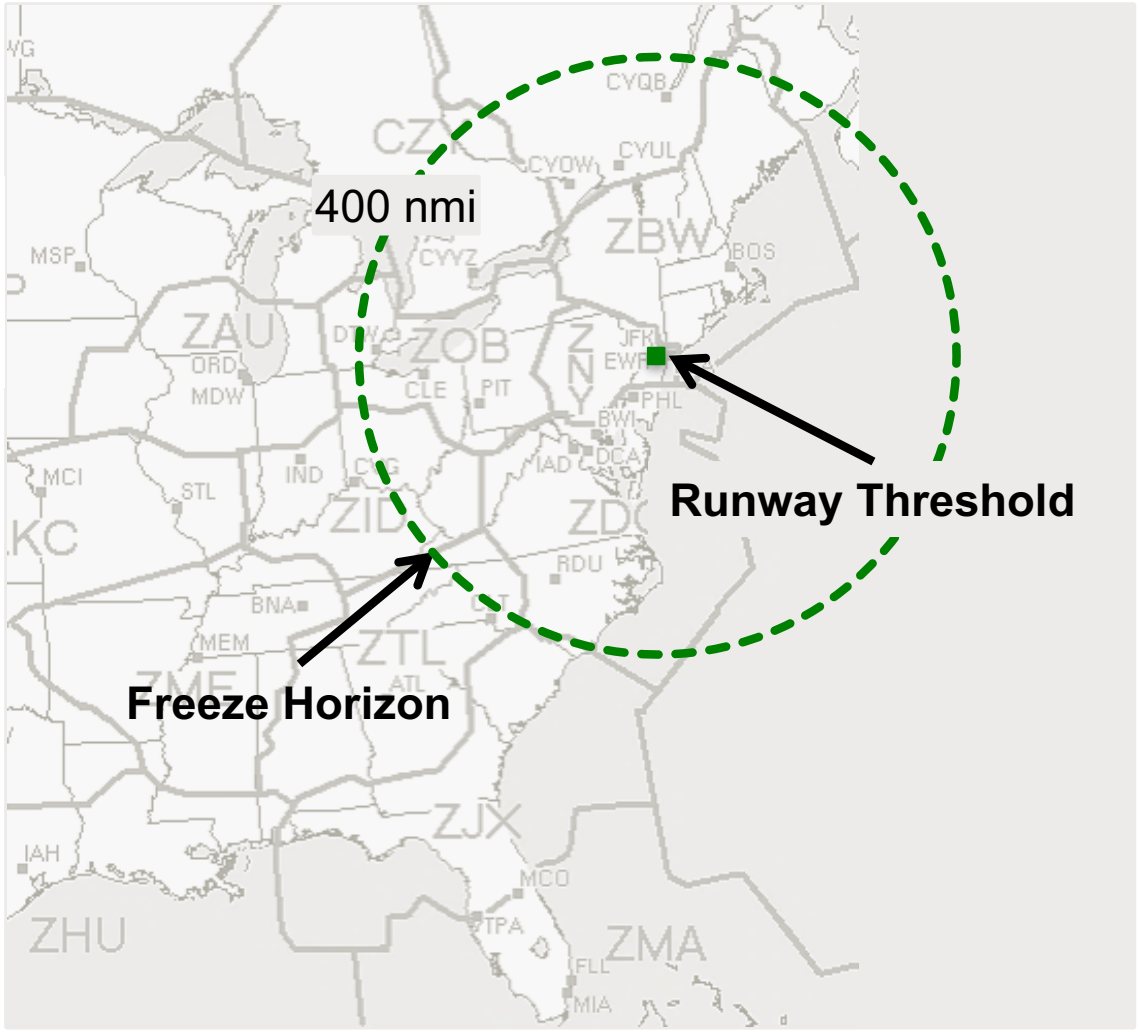


Tactical planner emulator

- Scheduler developed in house at NASA
  - Can run in fast-time
  - Code easily accessible for modification
- Adapted for Newark Liberty International Airport
- Modified to schedule internal departures automatically

Tactical planning



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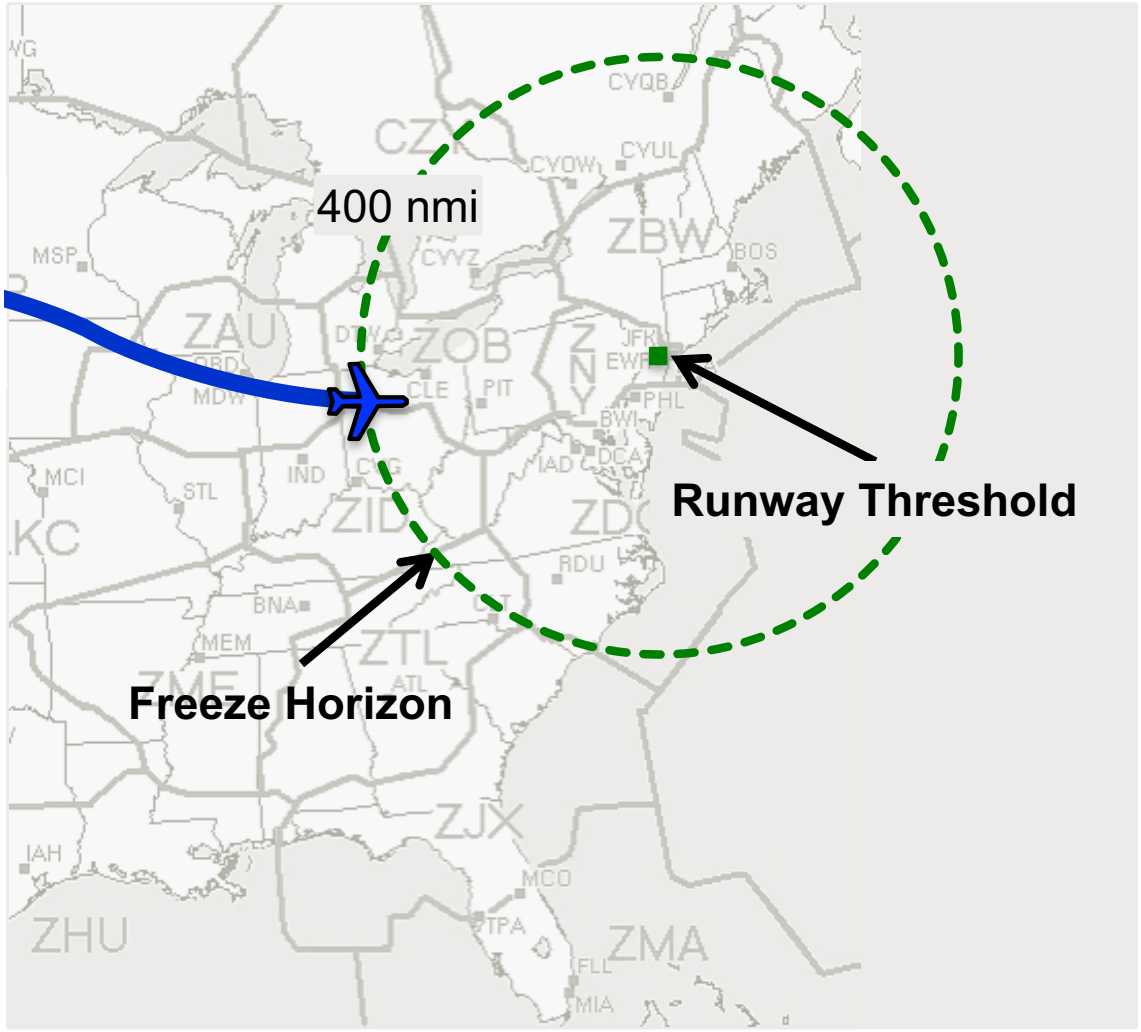

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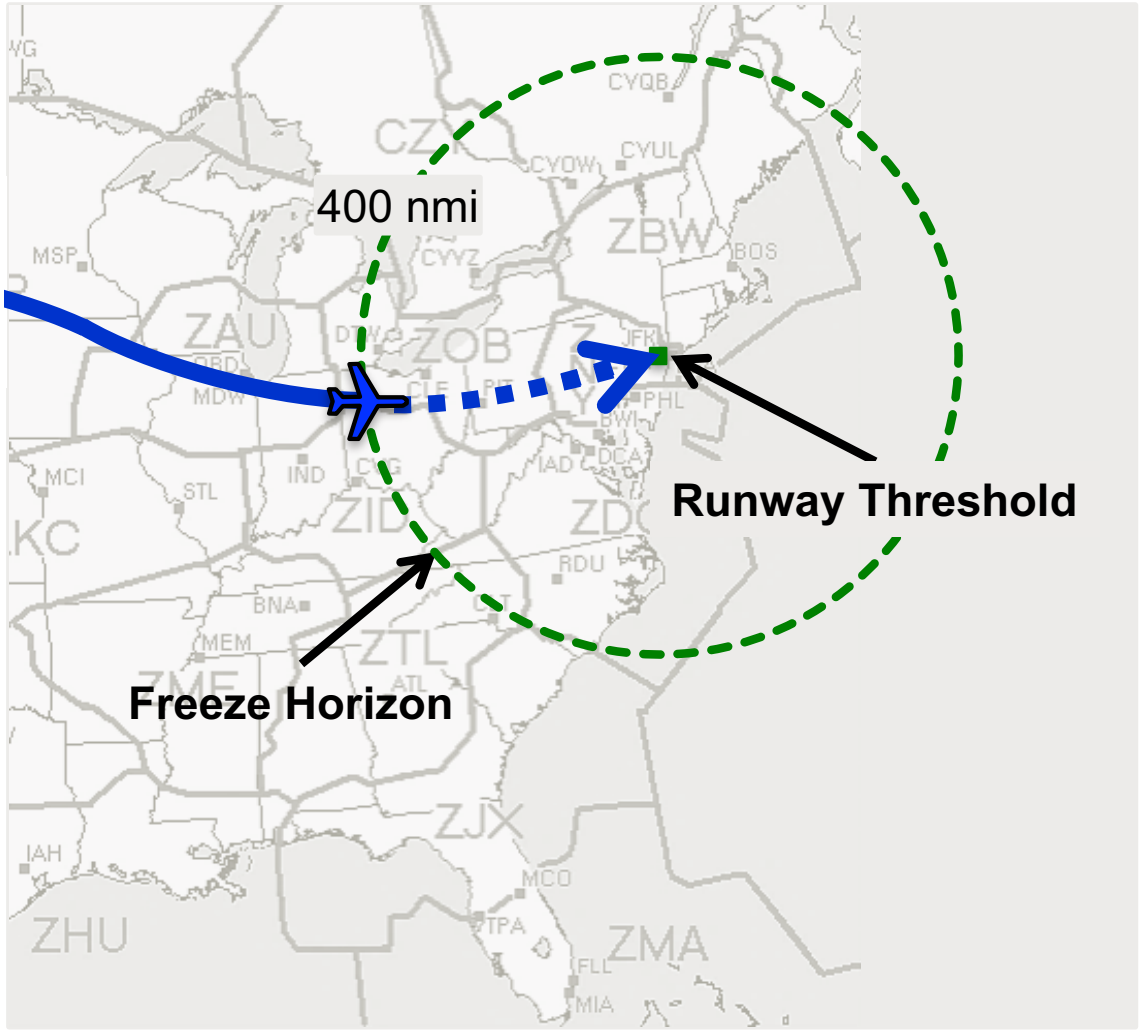

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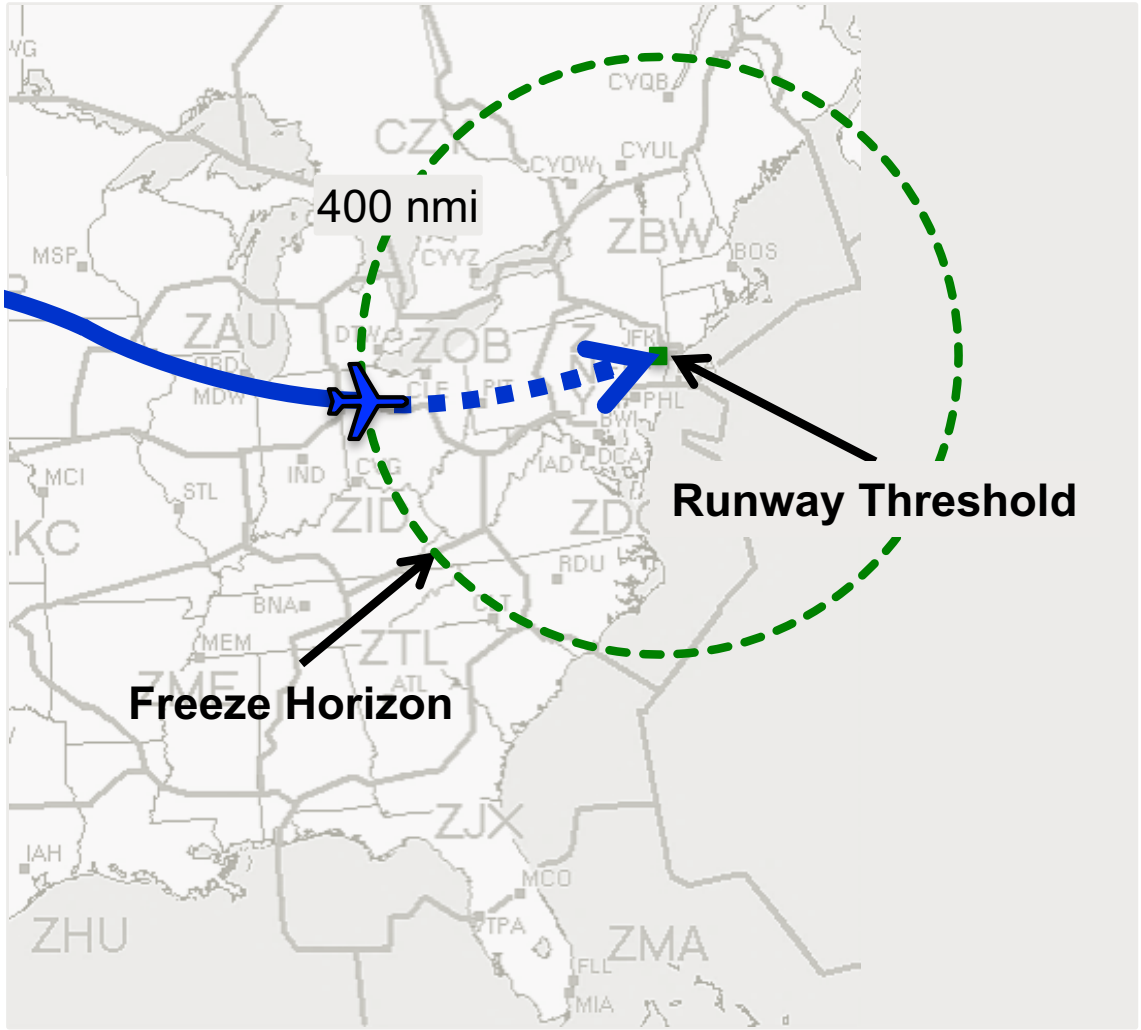

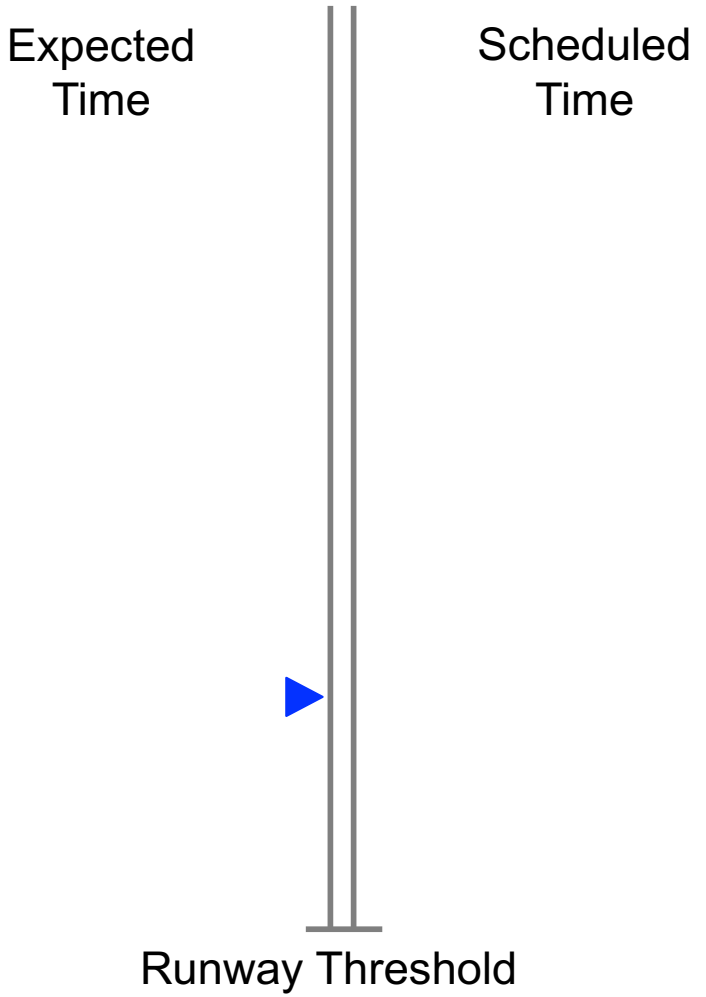

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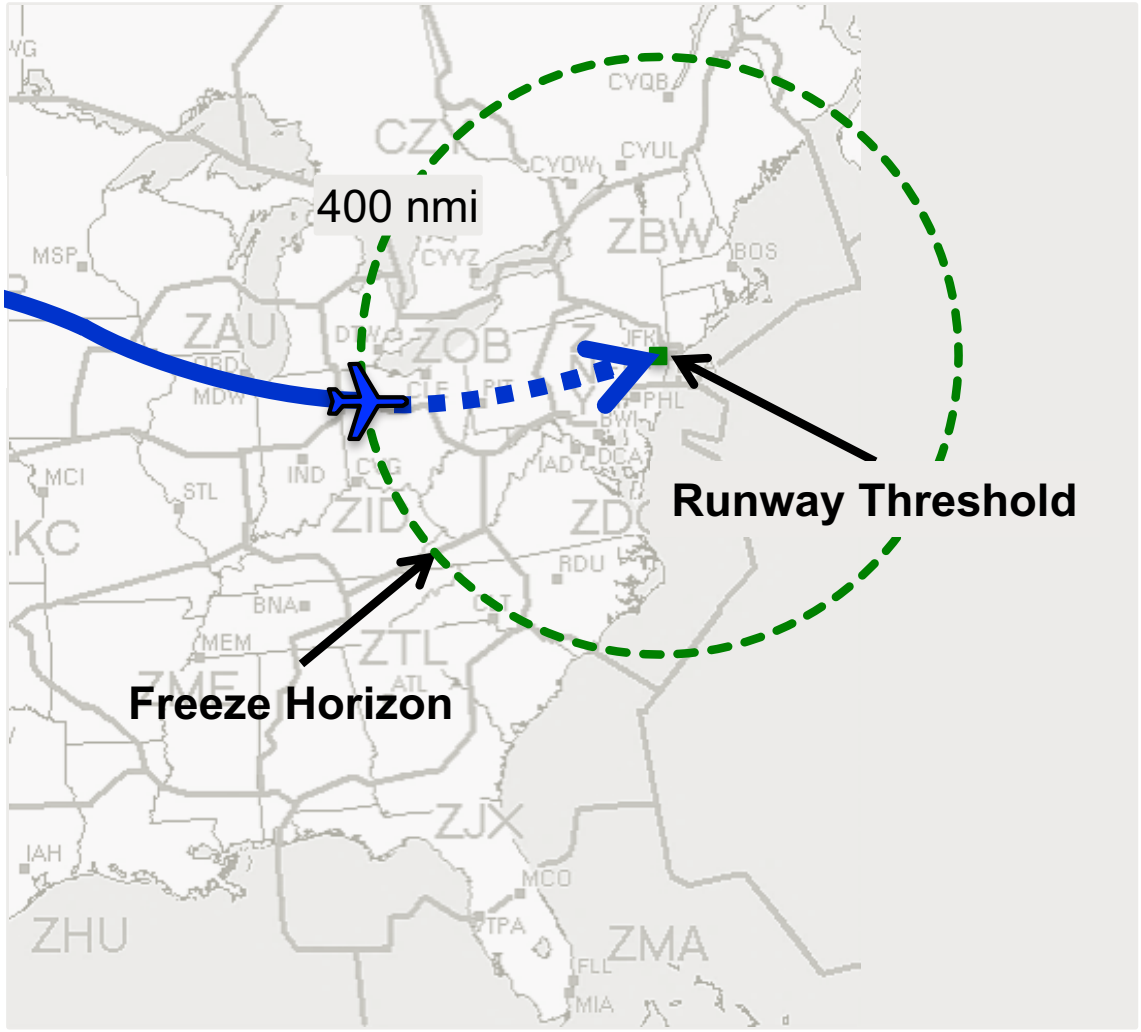

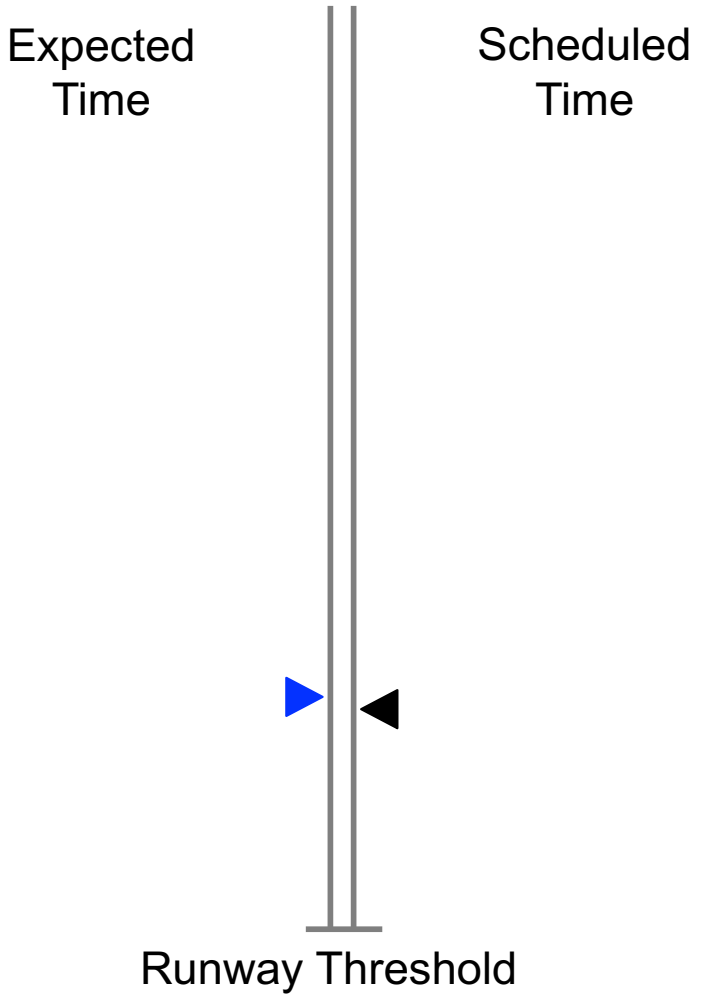

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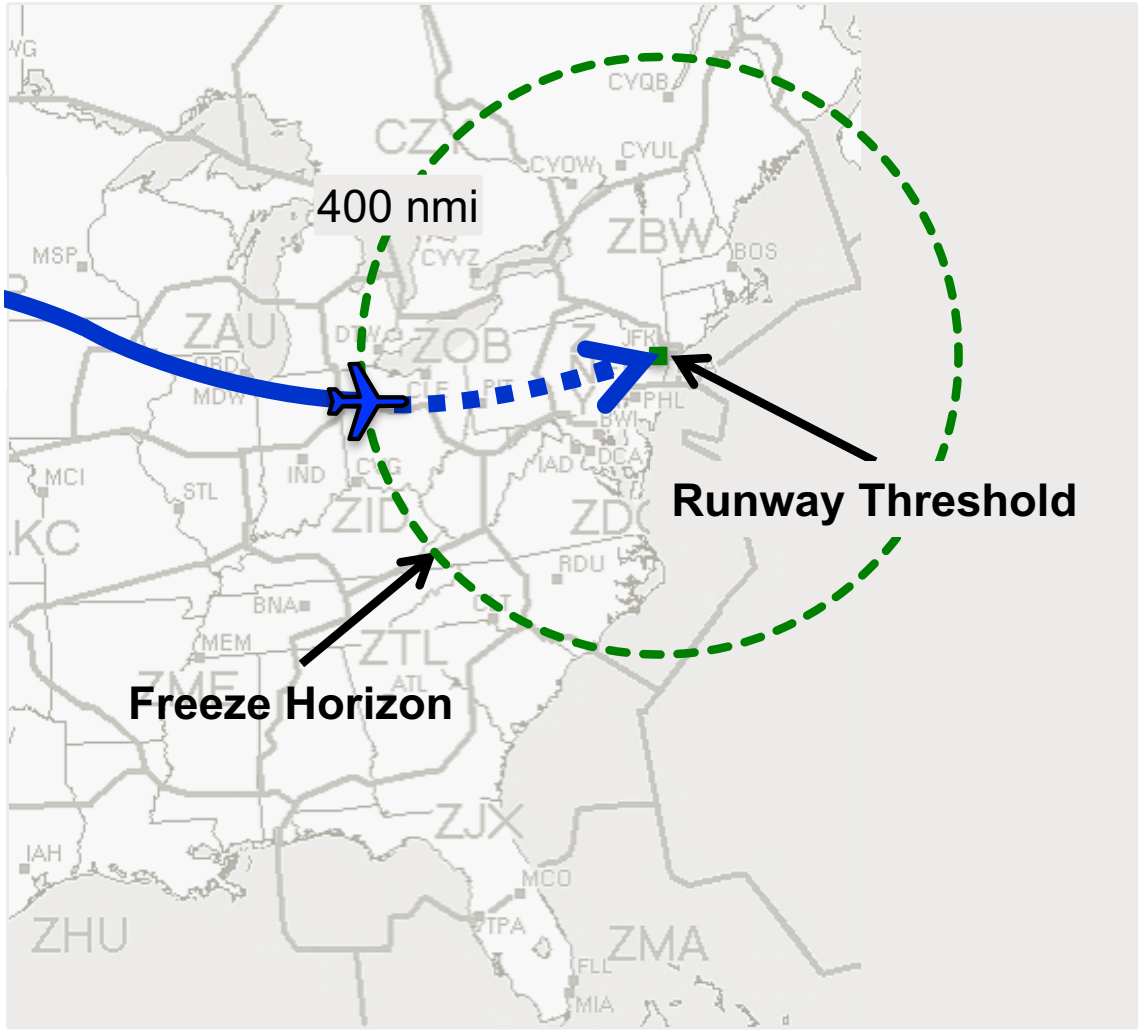

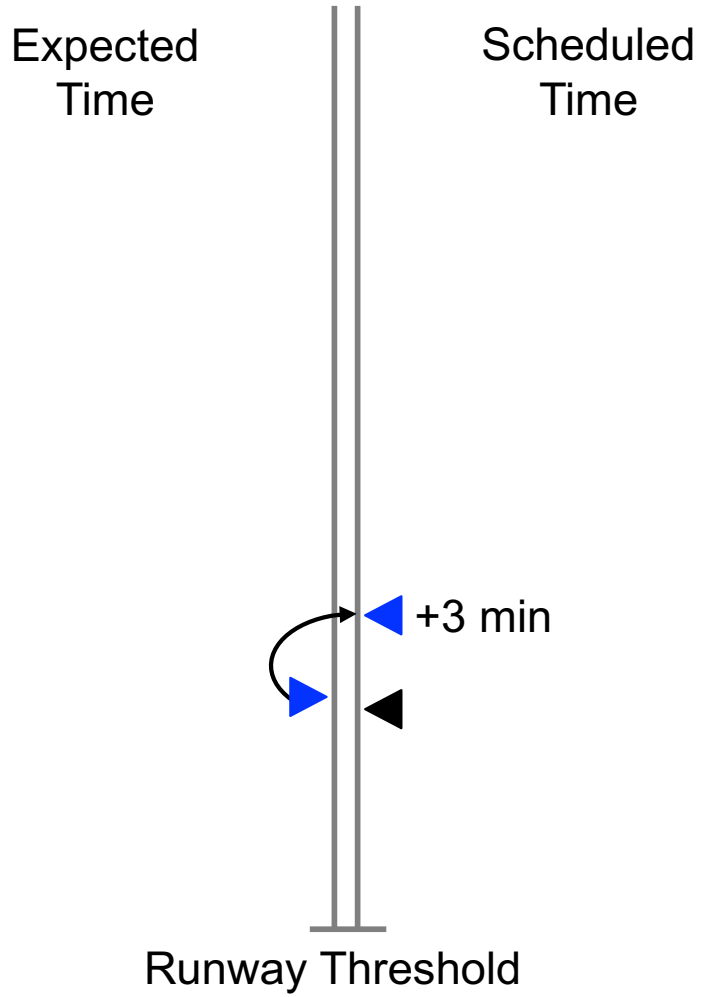

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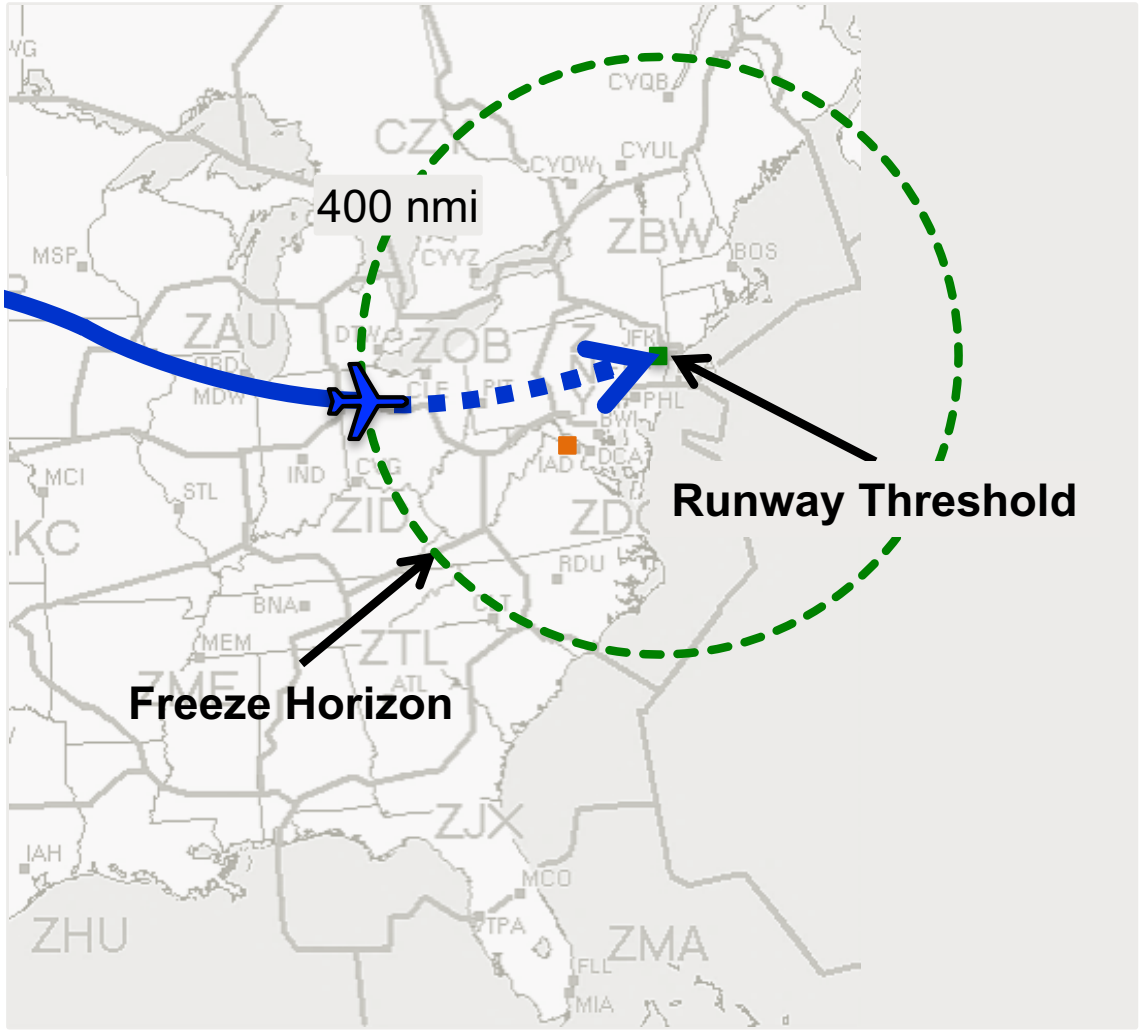

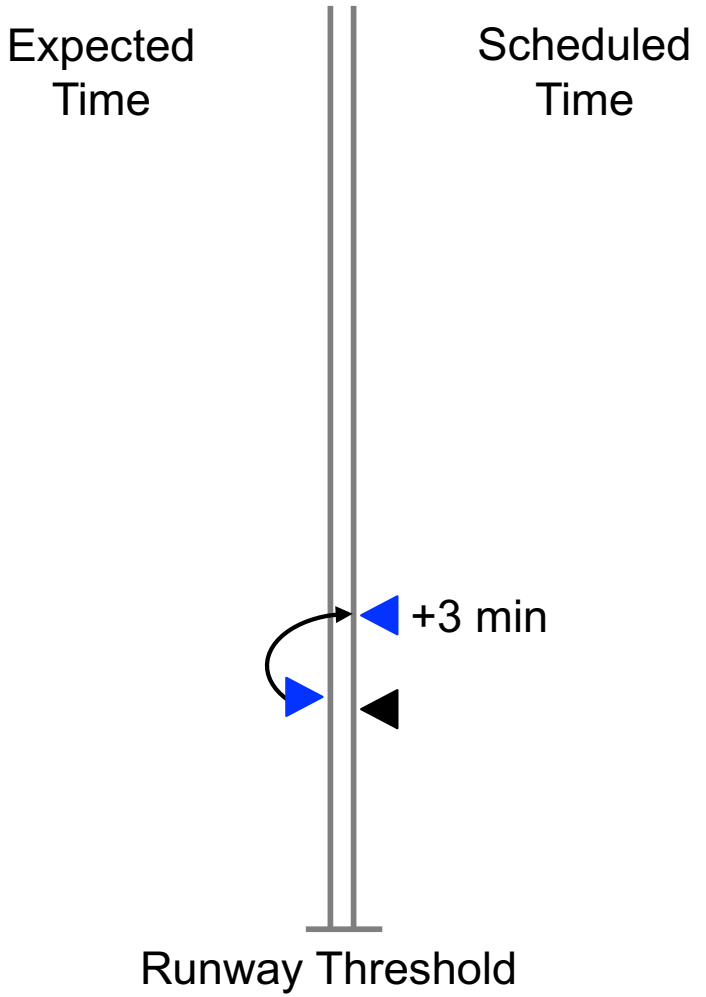

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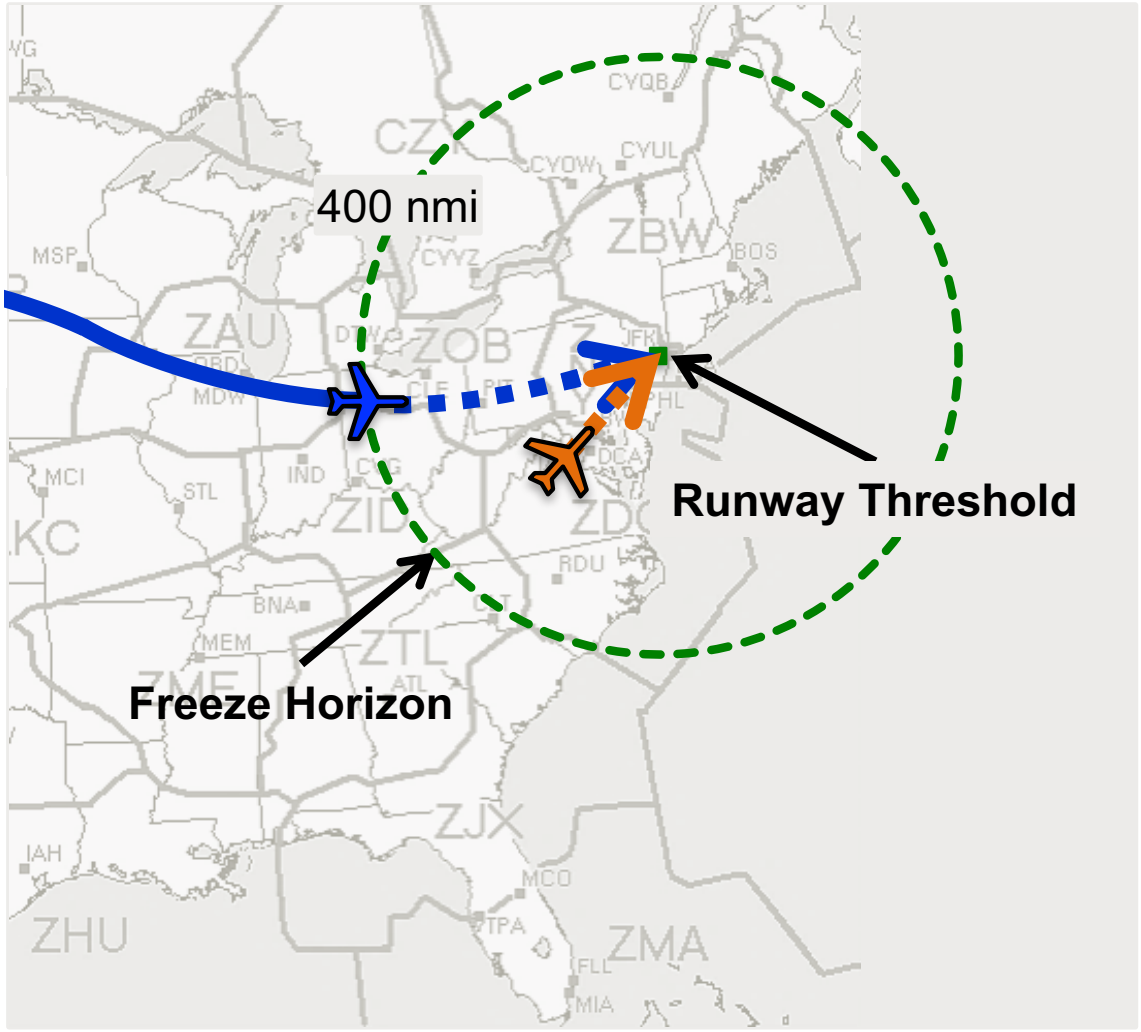

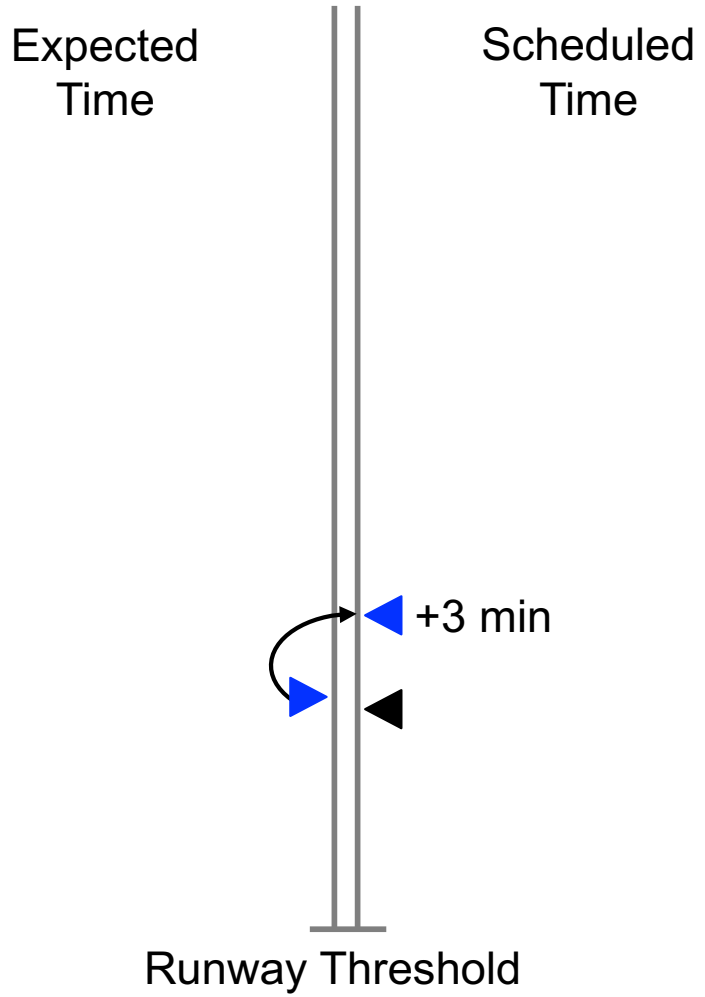

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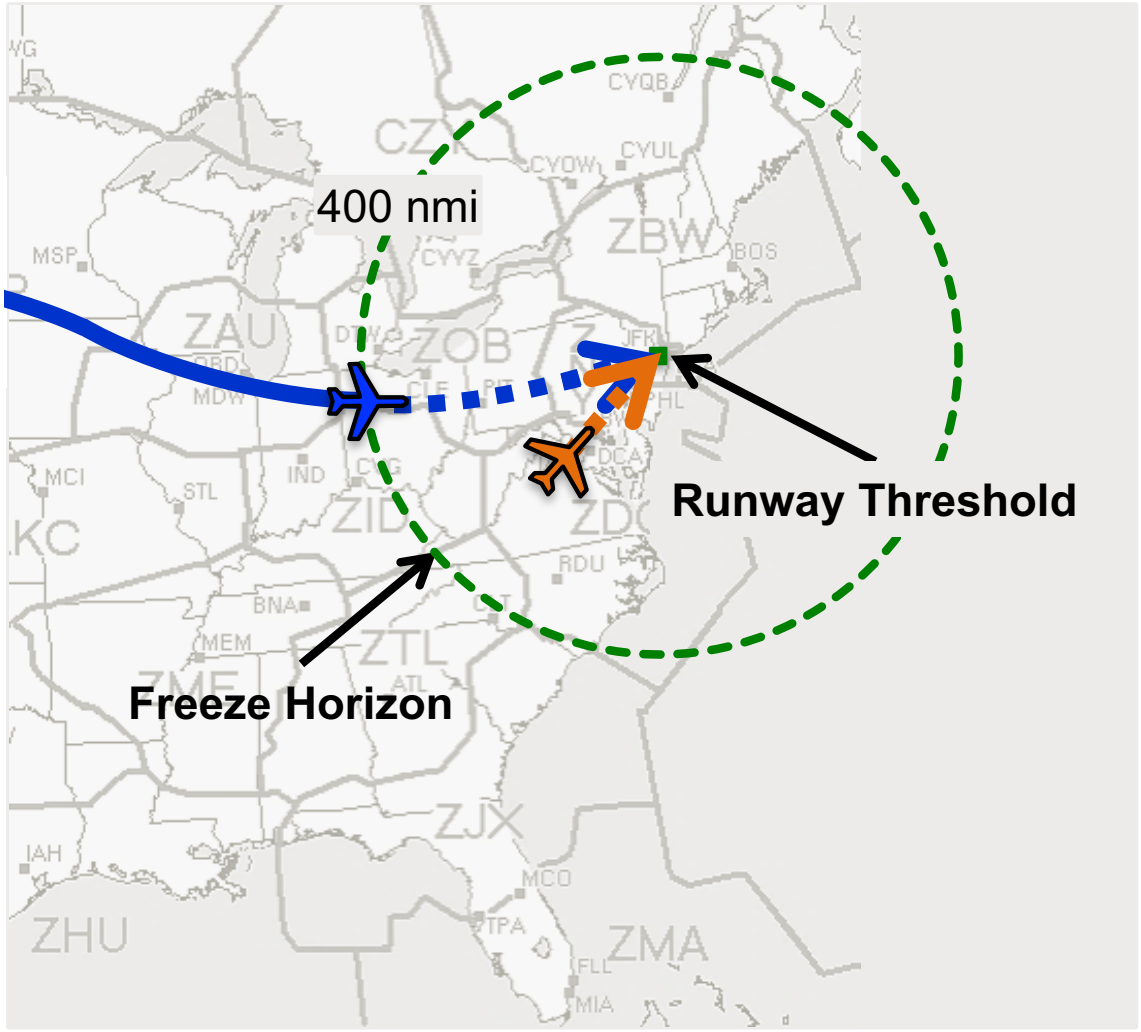

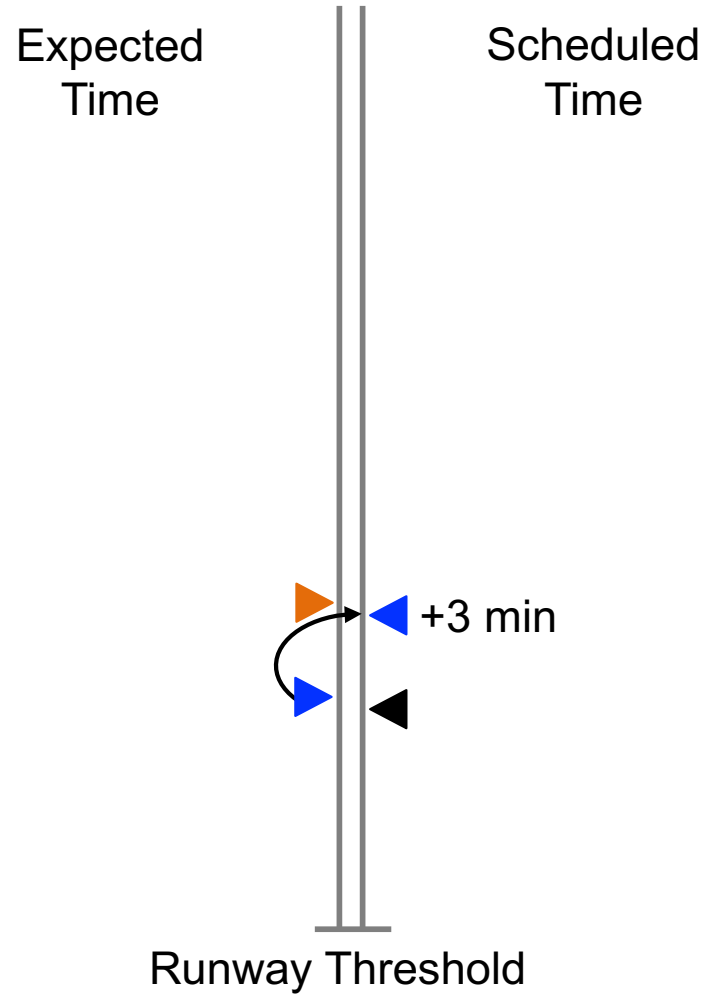

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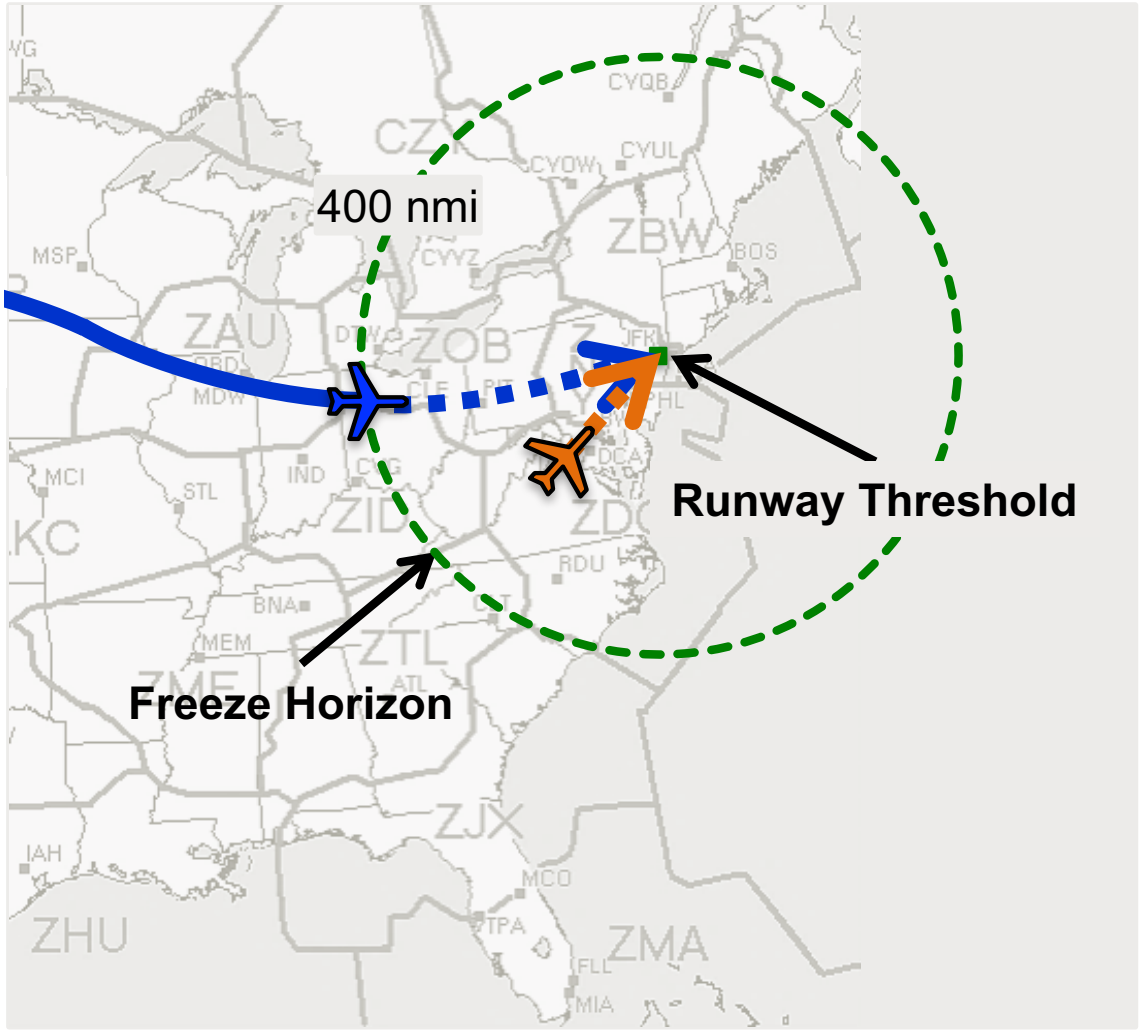

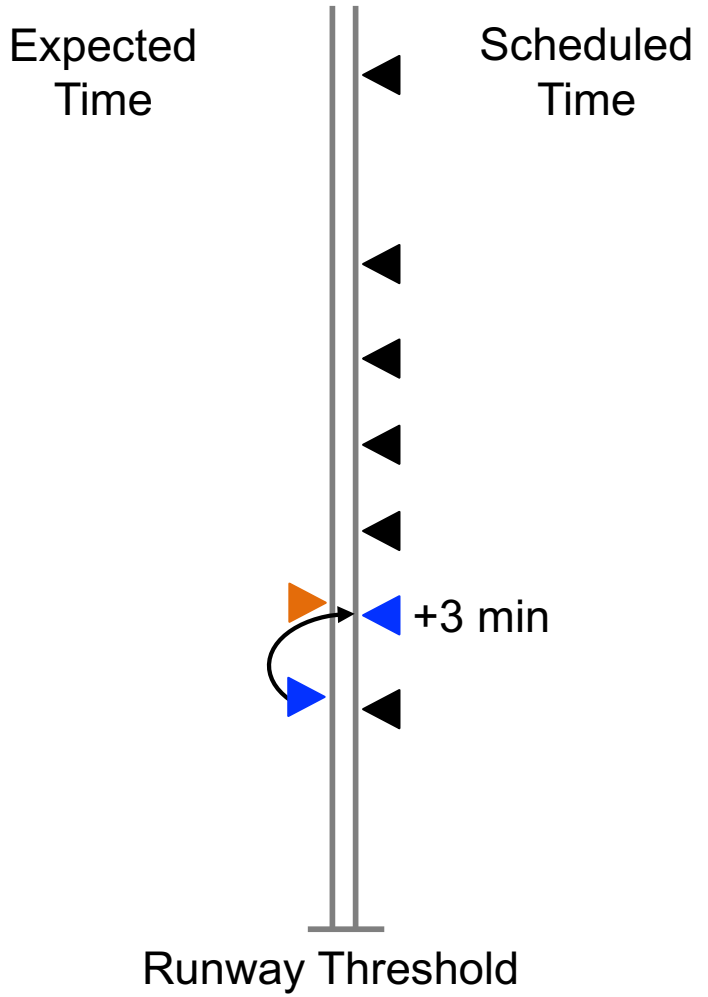

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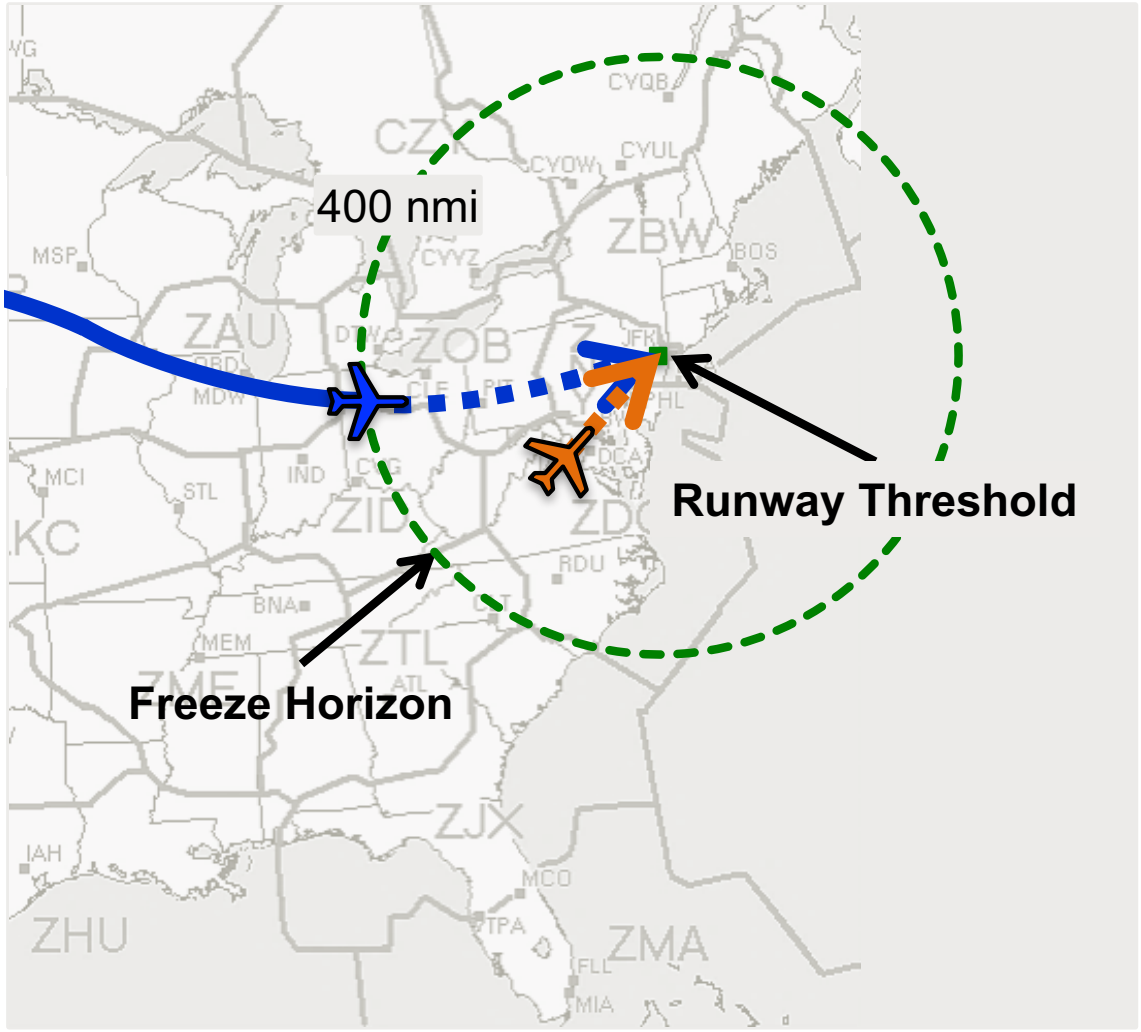
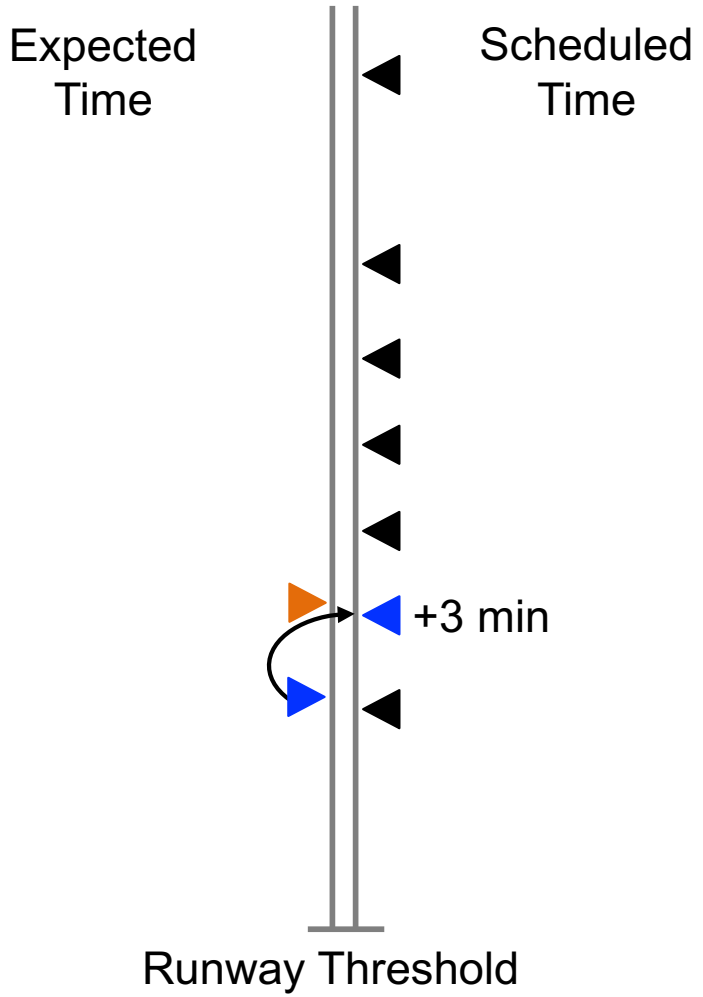


Priority to airborne flights



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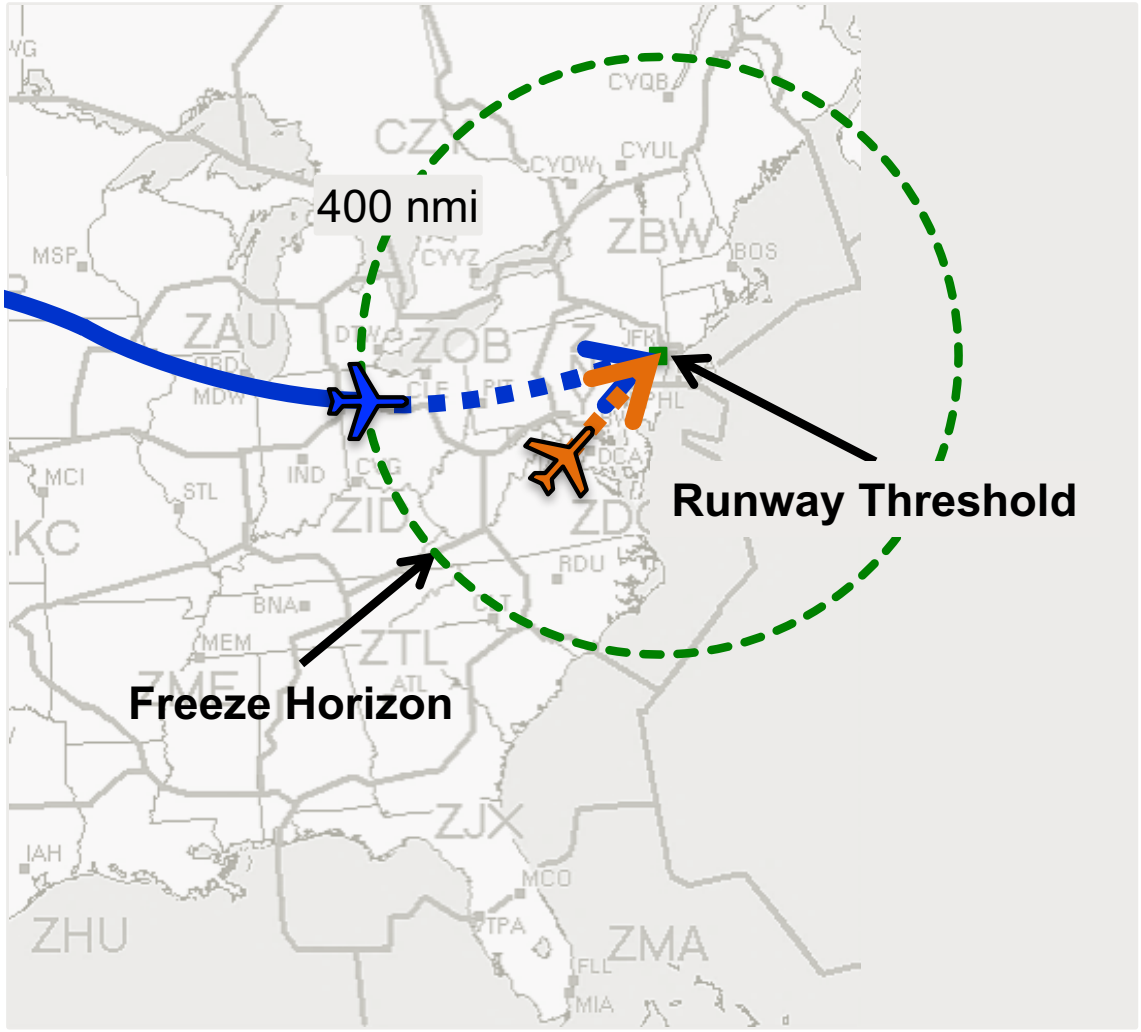

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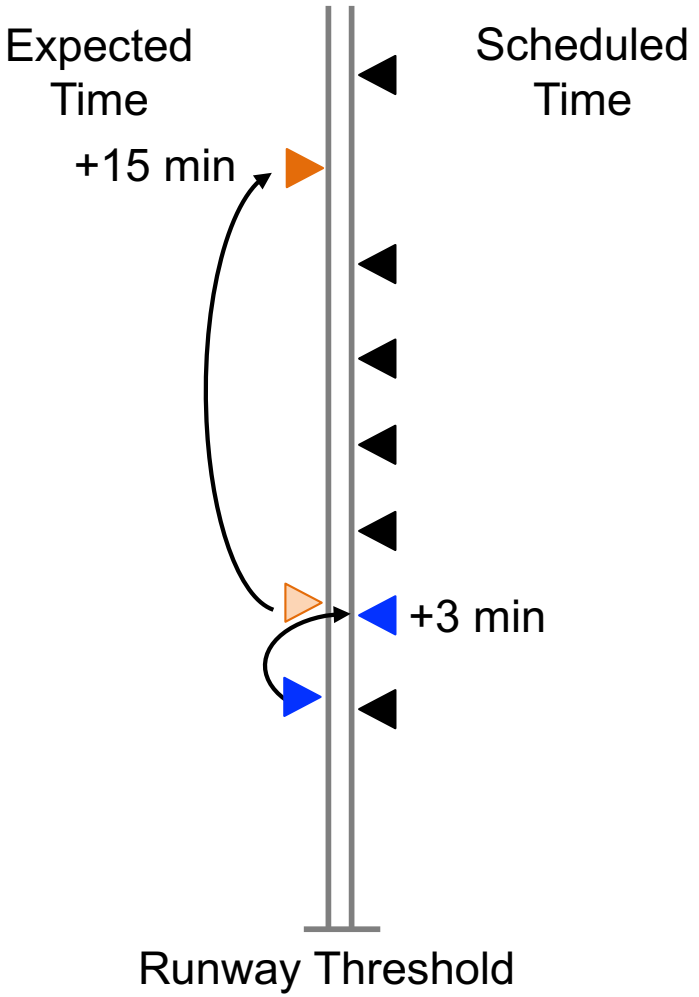
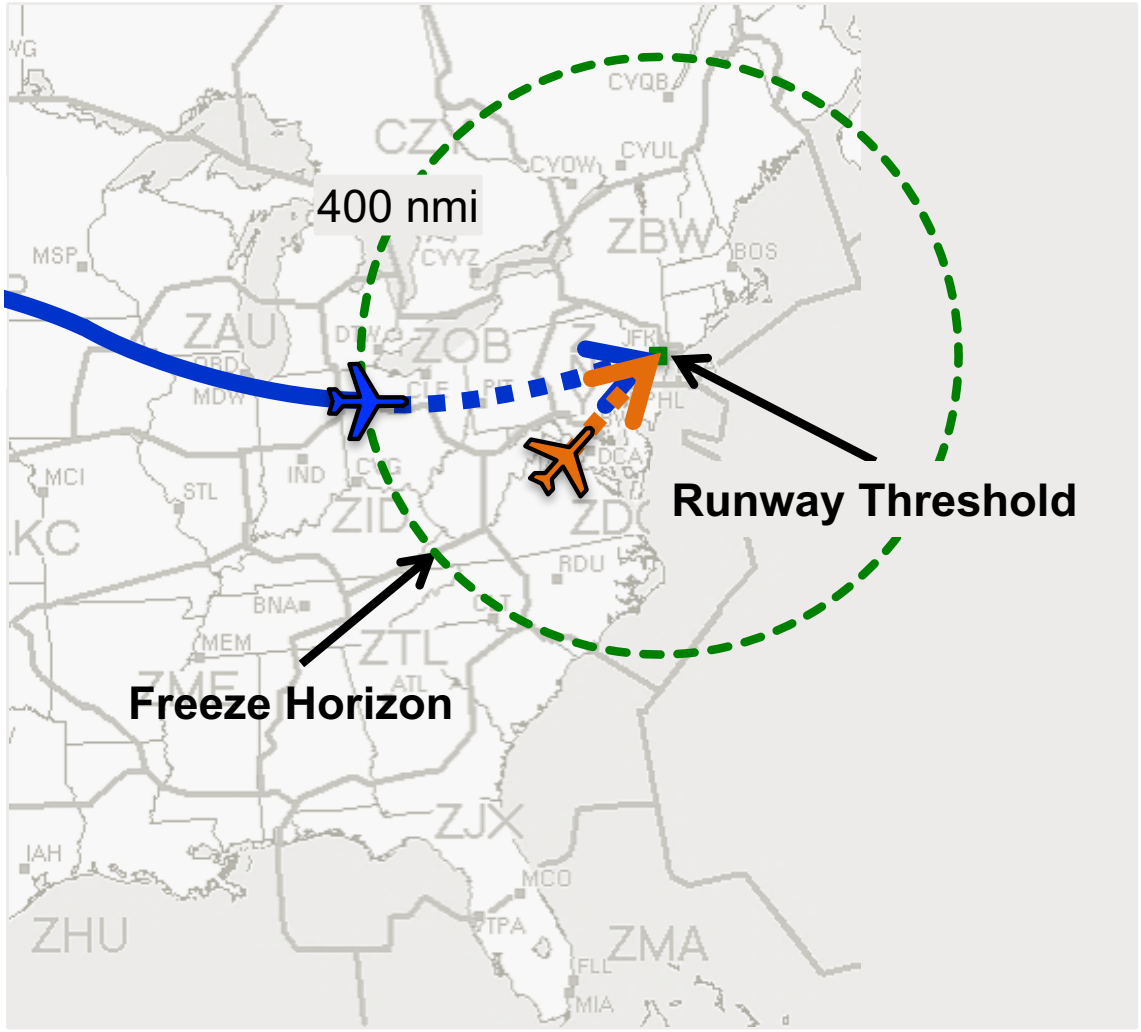
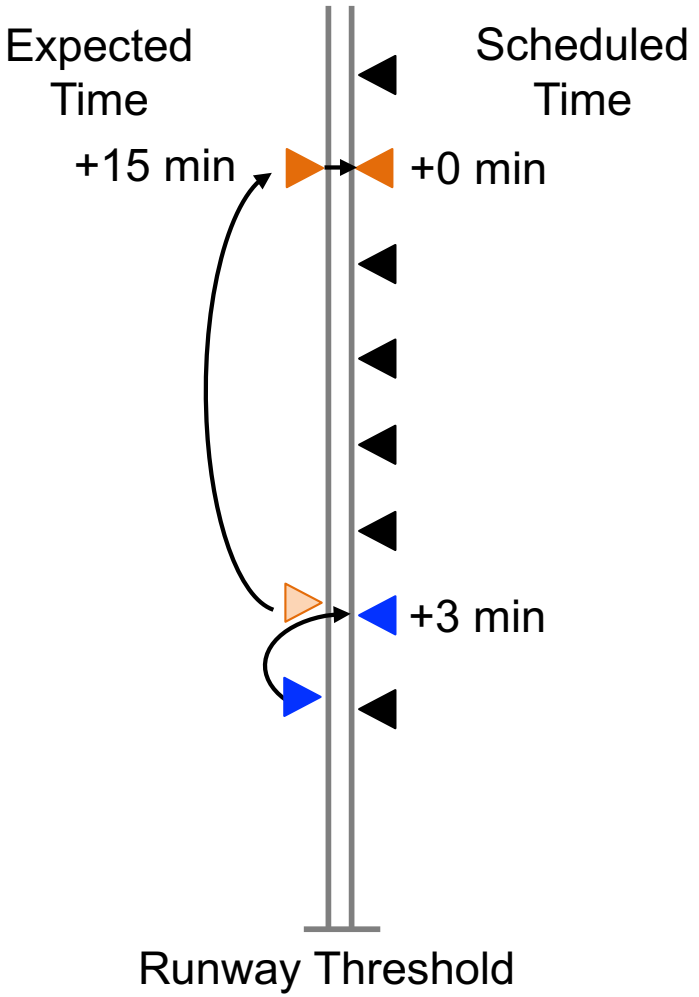


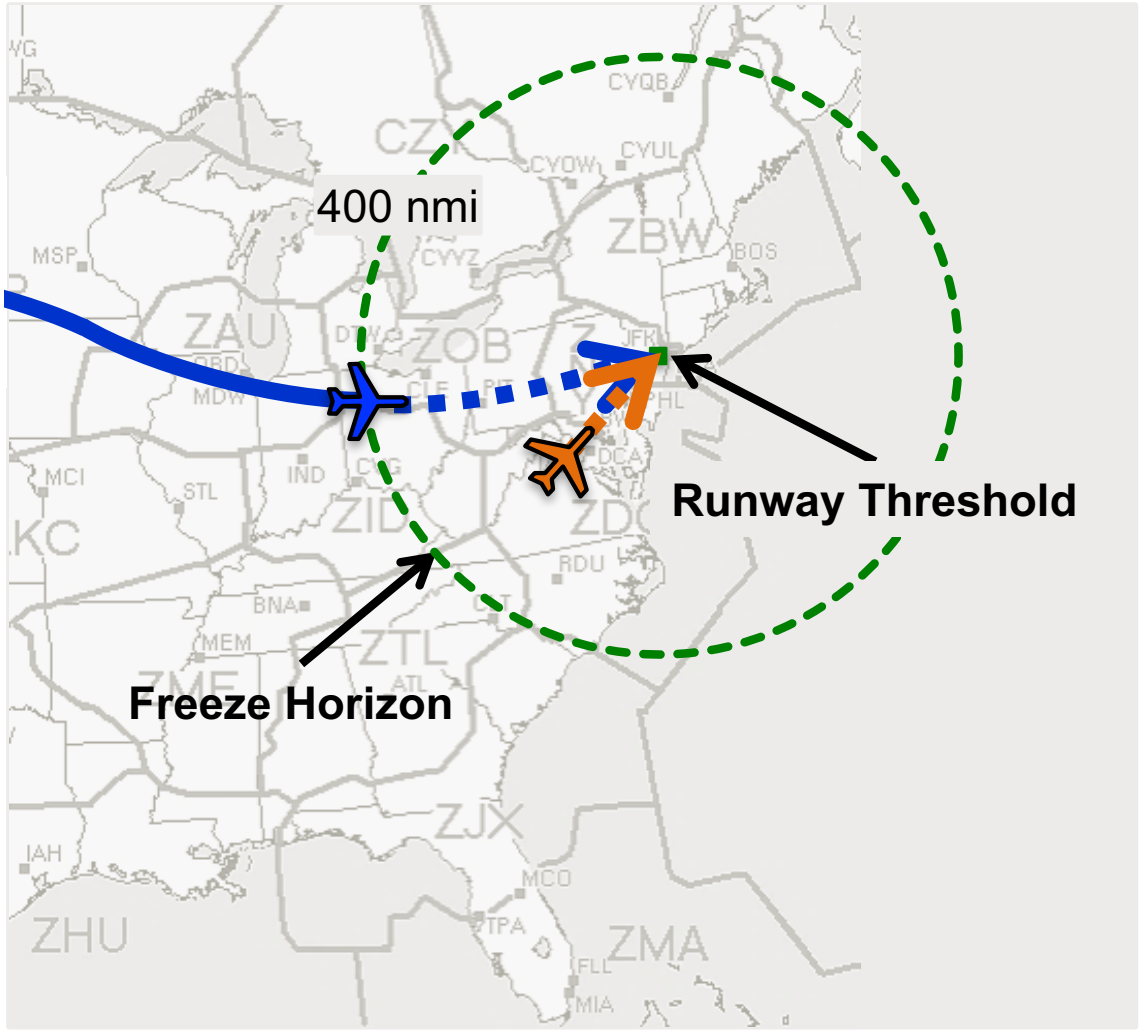
Tactical planning

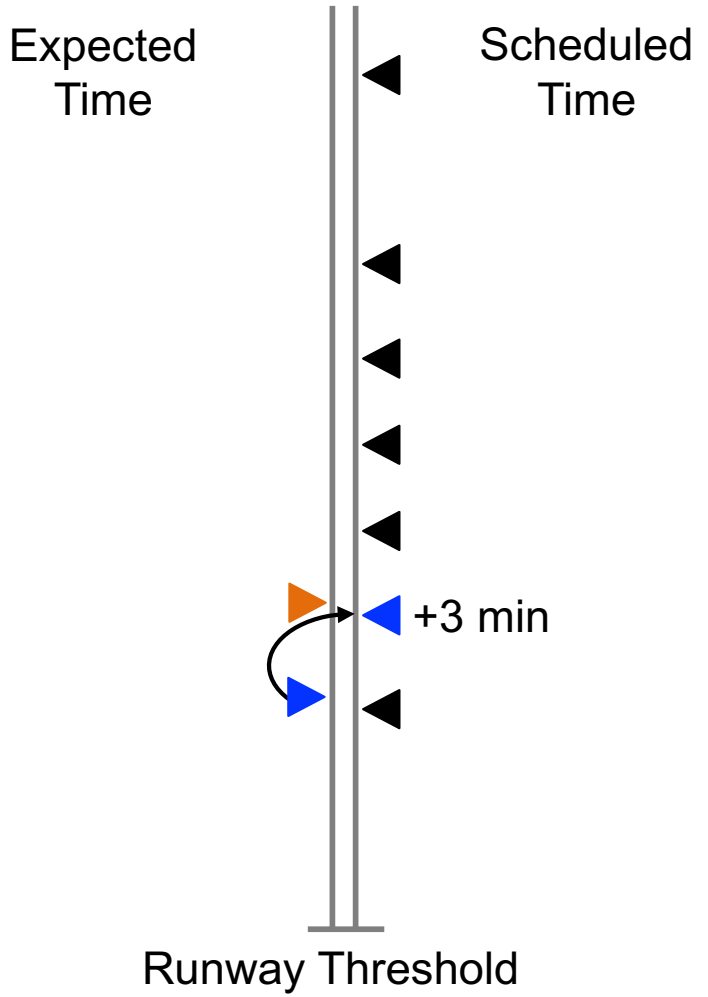


Priority to airborne flights

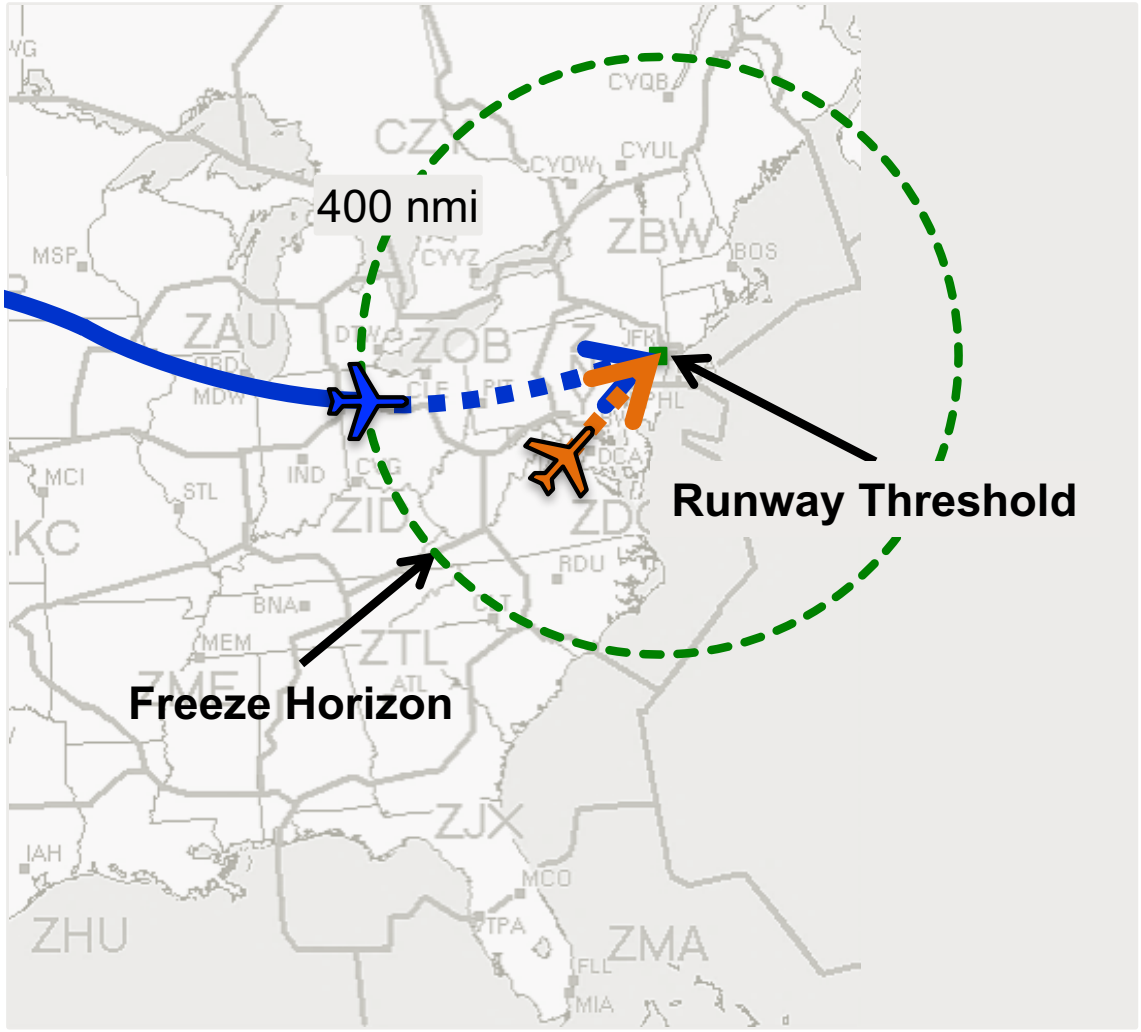


Tactical planning

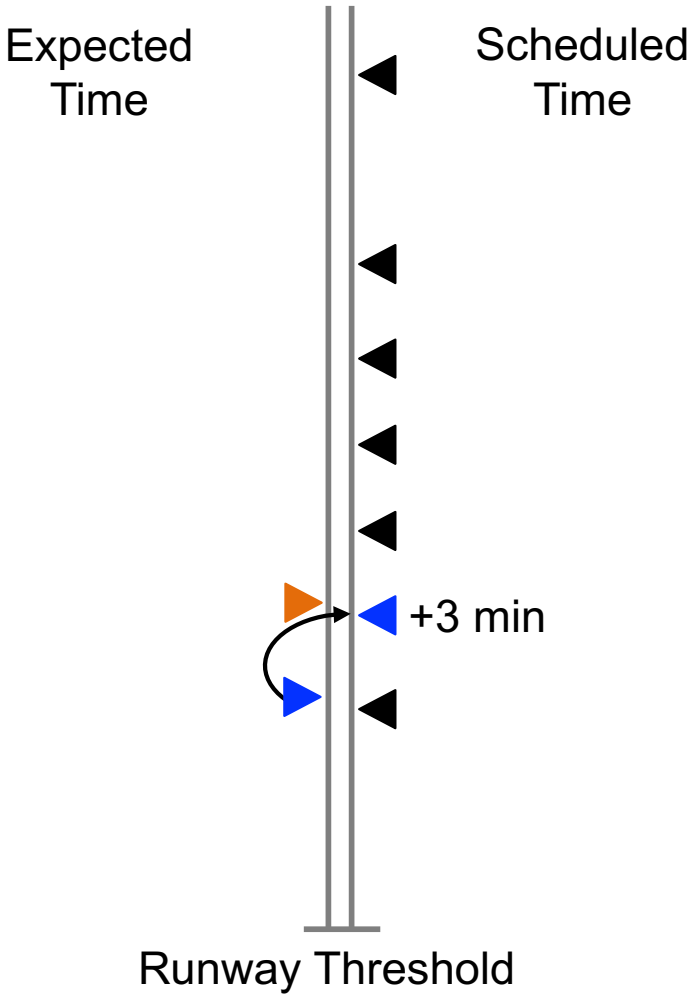




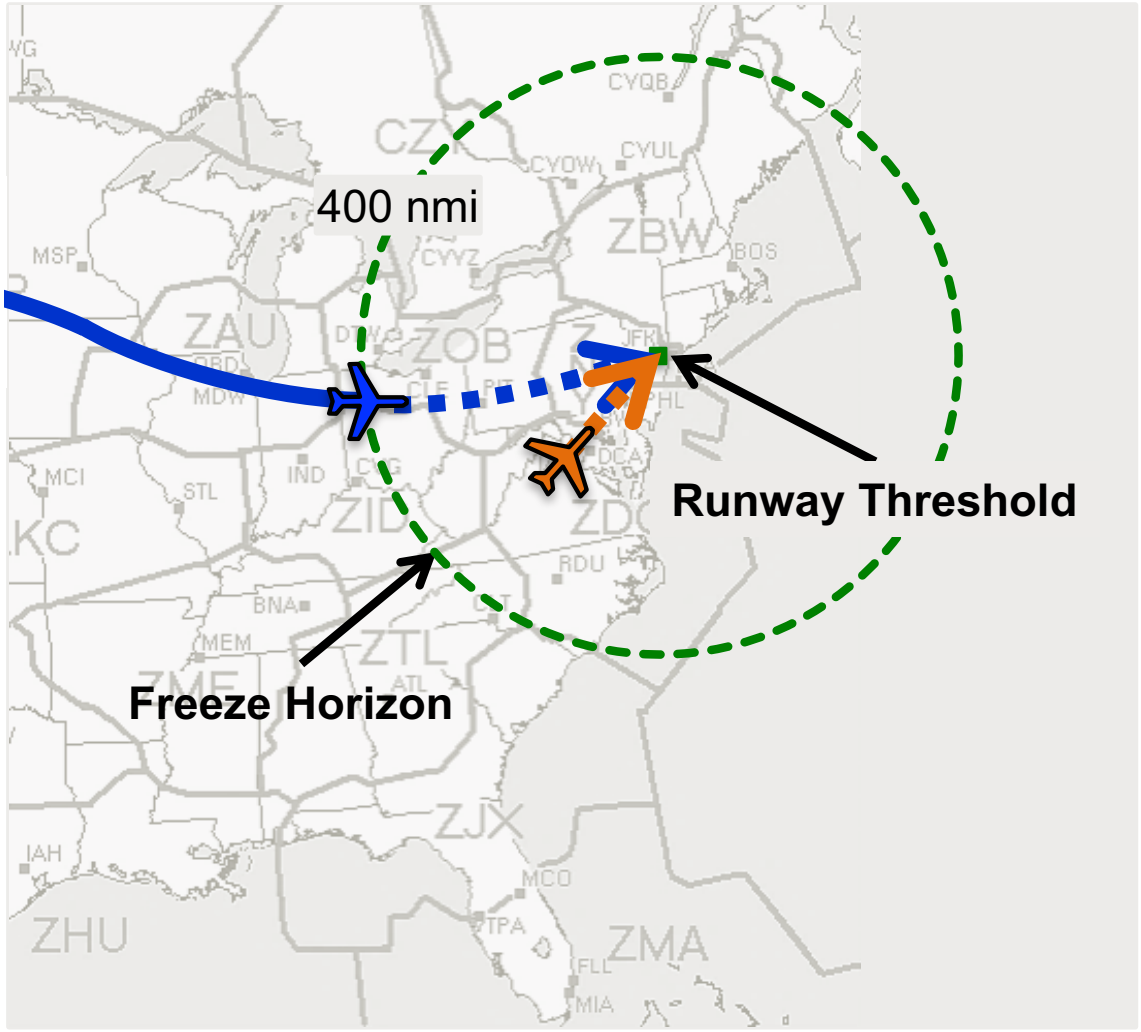
Tactical planning



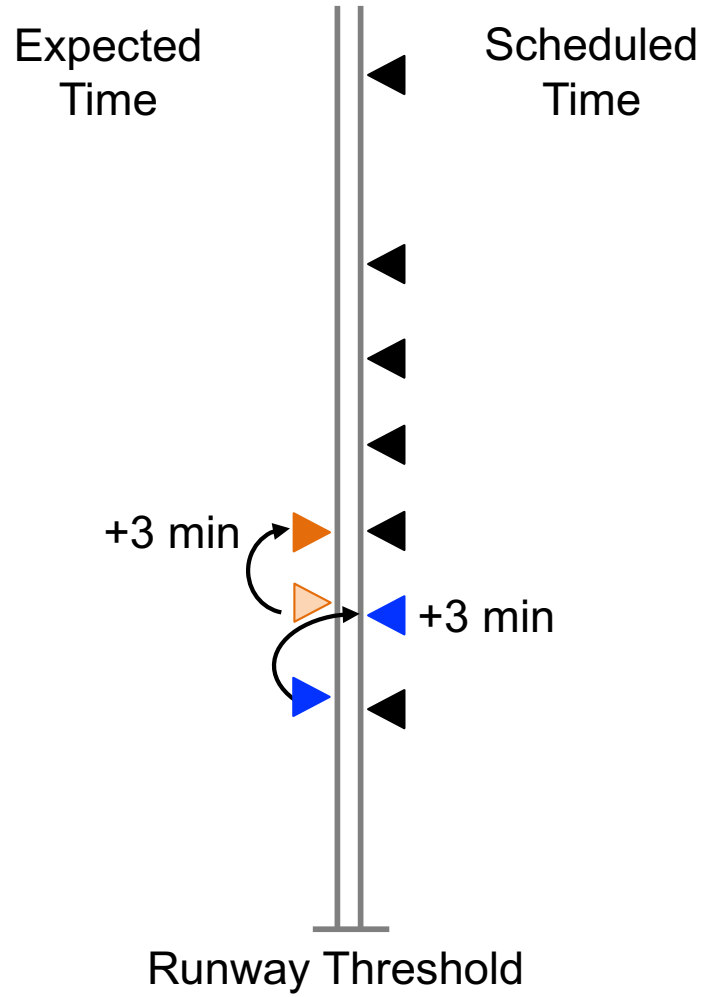
Priority to internal departures



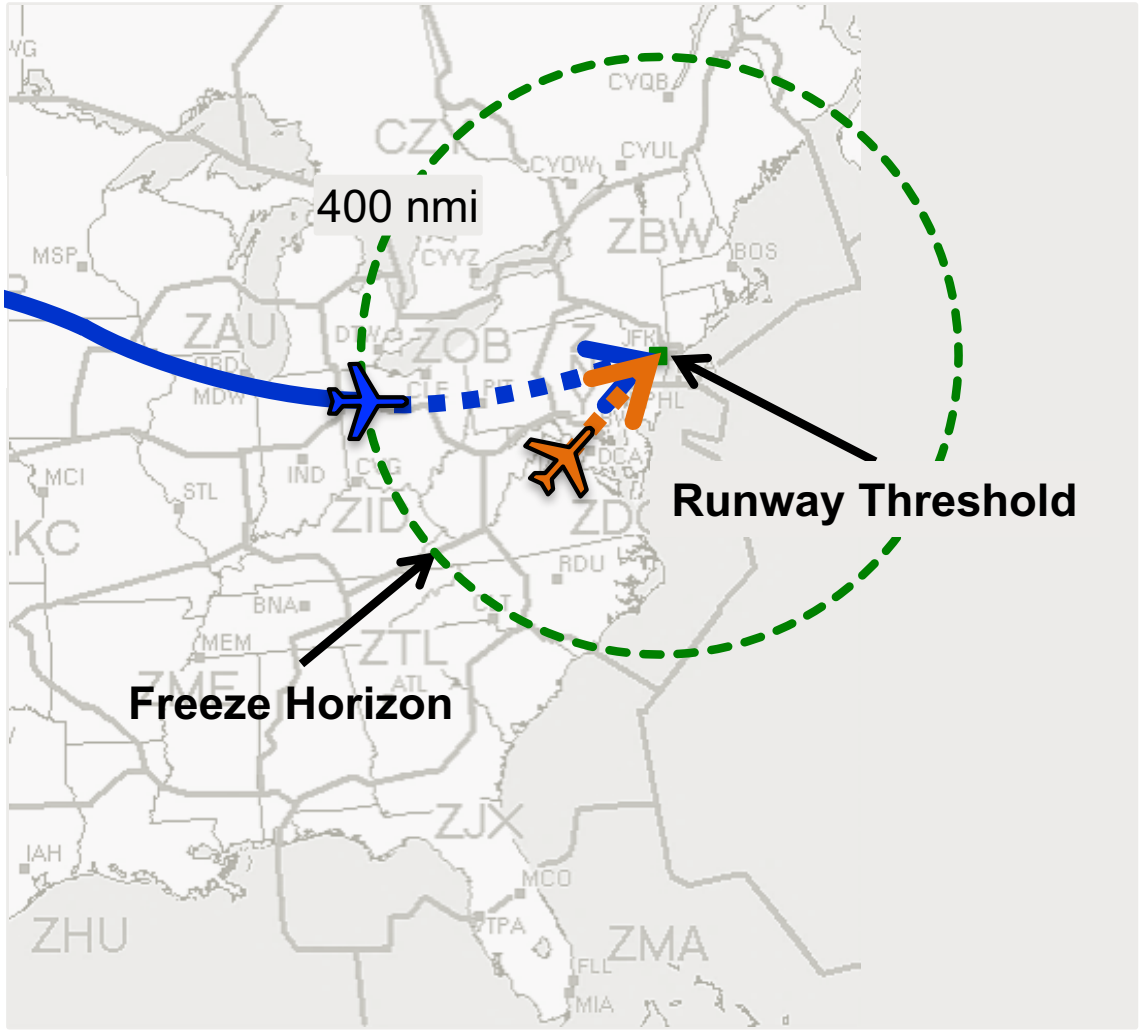
Tactical planning



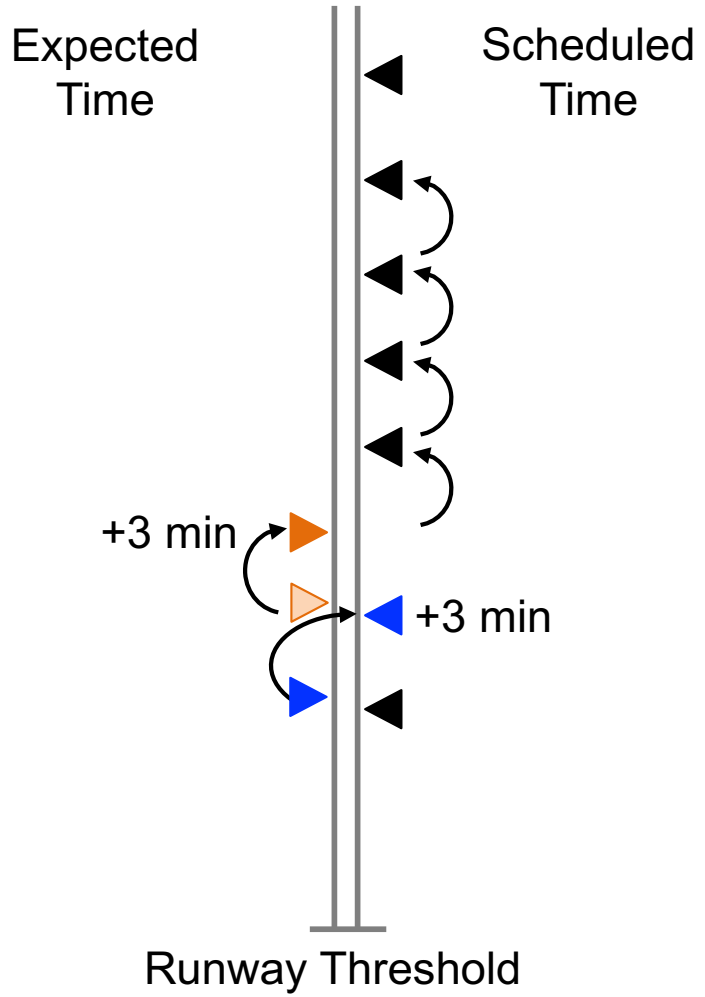
Priority to internal departures



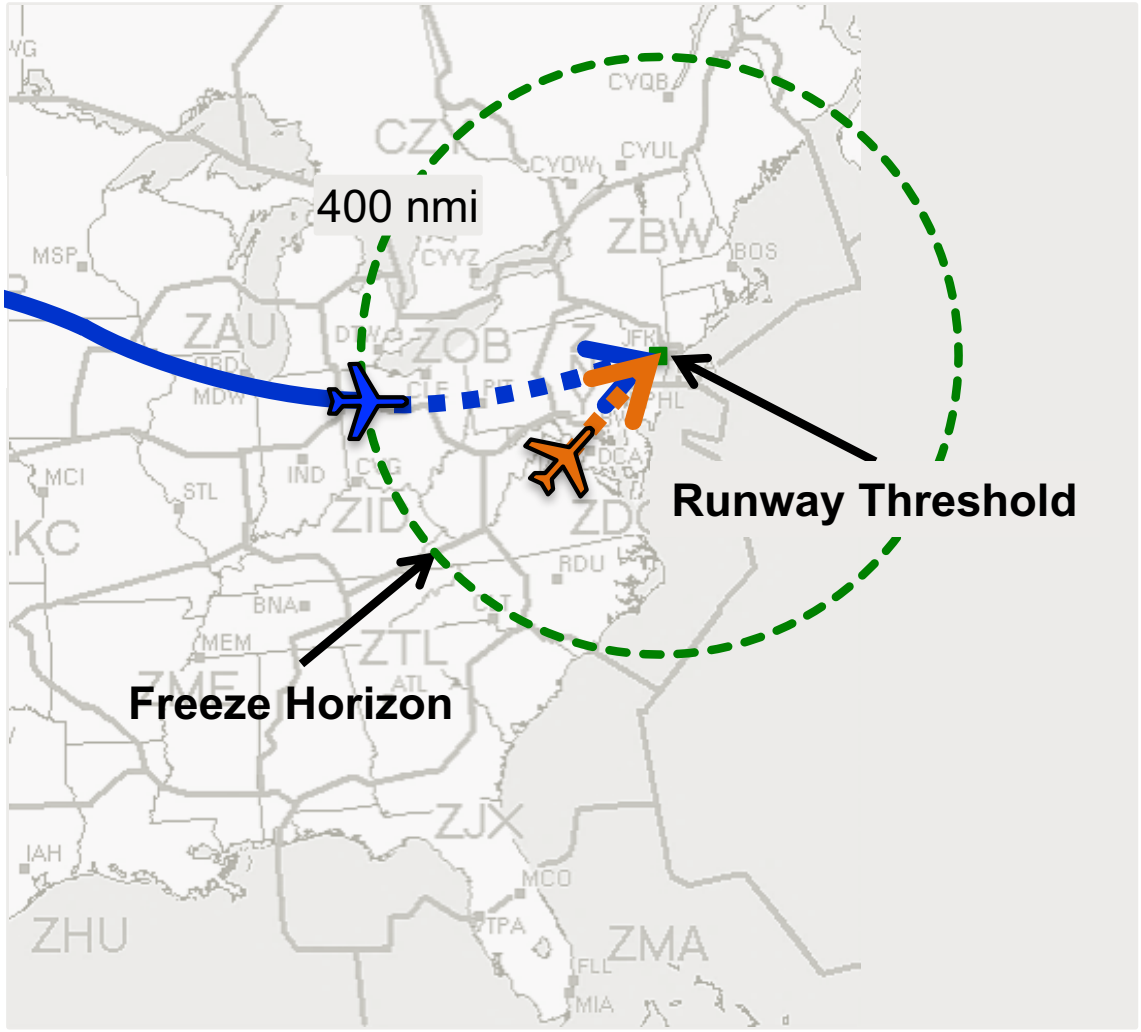
Tactical planning



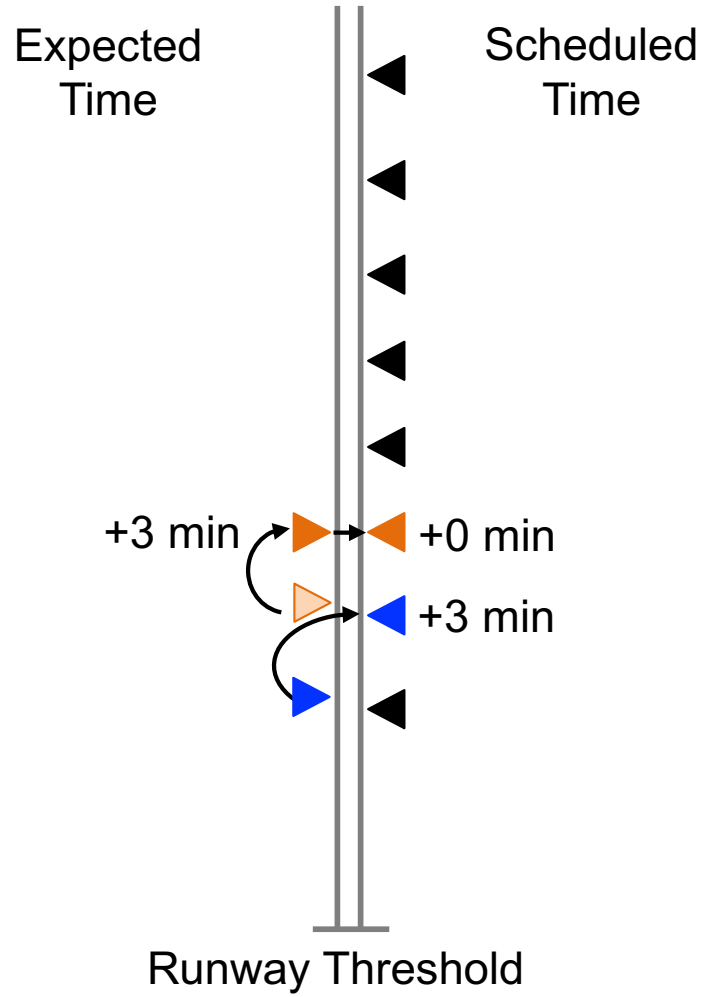
Priority to internal departures



Tactical planning



Priority to internal departures



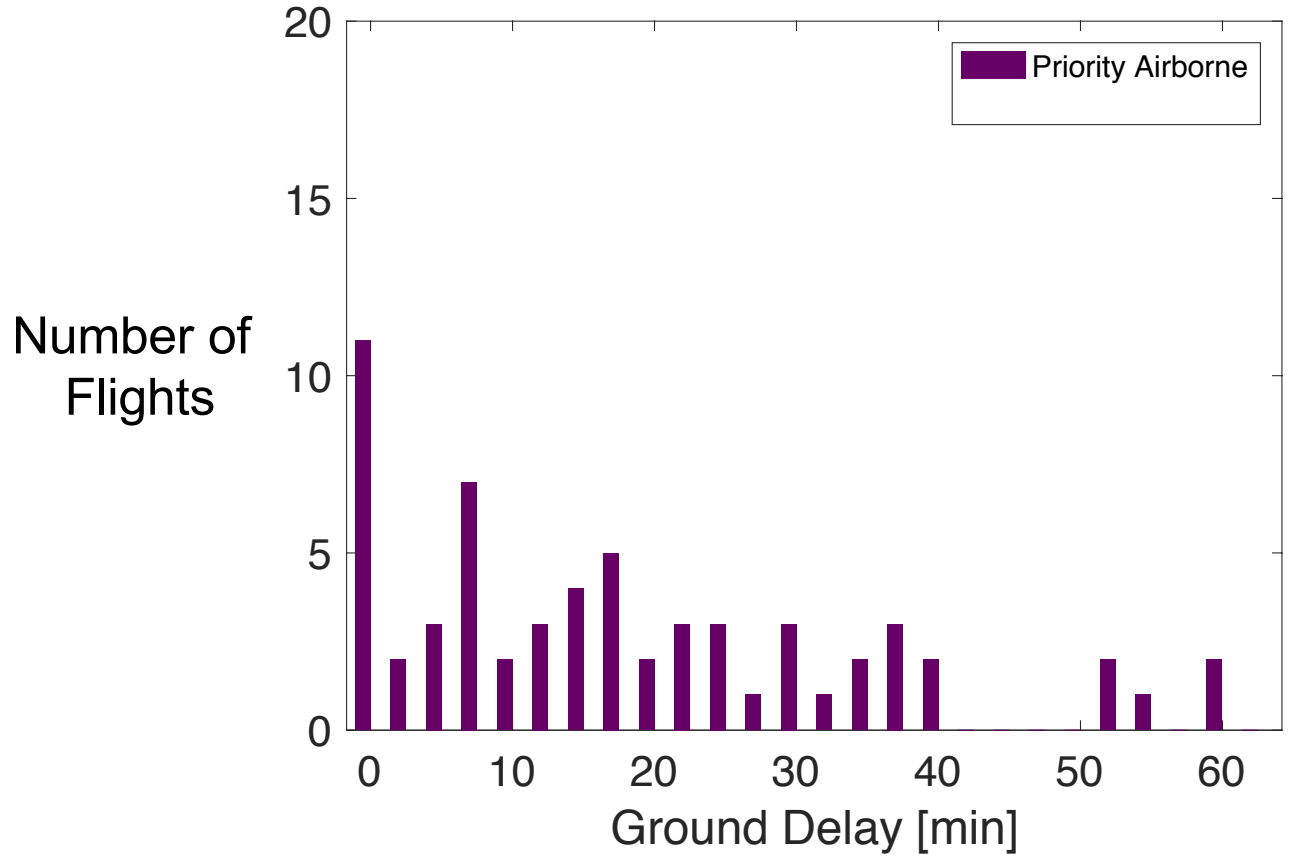
Experimental setup

- Duration of 5 hours
- 253 flights
  - 98 airborne at simulation start
  - 91 external departures
  - 64 internal departures
- Flights depart with some error
- Tactical scheduling paradigms
  - Priority given to airborne flights
  - Priority given to internal departures

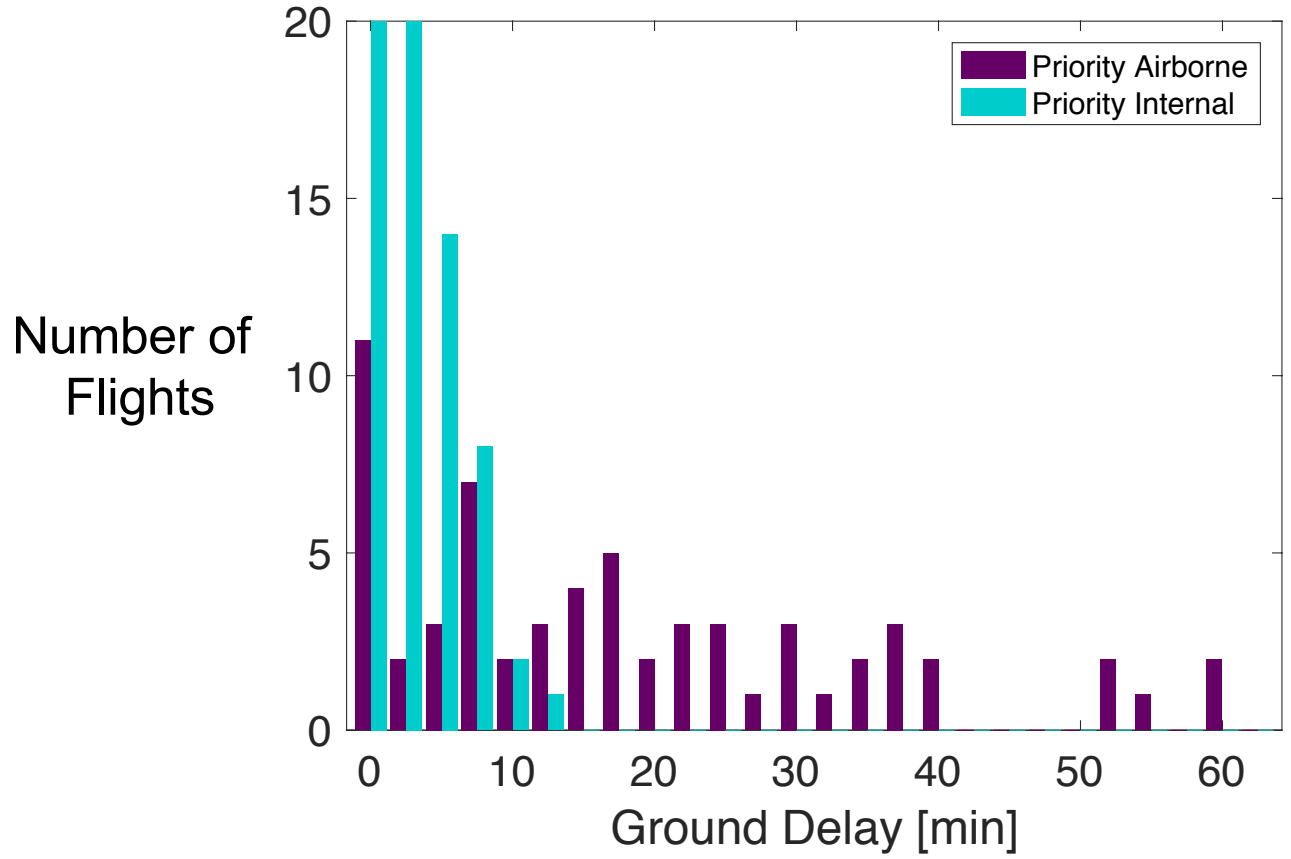
Expected results

- Generate results *qualitatively* similar HITL
- HITL simulations have shown:
  - Priority given to airborne flights
    - ⇨ Relatively high ground delay for internal departures
  - Priority given to internal departures
    - ⇨ Significant reduction in ground delay for internal departures
    - ⇨ Required airborne delay is manageable

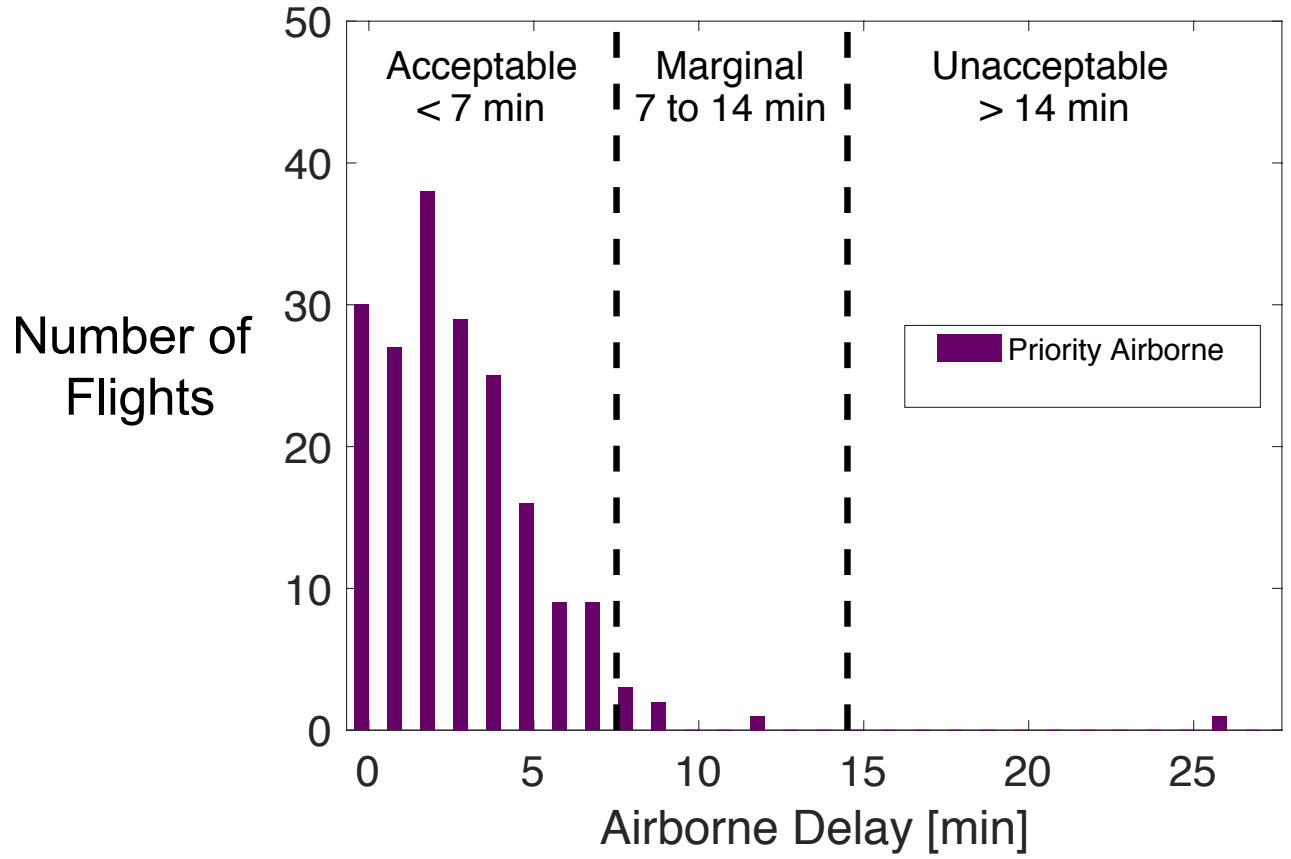
Internal departure ground delay



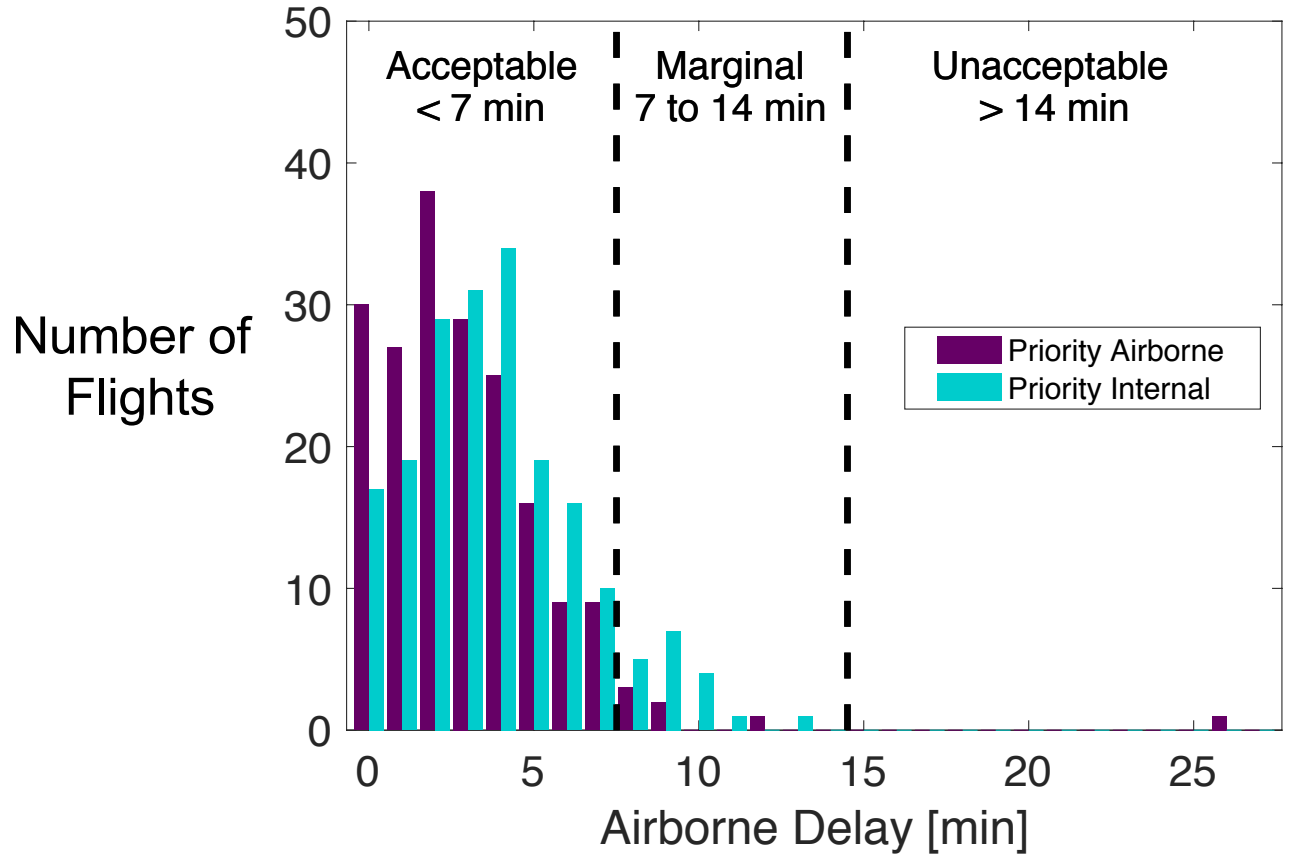
Internal departure ground delay



Airborne delay



Airborne delay



Comparison to HITL simulation

Tactical Scheduling Paradigm	Simulation	Tactical Airborne Delay		
		Acceptable (<7 min)	Marginal (7-14 min)	Unacceptable (>14 min)
Priority Internals	HITL	82 %	17 %	1 %
	Automated	87 %	13 %	0 %
Priority Airborne	HITL			
	Automated	94 %	5 %	1 %

Comparison to week-long HITL

	HITL	Automated	Automated fast-time (5x)
Subject matter experts	320 hours	0 hours	0 hours
Simulation technician	32 hours	1 hour	1 hour
Number of simulations	4	20	104
Active Simulation Time	20 hours	100 hours	104 hours

Conclusions

Automated simulation capability

- Automate HITL simulation
- Emulate HITL simulation results
- Maintain high fidelity trajectory simulation
- Incorporate updates to strategic planning tool

Conclusions

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- Emulate HITL simulation results
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- Incorporate updates to strategic planning tool

Benefits

- Evaluate over larger variation in parameters
- Simulate larger, more realistic traffic scenarios
- Augment HITL by automated background traffic

Future work

Development

- Add other New York airports:
  - LaGuardia Airport (LGA)
  - John F. Kennedy International Airport (JFK)
- Augment HITL simulations with more traffic
- Enable fast-time simulation (up to 5x real-time)

Research

- Parameter studies
- Uncertainty in departure and flight time

Backup

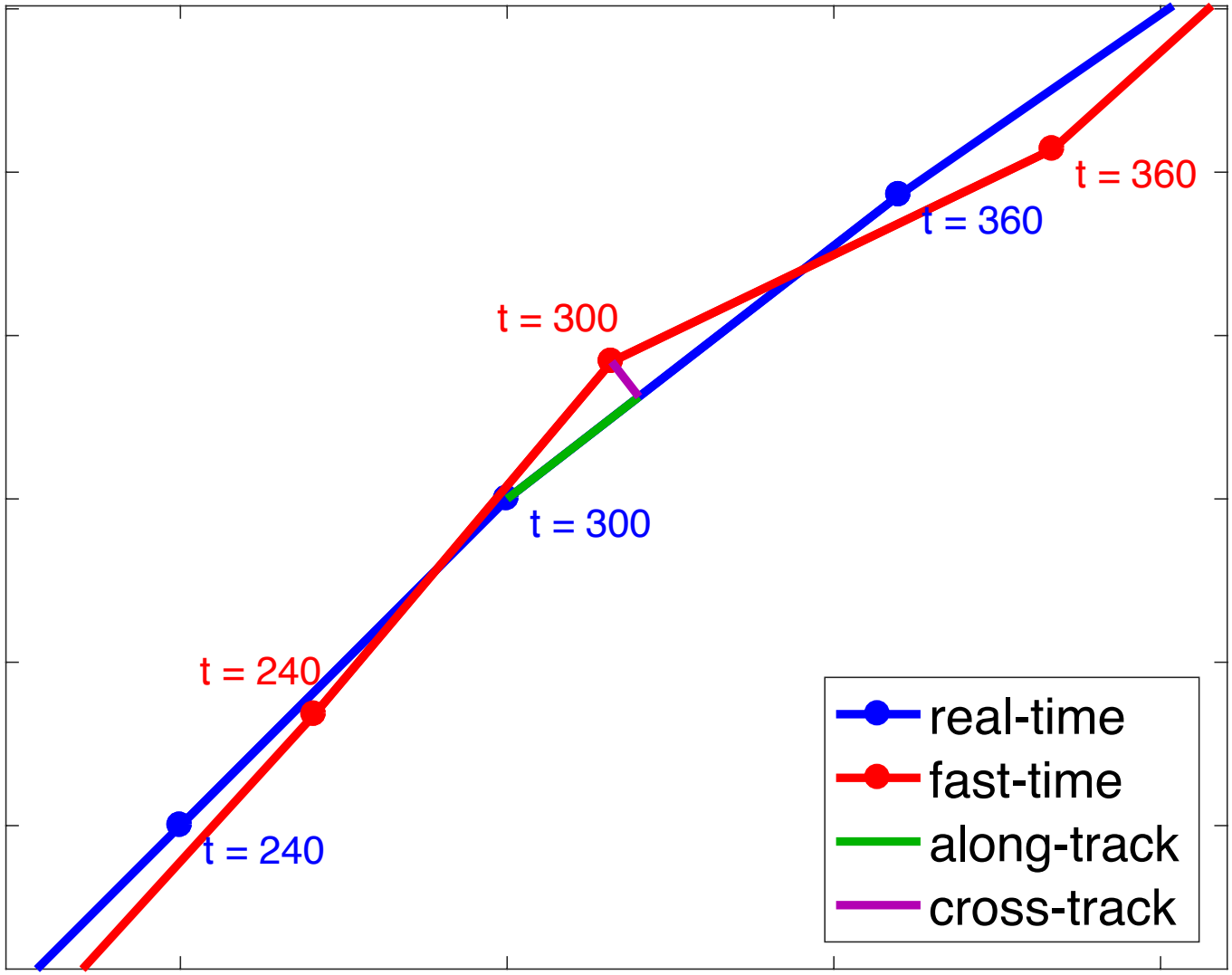
Fast Time MACS

Fast time MACS

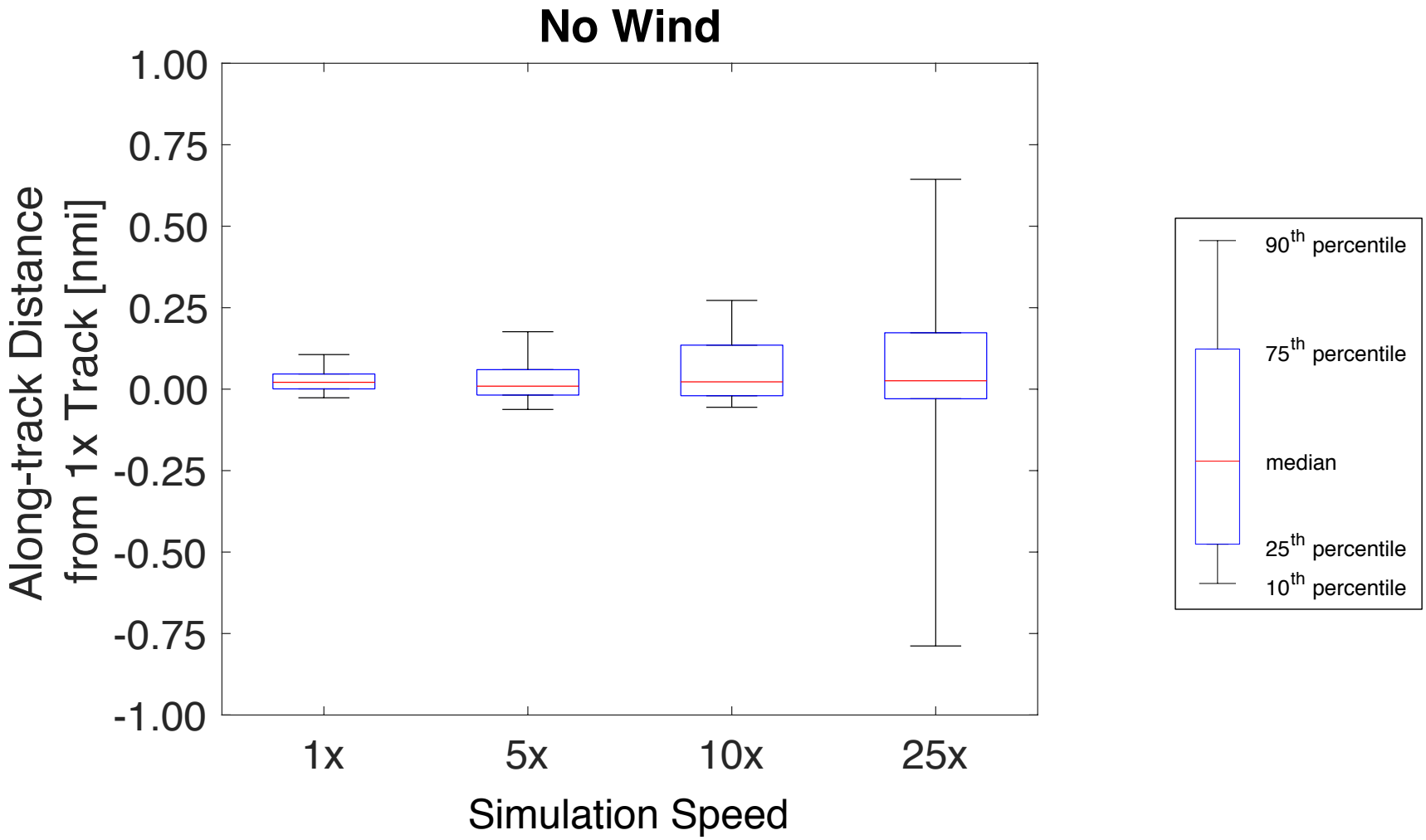
- Flights analyzed: 196
- FlightState data output from MACS
- Trajectory information ever 12 seconds
- Resampled in 1 minute intervals

  (for 1x reference sim and 1x, 5x, 10x, 25x sim)

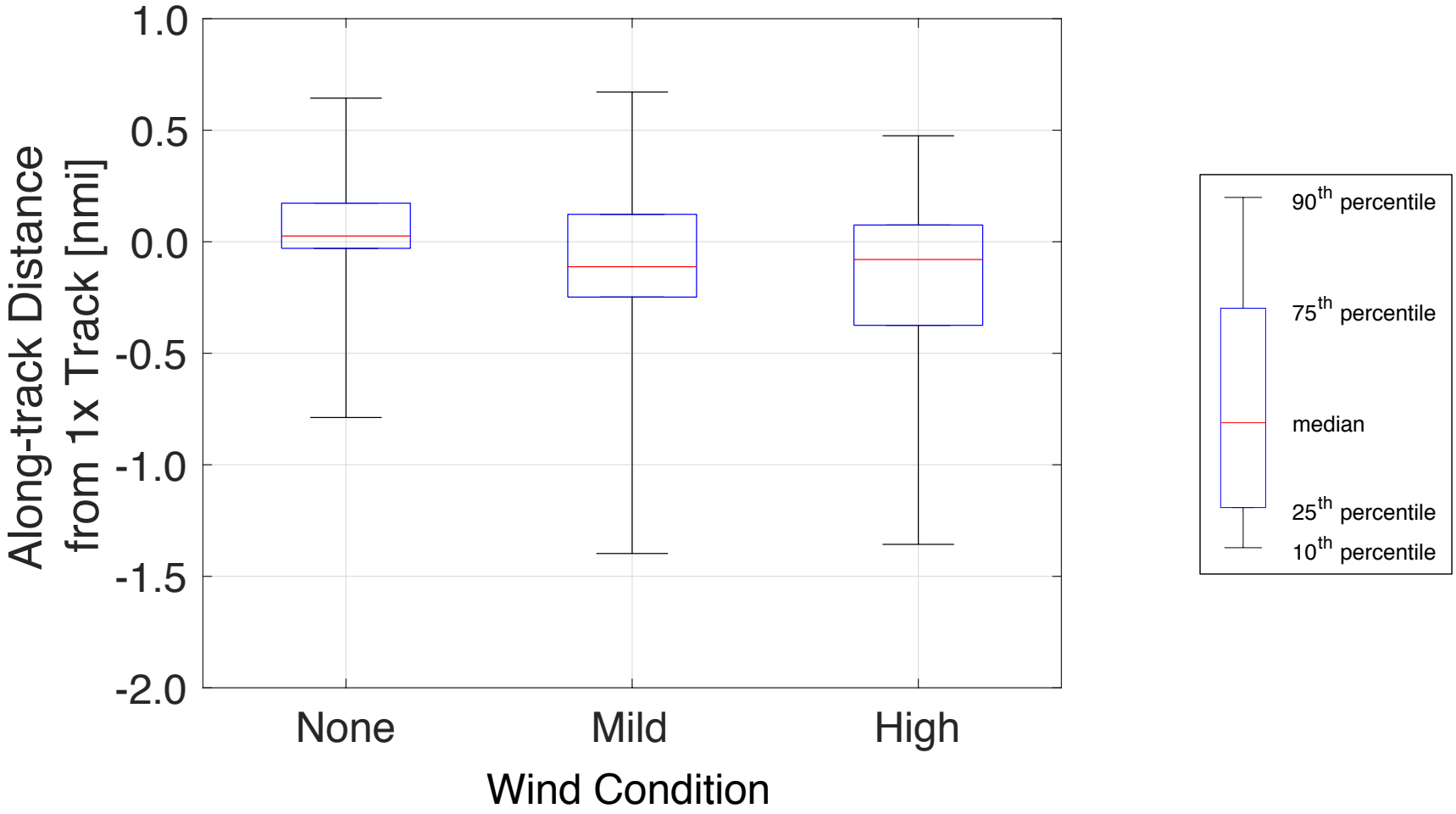
Distance measure



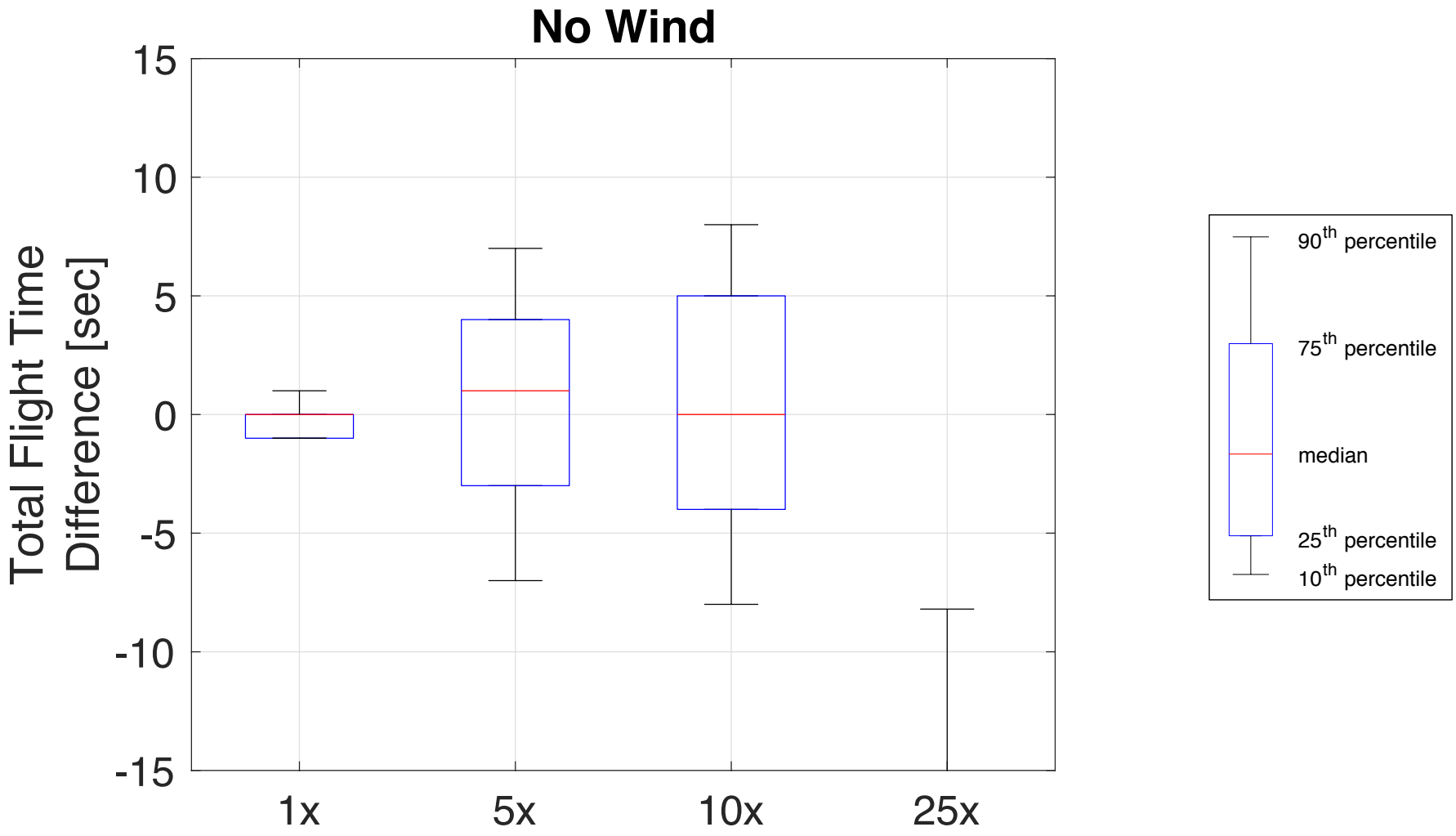
Along-track distance



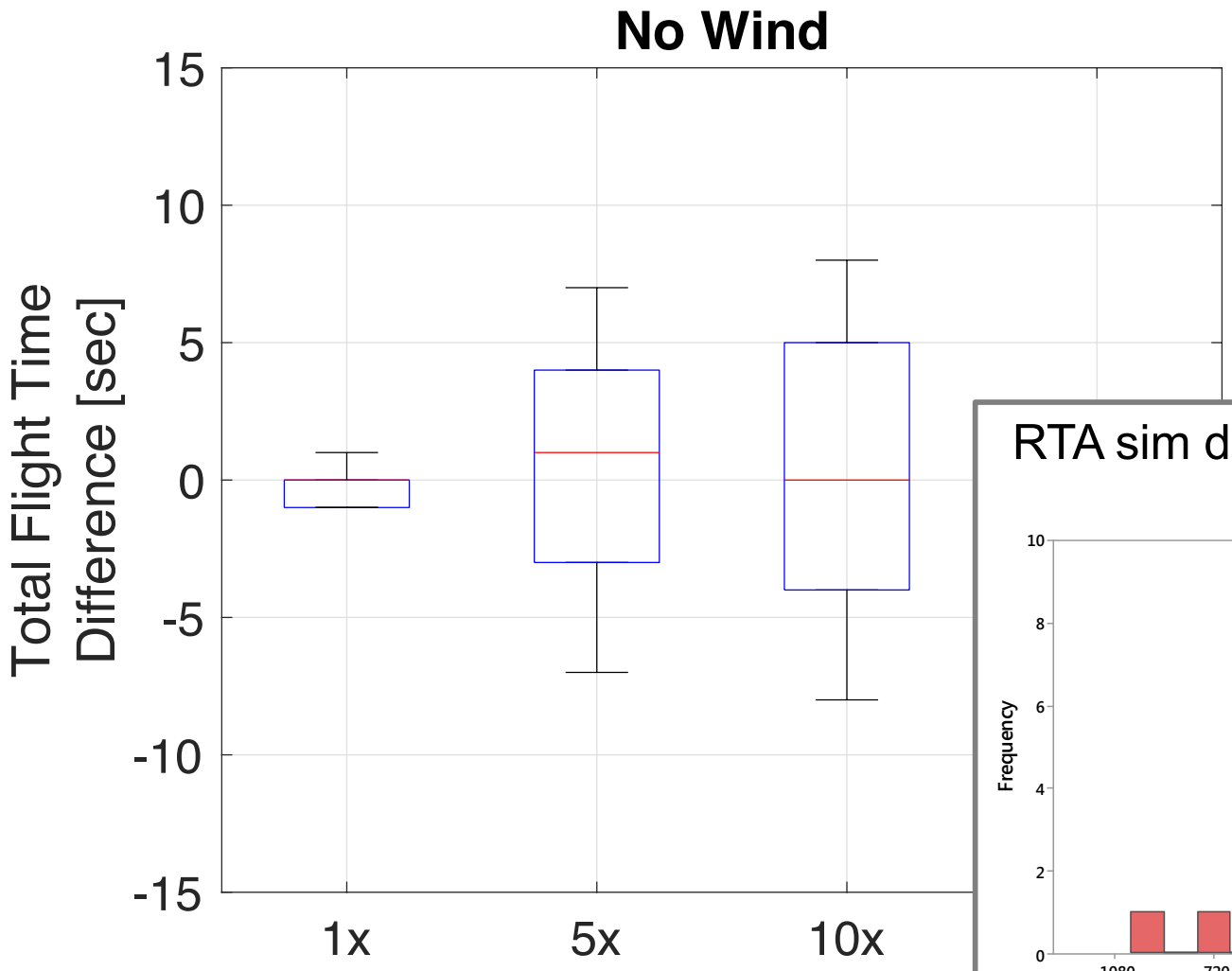
With wind, 25x: along-track distance



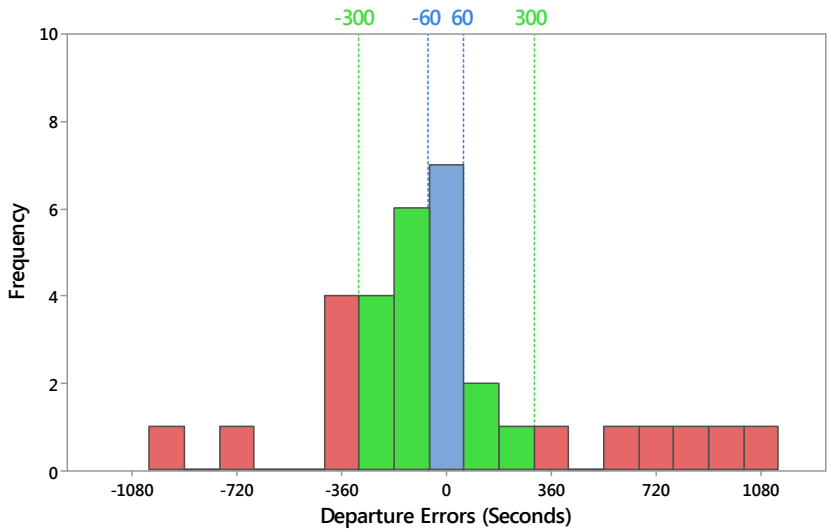
Flight time difference



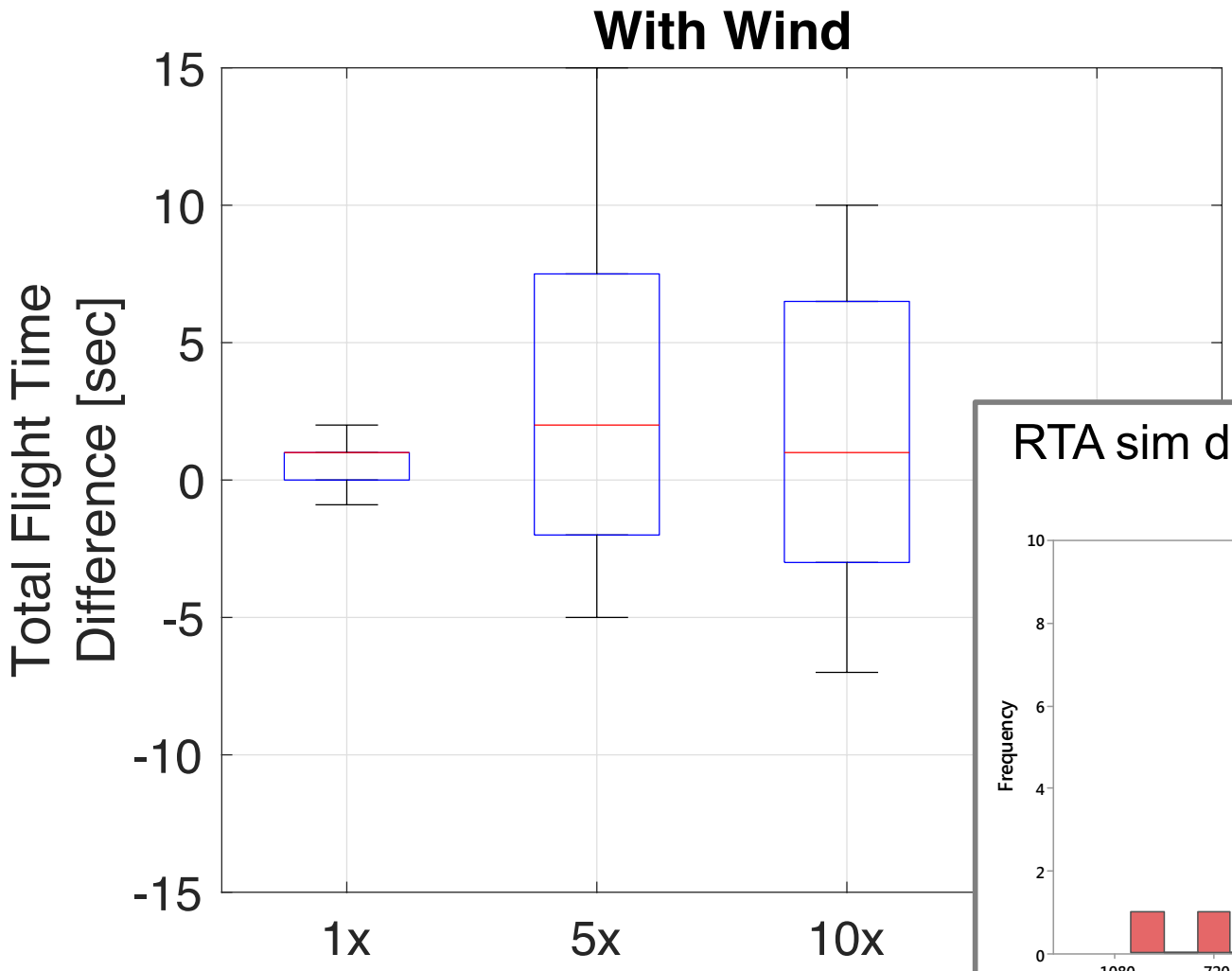
Flight time difference



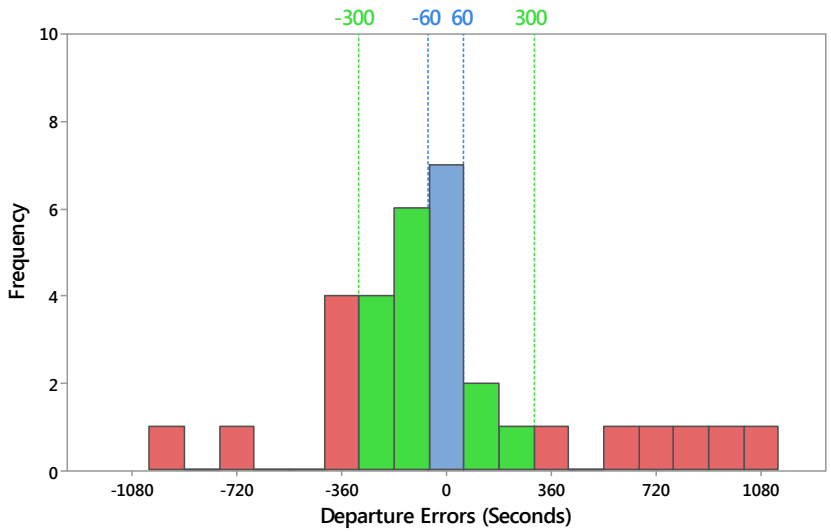
RTA sim departure error [Yoo 2016]



Flight time difference

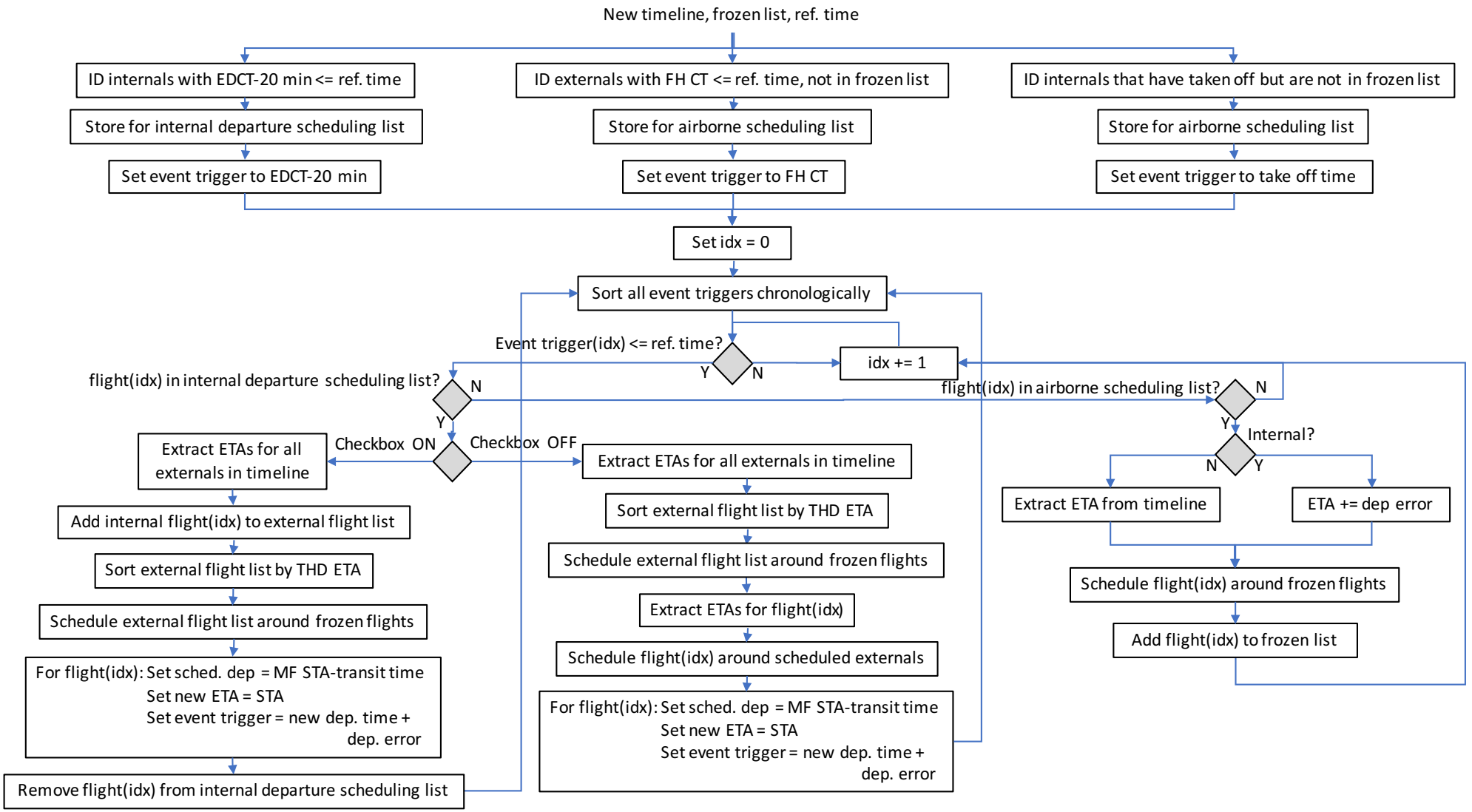


RTA sim departure error [Yoo 2016]



TBFM Emulator

Scheduling internal departures



TBFM Emulator

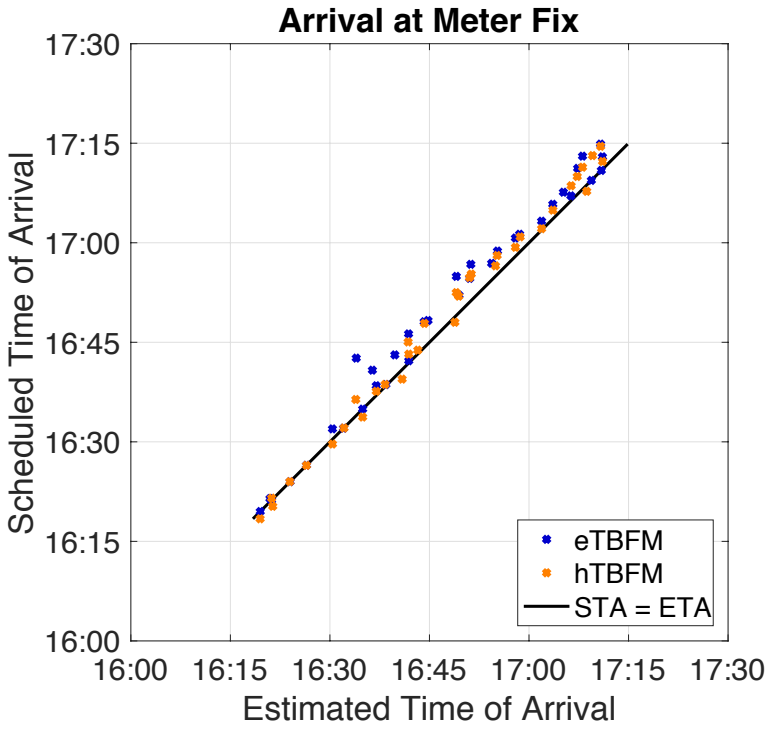
- Scheduler from Optimized Route Capability (ORC)
  - Fast-time
  - Code easily accessible for modification
- Adapted for EWR
- Modified to schedule internal departures automatically
  - Check box ON/OFF
- Integrated with Automated Simulation Capability / MACS

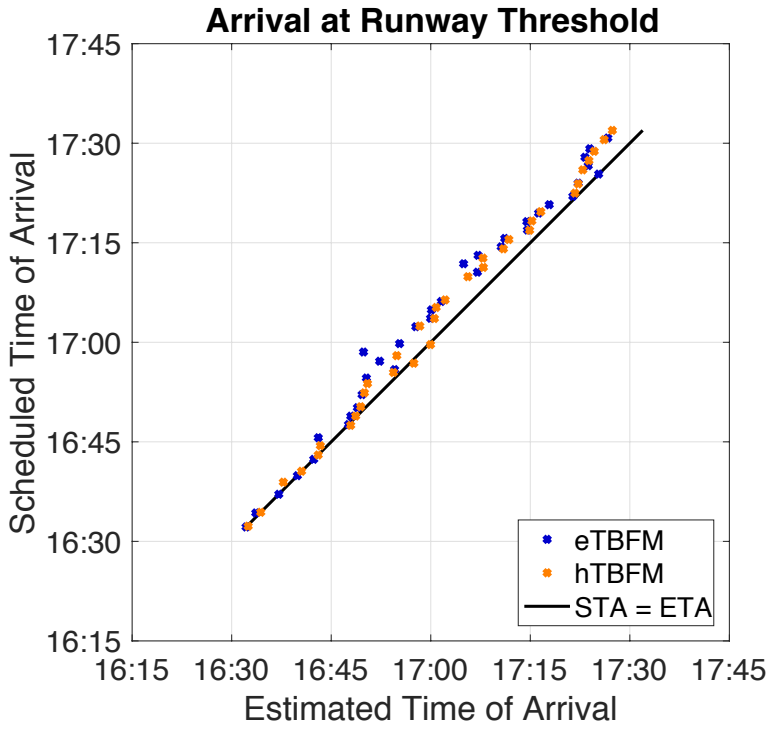
TBFM Emulator Capabilities

Capability	rTBFM	eTBFM
Fast-time		✓
EWR adaptation	✓	✓
Schedule flights at Meter Fix	✓	✓
Schedule flights at Runway Threshold	✓	✓
Schedule flights at Final Approach Fix	✓	Planned
Model wind effects inside TRACON	✓	Planned
Model wind effects upstream of TRACON	✓	✓
Automated scheduling of internal departures (Check Box ON/OFF)		✓
Extended metering	✓	Planned
Coupled scheduling	✓	
Integrated with Automated Simulation Capability / MACS		✓
Interface directly with SMART-NAS Testbed		Planned

Initial validation: ORC scheduler

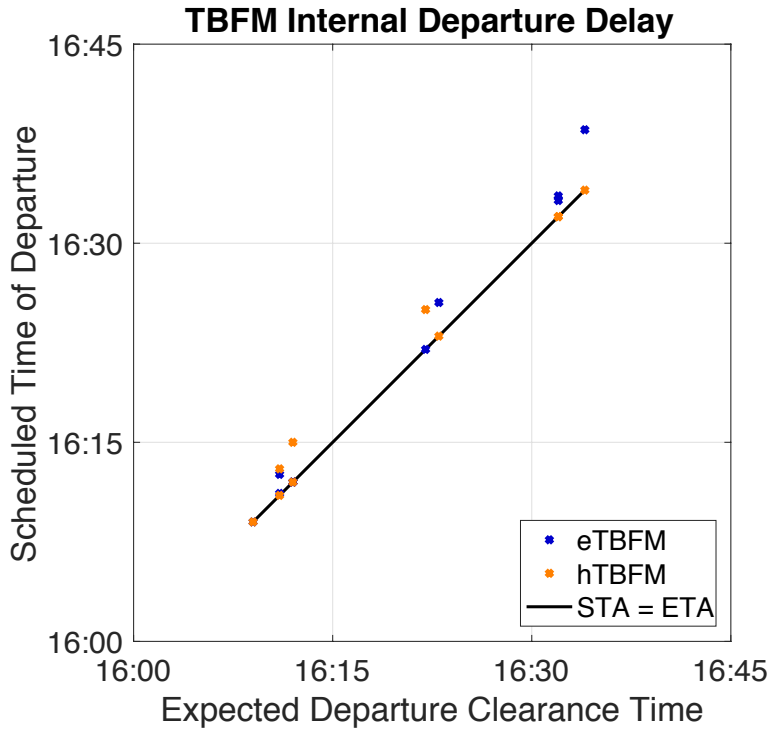
	Meter Fix [Seconds]		Threshold [Seconds]	
Avg. hTBFM metering delay (standard deviation)	80	(104)	136	(106)
Avg. eTBFM emulator metering delay (standard deviation)	143	(131)	180	(135)
Avg. ETA Error: hTBFM-eTBFM (standard deviation)	19	(75)	52	(77)
Avg. STA Error: hTBFM-eTBFM (standard deviation)	-43	(104)	7	(100)





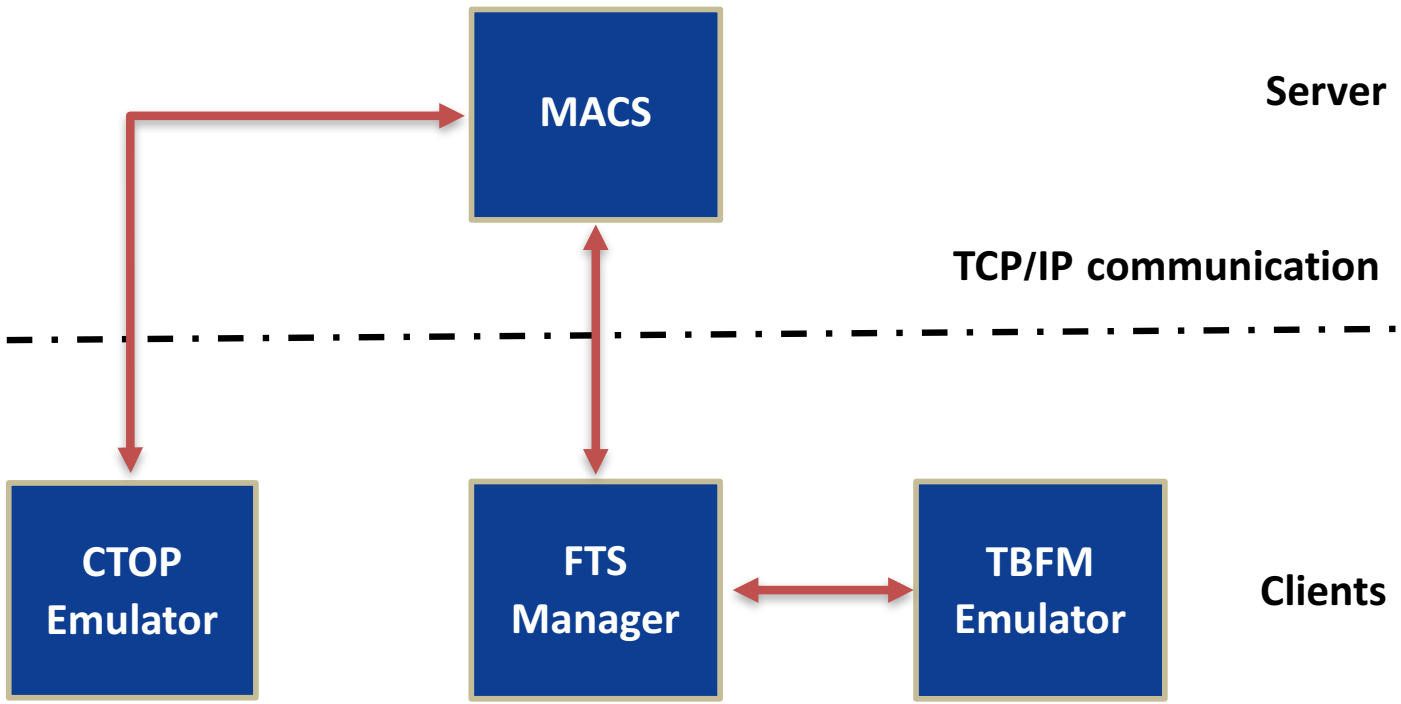
Initial validation: TBFM emulator

	[Seconds]	
Avg. rTBFM internal departure scheduling delay	66	(72)
Avg. eTBFM internal departure scheduling delay	70	(90)
Avg. scheduled departure time error (rTBFM-eTBFM)	-4	(129)



Simulation Manager

Simulation manager



Communication GUI

Demo

Create and run batch process

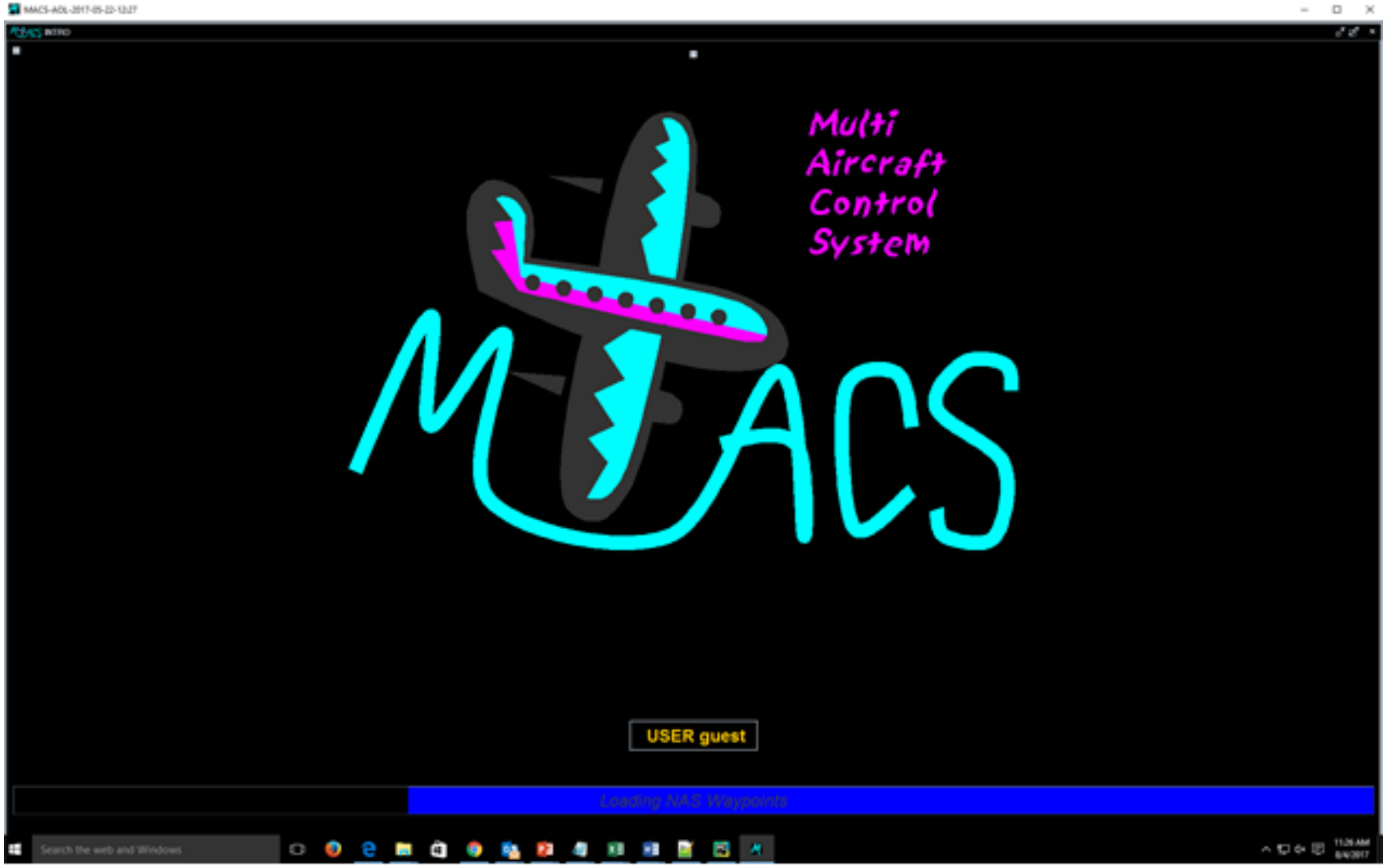
- Create batch file `FTS_bat.txt`

```
#RunName     Scenario     TimeFactor     RunMinutes     startnCTOPseconds
proc1 C:/fts-tbfm/input_files/EWR/Scenario/GAG_v9.txt                              1x 30 10
proc2 C:/fts-tbfm/input_files/EWR/Scenario/MACS_20170421_1hr_traffic_NOdeperr.txt  1x 30 10
```

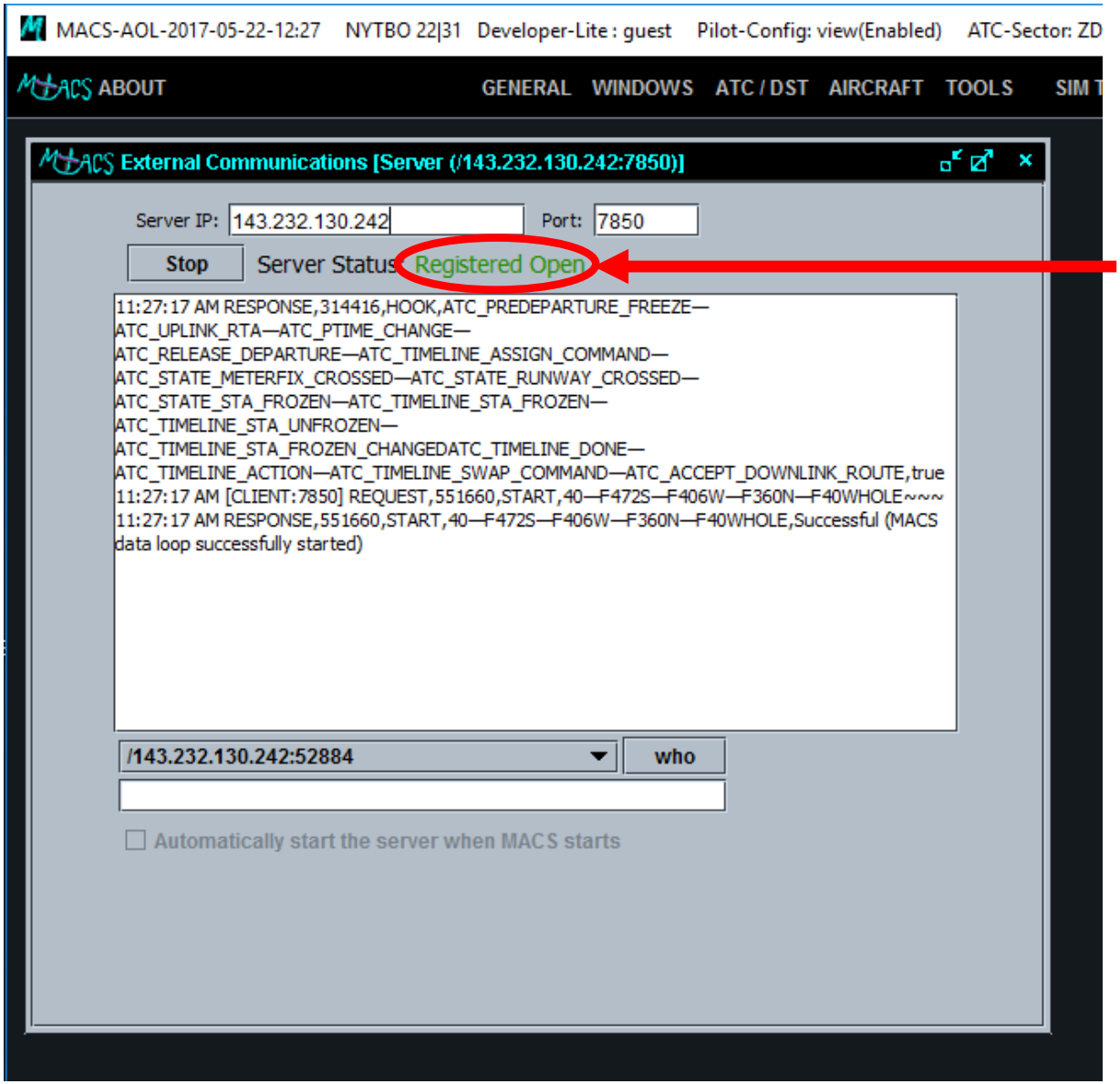
- Python command

```
Python FTS_Macs-batch.py FTS_bat.txt
```

Launch MACS

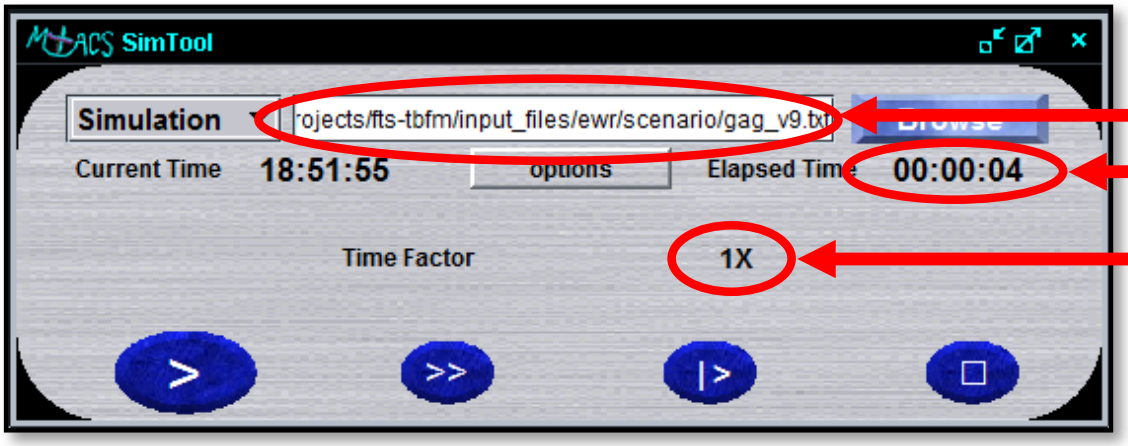

Multi
Aircraft
Control
System
MACS
USER guest
Loading NAS Waypoints

Enable external communication

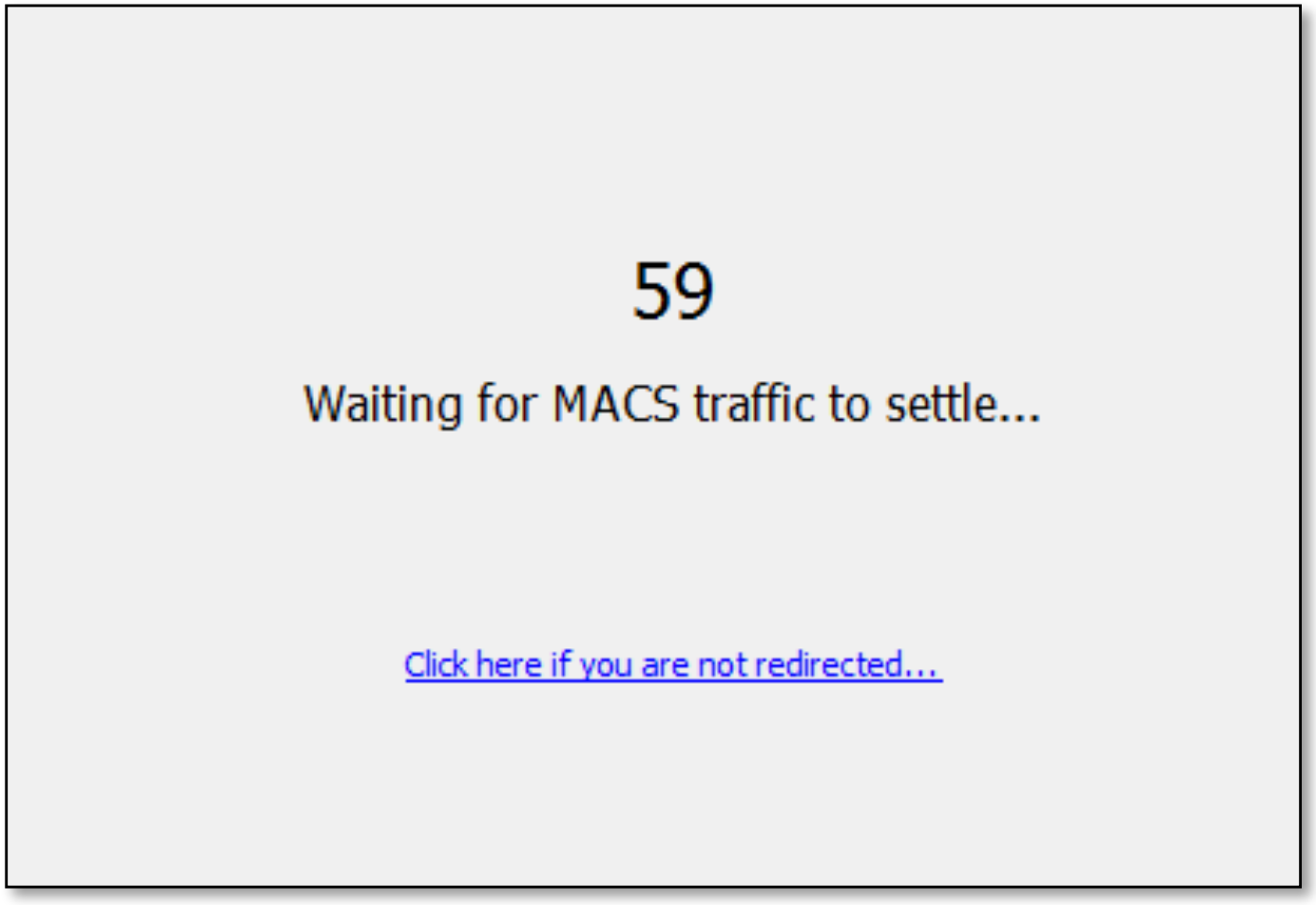


Communication window
Server Status: Registered Open

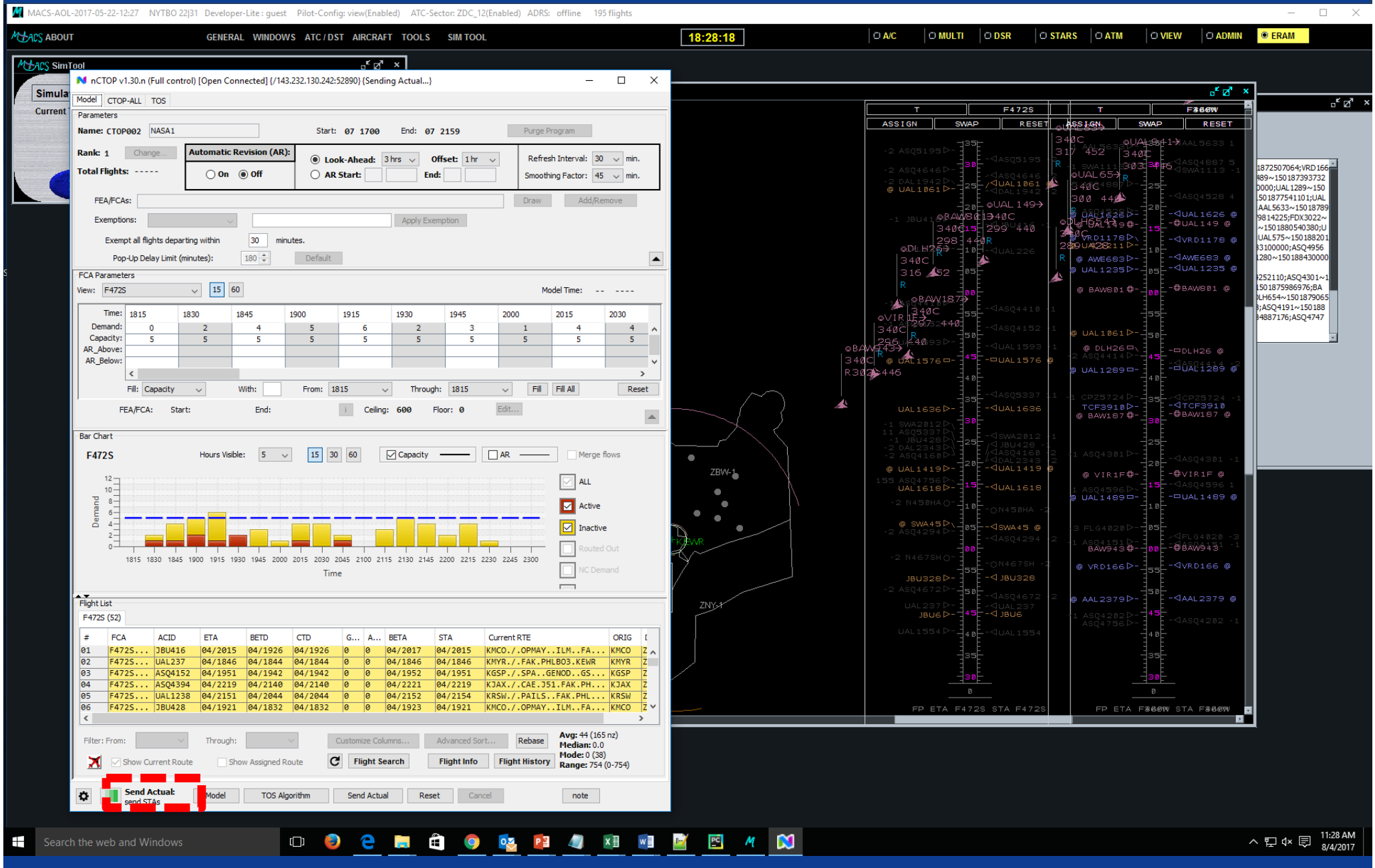
Start simulation



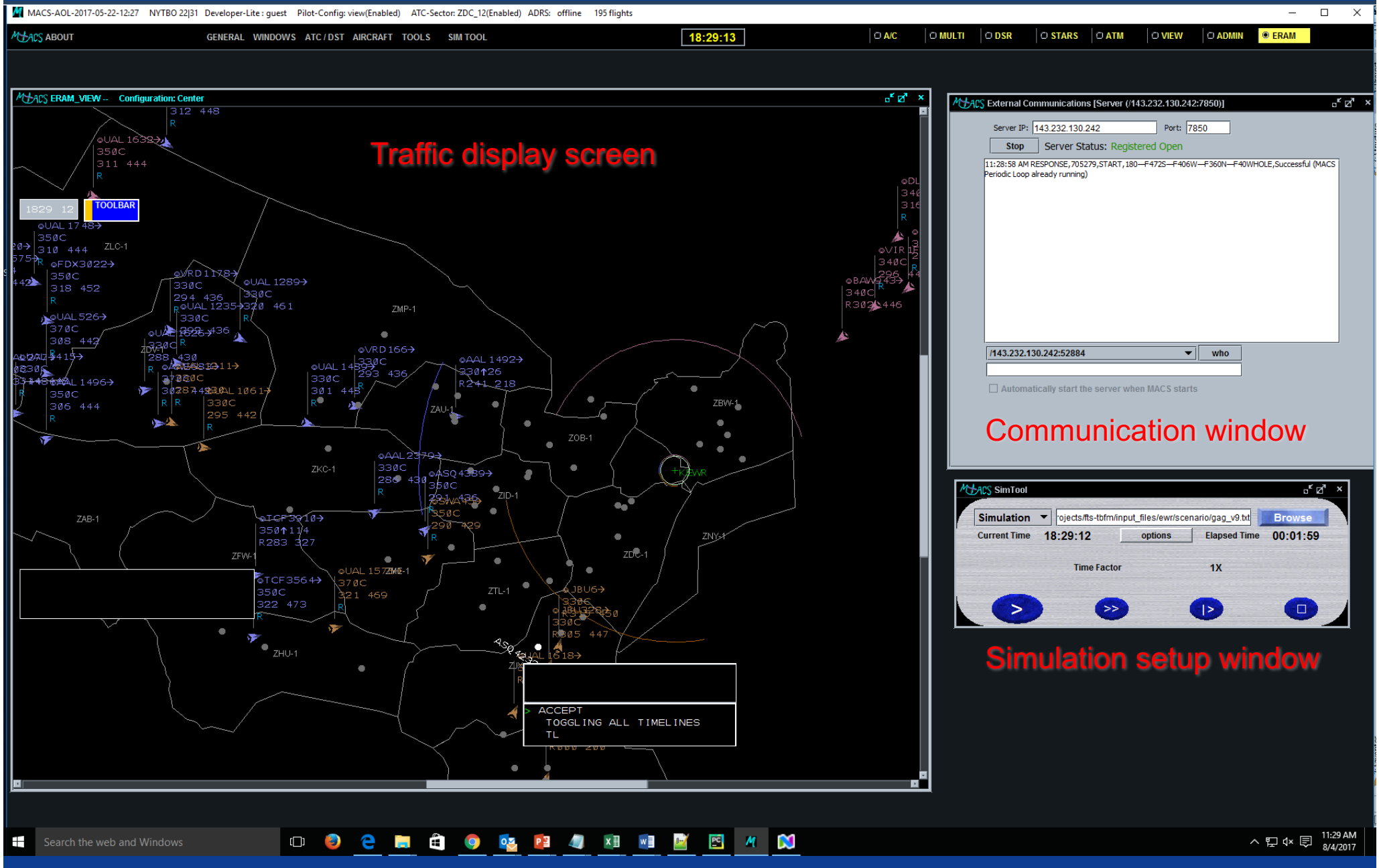
Launch nCTOP



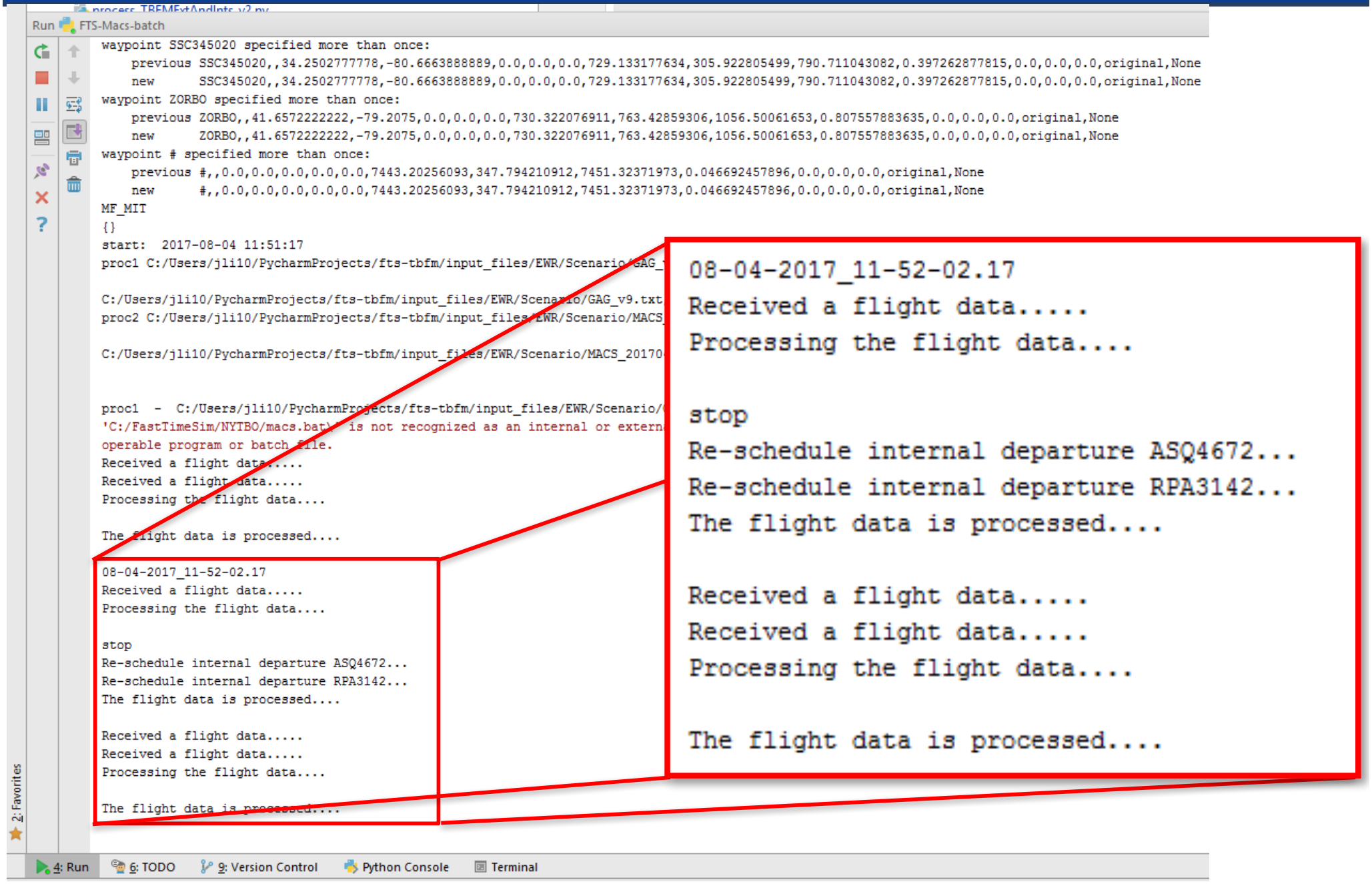
Calculate new departure times



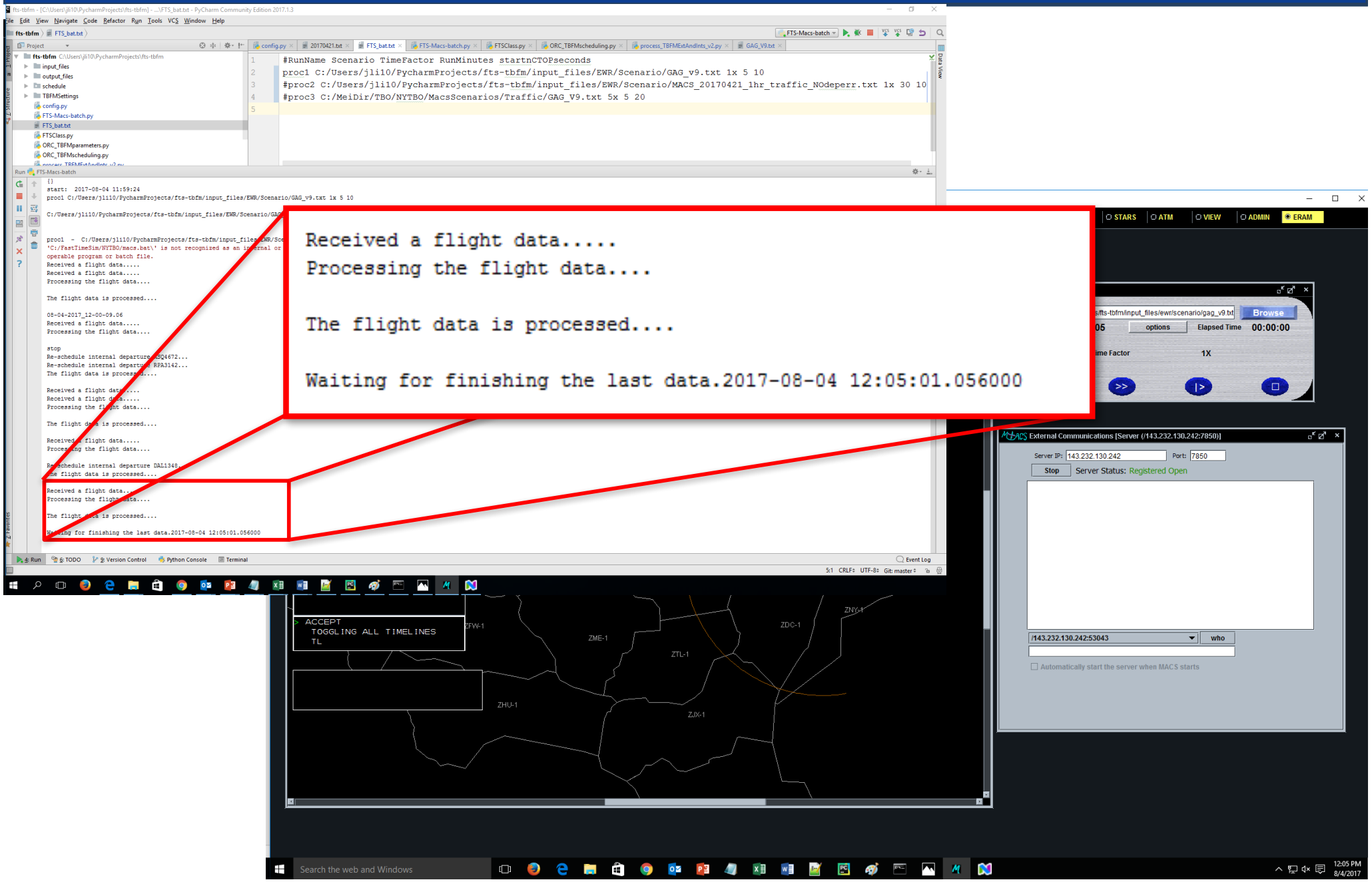
Run simulation



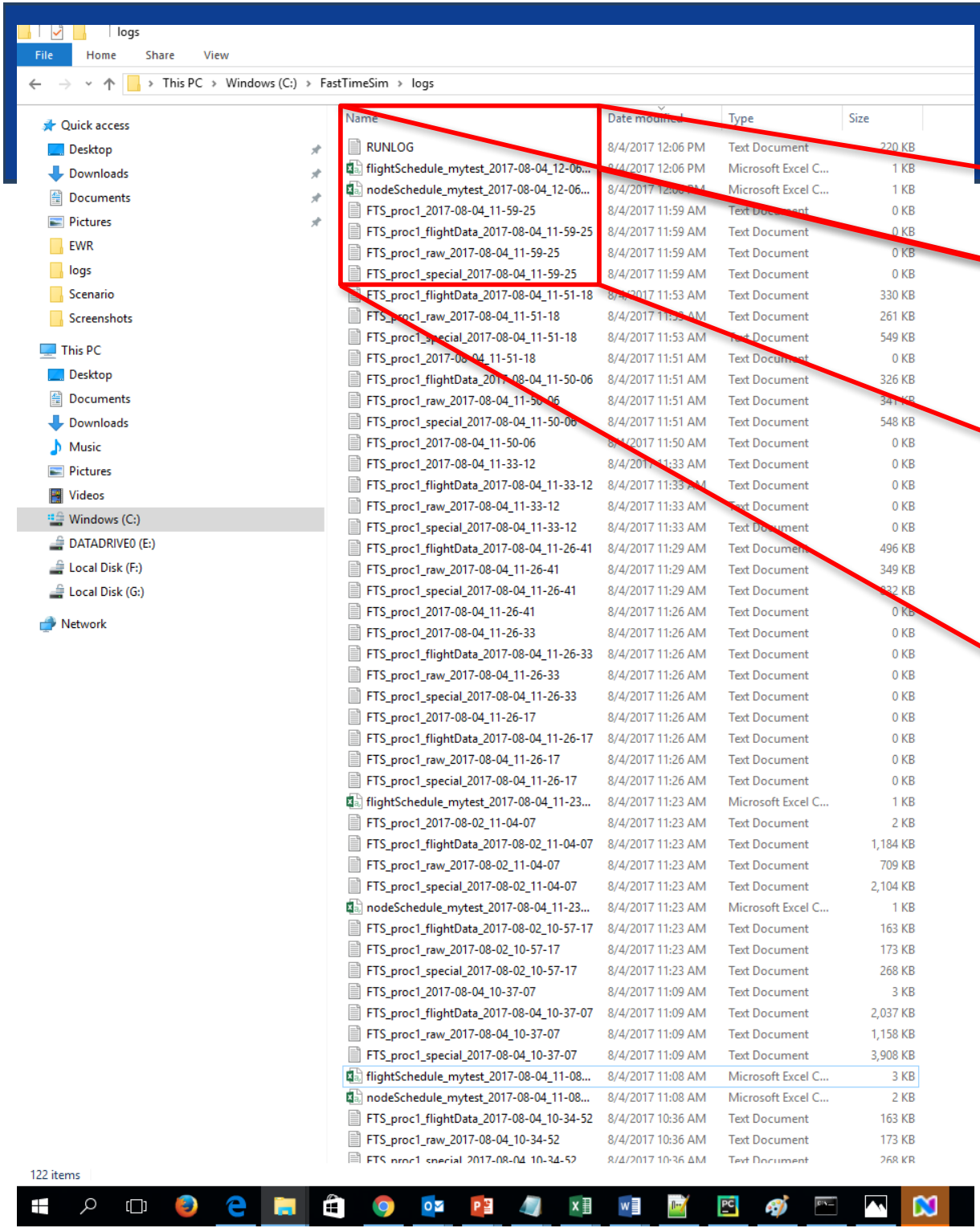
Monitor simulation status



Batch process terminated



Log data


logs
File
Home
Share
View
This PC › Windows (C:) › FastTimeSim › logs
Quick access
Desktop
Downloads
Documents
Pictures
EWR
logs
Scenario
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This PC
Desktop
Documents
Downloads
Music
Pictures
Videos
Windows (C:)
DATADRIVE0 (E:)
Local Disk (F:)
Local Disk (G:)
Network
Name
Date modified
Type
Size
RUNLOG 8/4/2017 12:06 PM Text Document 220 KB
flightSchedule_mytest_2017-08-04_12-06... 8/4/2017 12:06 PM Microsoft Excel C... 1 KB
nodeSchedule_mytest_2017-08-04_12-06... Microsoft Excel C... 1 KB
FTS_proc1_2017-08-04_11-59-25 8/4/2017 11:59 AM Text Document 0 KB
FTS_proc1_flightData_2017-08-04_11-59-25 8/4/2017 11:59 AM Text Document 0 KB
FTS_proc1_raw_2017-08-04_11-59-25 8/4/2017 11:59 AM Text Document 0 KB
FTS_proc1_special_2017-08-04_11-59-25 8/4/2017 11:59 AM Text Document 0 KB
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FTS_proc1_flightData_2017-08-04_11-50-06 8/4/2017 11:51 AM Text Document 326 KB
FTS_proc1_raw_2017-08-04_11-50-06 Text Document
FTS_proc1_special_2017-08-04_11-50-06 8/4/2017 11:51 AM Text Document 548 KB
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FTS_proc1_raw_2017-08-04_11-26-17 8/4/2017 11:26 AM Text Document 0 KB
FTS_proc1_special_2017-08-04_11-26-17 8/4/2017 11:26 AM Text Document 0 KB
flightSchedule_mytest_2017-08-04_11-23... 8/4/2017 11:23 AM Microsoft Excel C... 1 KB
FTS_proc1_2017-08-02_11-04-07 8/4/2017 11:23 AM Text Document 2 KB
FTS_proc1_flightData_2017-08-02_11-04-07 8/4/2017 11:23 AM Text Document 1,184 KB
FTS_proc1_raw_2017-08-02_11-04-07 8/4/2017 11:23 AM Text Document 709 KB
FTS_proc1_special_2017-08-02_11-04-07 8/4/2017 11:23 AM Text Document 2,104 KB
nodeSchedule_mytest_2017-08-04_11-23... 8/4/2017 11:23 AM Microsoft Excel C... 1 KB
FTS_proc1_flightData_2017-08-02_10-57-17 8/4/2017 11:23 AM Text Document 163 KB
FTS_proc1_raw_2017-08-02_10-57-17 8/4/2017 11:23 AM Text Document 173 KB
FTS_proc1_special_2017-08-02_10-57-17 8/4/2017 11:23 AM Text Document 268 KB
FTS_proc1_2017-08-04_10-37-07 8/4/2017 11:09 AM Text Document 3 KB
FTS_proc1_flightData_2017-08-04_10-37-07 8/4/2017 11:09 AM Text Document 2,037 KB
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nodeSchedule_mytest_2017-08-04_11-08... 8/4/2017 11:08 AM Microsoft Excel C... 2 KB
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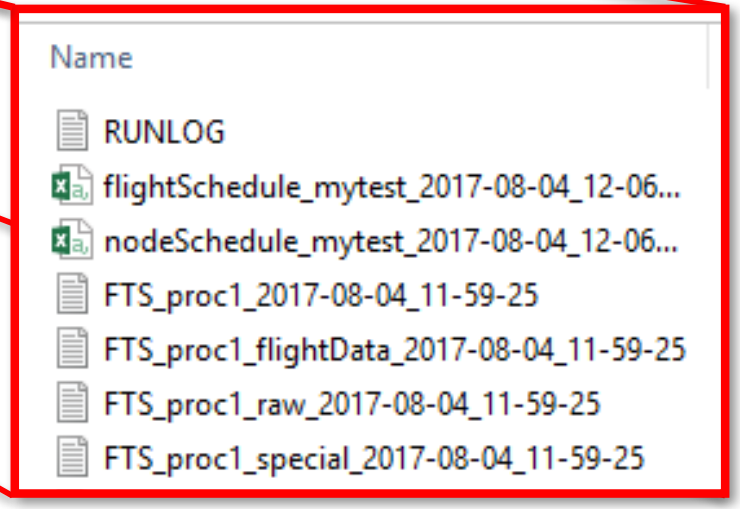
122 items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RUNLOG
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FTS_proc1_flightData_2017-08-04_11-59-25
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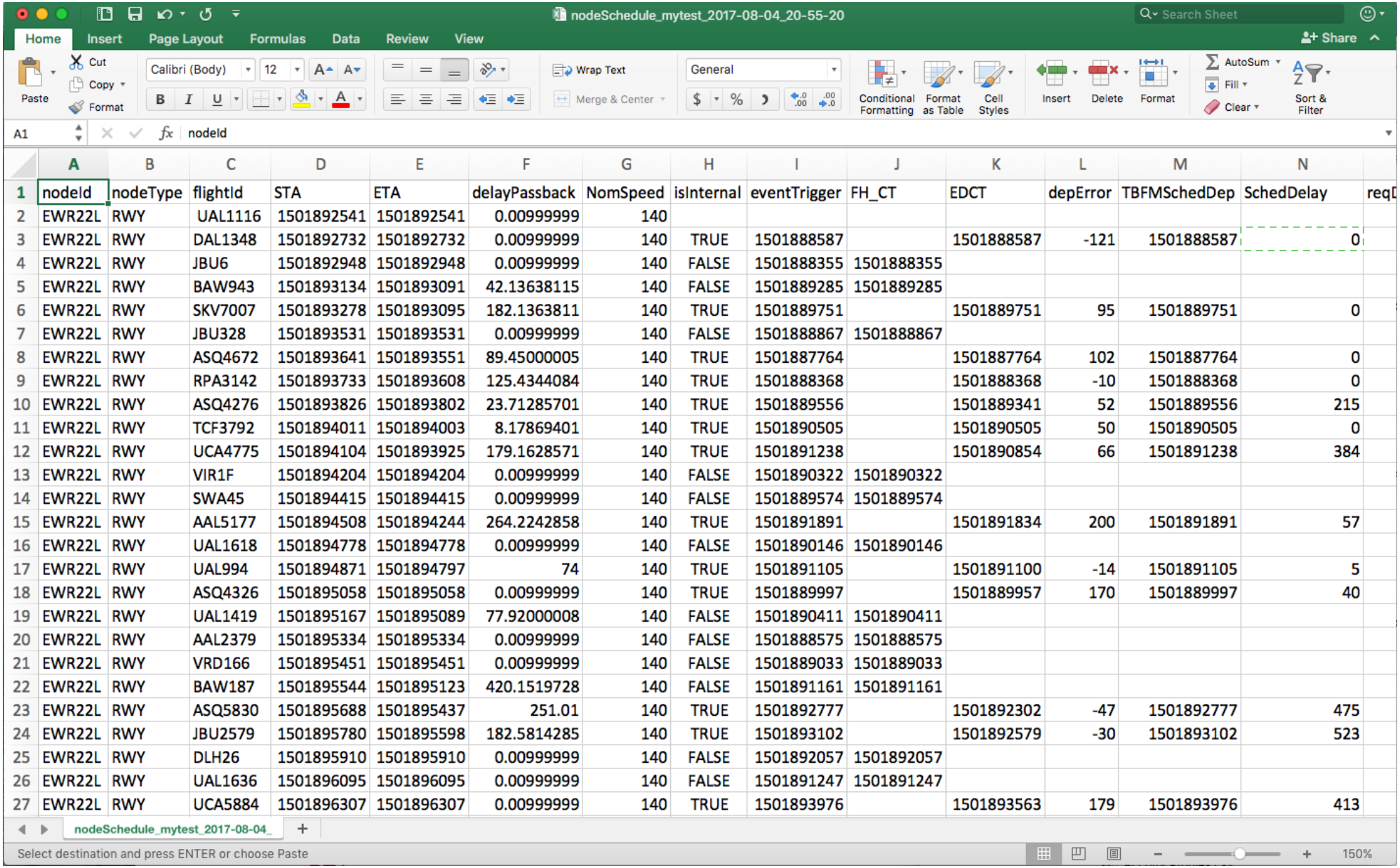
FTS_proc1_special_2017-08-04_11-59-25

Sample output



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1	nodeId	nodeType	flightId	STA	ETA	delayPassback	NomSpeed	isInternal	eventTrigger	FH_CT	EDCT	depError	TBFMSchedDep	SchedDelay	reqD
2	EWR22L	RWY	UAL1116	1501892541	1501892541	0.00999999	140								
3	EWR22L	RWY	DAL1348	1501892732	1501892732	0.00999999	140	TRUE	1501888587		1501888587	-121	1501888587	0	
4	EWR22L	RWY	JBU6	1501892948	1501892948	0.00999999	140	FALSE	1501888355	1501888355					
5	EWR22L	RWY	BAW943	1501893134	1501893091	42.13638115	140	FALSE	1501889285	1501889285					
6	EWR22L	RWY	SKV7007	1501893278	1501893095	182.1363811	140	TRUE	1501889751		1501889751	95	1501889751	0	
7	EWR22L	RWY	JBU328	1501893531	1501893531	0.00999999	140	FALSE	1501888867	1501888867					
8	EWR22L	RWY	ASQ4672	1501893641	1501893551	89.45000005	140	TRUE	1501887764		1501887764	102	1501887764	0	
9	EWR22L	RWY	RPA3142	1501893733	1501893608	125.4344084	140	TRUE	1501888368		1501888368	-10	1501888368	0	
10	EWR22L	RWY	ASQ4276	1501893826	1501893802	23.71285701	140	TRUE	1501889556		1501889341	52	1501889556	215	
11	EWR22L	RWY	TCF3792	1501894011	1501894003	8.17869401	140	TRUE	1501890505		1501890505	50	1501890505	0	
12	EWR22L	RWY	UCA4775	1501894104	1501893925	179.1628571	140	TRUE	1501891238		1501890854	66	1501891238	384	
13	EWR22L	RWY	VIR1F	1501894204	1501894204	0.00999999	140	FALSE	1501890322	1501890322					
14	EWR22L	RWY	SWA45	1501894415	1501894415	0.00999999	140	FALSE	1501889574	1501889574					
15	EWR22L	RWY	AAL5177	1501894508	1501894244	264.2242858	140	TRUE	1501891891		1501891834	200	1501891891	57	
16	EWR22L	RWY	UAL1618	1501894778	1501894778	0.00999999	140	FALSE	1501890146	1501890146					
17	EWR22L	RWY	UAL994	1501894871	1501894797	74	140	TRUE	1501891105		1501891100	-14	1501891105	5	
18	EWR22L	RWY	ASQ4326	1501895058	1501895058	0.00999999	140	TRUE	1501889997		1501889957	170	1501889997	40	
19	EWR22L	RWY	UAL1419	1501895167	1501895089	77.92000008	140	FALSE	1501890411	1501890411					
20	EWR22L	RWY	AAL2379	1501895334	1501895334	0.00999999	140	FALSE	1501888575	1501888575					
21	EWR22L	RWY	VRD166	1501895451	1501895451	0.00999999	140	FALSE	1501889033	1501889033					
22	EWR22L	RWY	BAW187	1501895544	1501895123	420.1519728	140	FALSE	1501891161	1501891161					
23	EWR22L	RWY	ASQ5830	1501895688	1501895437	251.01	140	TRUE	1501892777		1501892302	-47	1501892777	475	
24	EWR22L	RWY	JBU2579	1501895780	1501895598	182.5814285	140	TRUE	1501893102		1501892579	-30	1501893102	523	
25	EWR22L	RWY	DLH26	1501895910	1501895910	0.00999999	140	FALSE	1501892057	1501892057					
26	EWR22L	RWY	UAL1636	1501896095	1501896095	0.00999999	140	FALSE	1501891247	1501891247					
27	EWR22L	RWY	UCA5884	1501896307	1501896307	0.00999999	140	TRUE	1501893976		1501893563	179	1501893976	413	