





Outline



- Objectives for N90 workshop series
- Initial validation of ML models
- Overview of scheduling algorithm
- Real-time performance monitoring tools
- Post-operations analysis reports available
- Discussion



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Motivation for N90 Workshop



- NASA predictive engine developed to support Sustainable Flight National Partnership Ops 1 (SFNP Ops-1) demo in North TX and Houston area
- SFNP Ops-1 is demonstrating pre-departure TOS reroutes within the lockout period which require ATC coordination
- Demonstration of use cases that require ATC coordination is constrained to specific locations agreed upon between NASA/FAA/NATCA
- N90 workshop to explore **use cases of predictive engine that don't require ATC coordination**



N90 Workshop Potential Use Cases



- Flight plan filing outside the lockout period (predictable demand capacity imbalance at the terminal boundary)
- Prediction of OFF time to support Mandatory OFF Time (MOT) decisions
- Prediction of arrival gate conflict
- Additional use cases identified during the workshop series...



Objectives of N90 Workshop



- Identify and demonstrate additional use cases of predictive engine and quantify associated benefits
- Identify improvements or new requirements needed for predictive engine to support additional use cases
- Knowledge transfer to increase understanding of NASA's predictive engine
- Knowledge transfer to better understand level of effort to build and validate predictive engine at new location



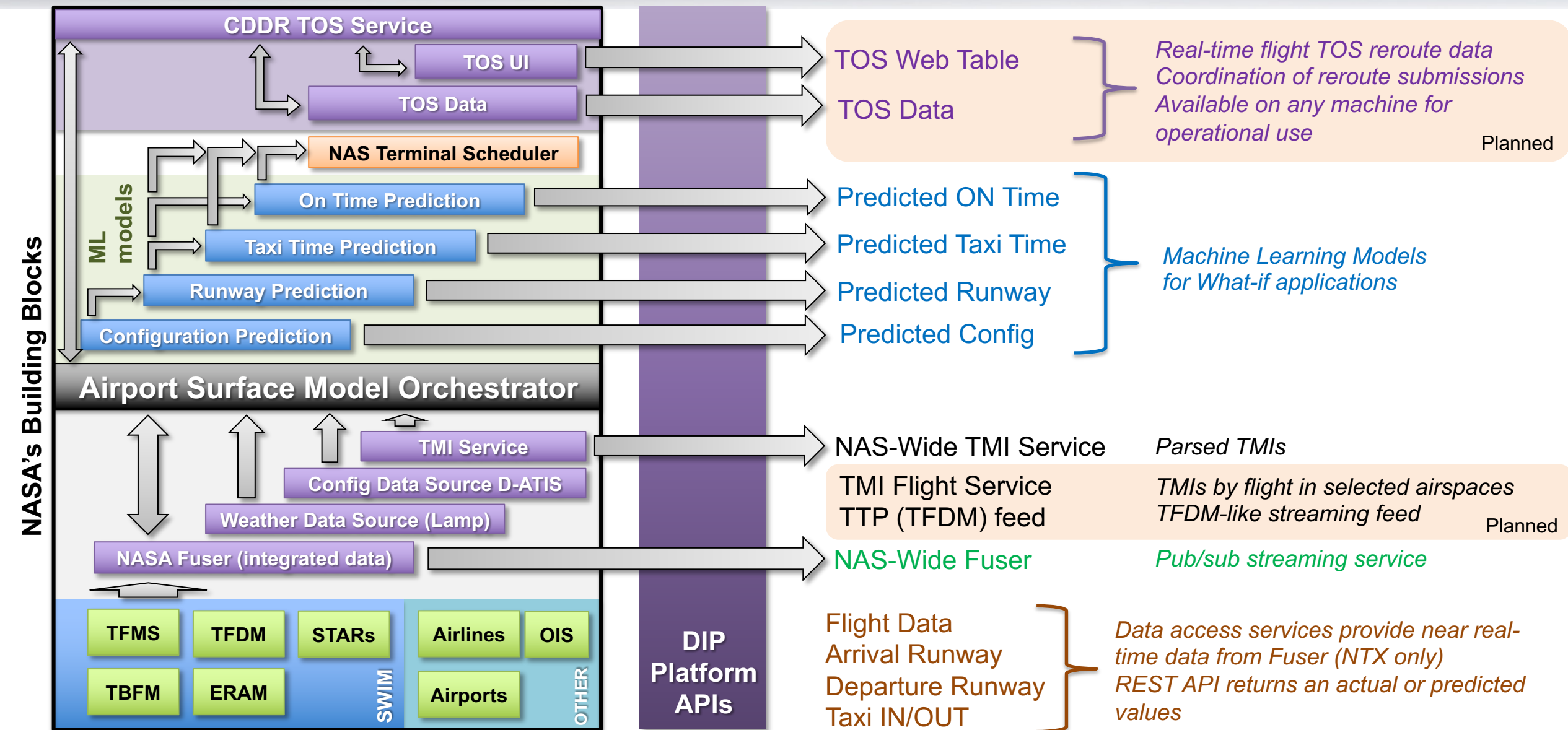
Outline

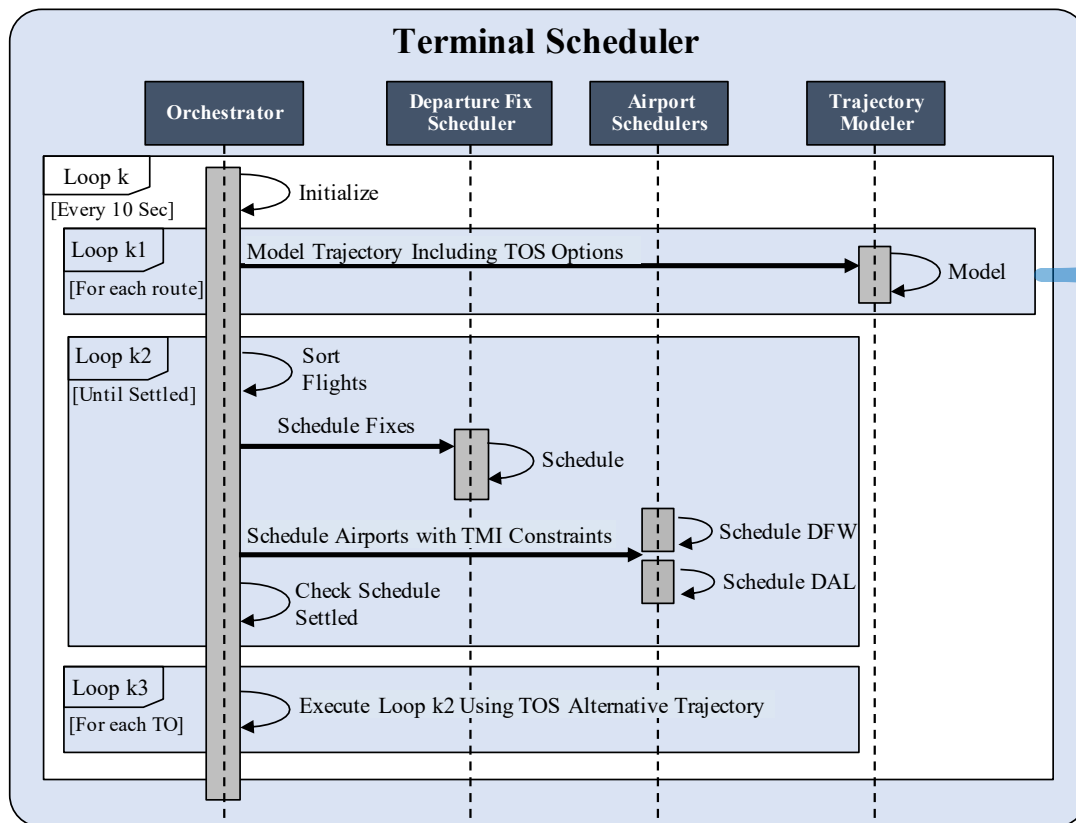


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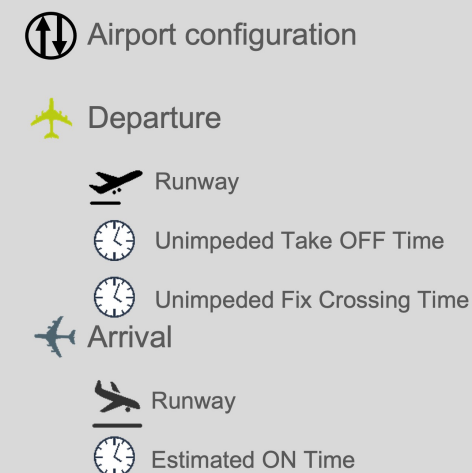
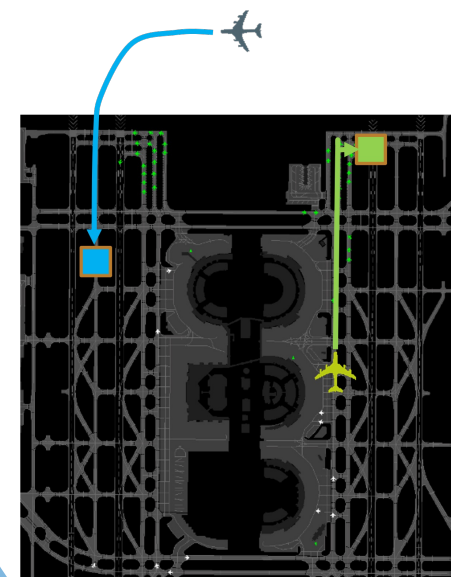


NASA Services Available via Digital Information Platform

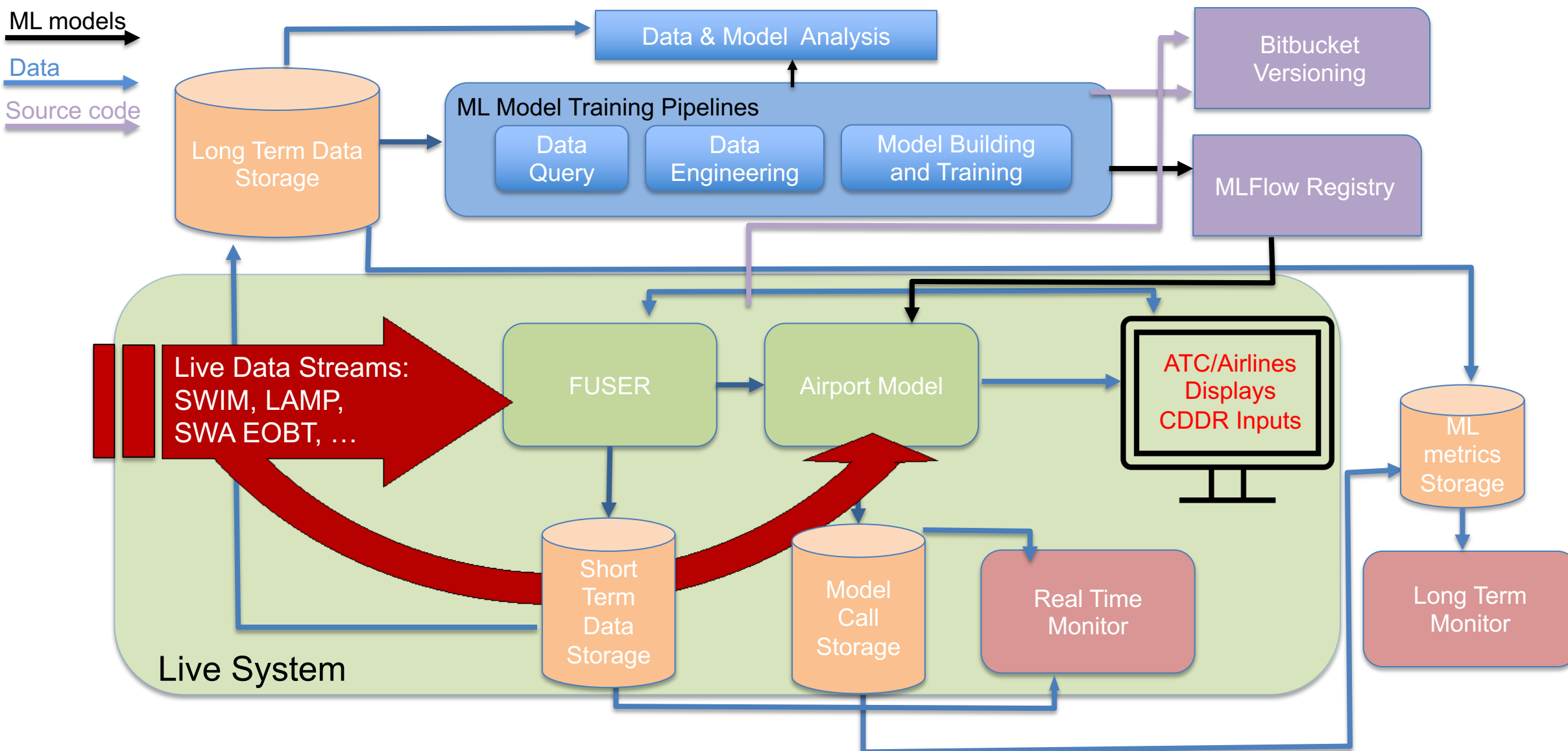




Machine Learning Airport Surface Model



- **Machine Learning:** generate unimpeded trajectory used as input by the scheduler
- **Scheduler:** generate OFF prediction while enforcing constraints at terminal boundary and each airport surface





Validation of ML Models



MLFlow Demo

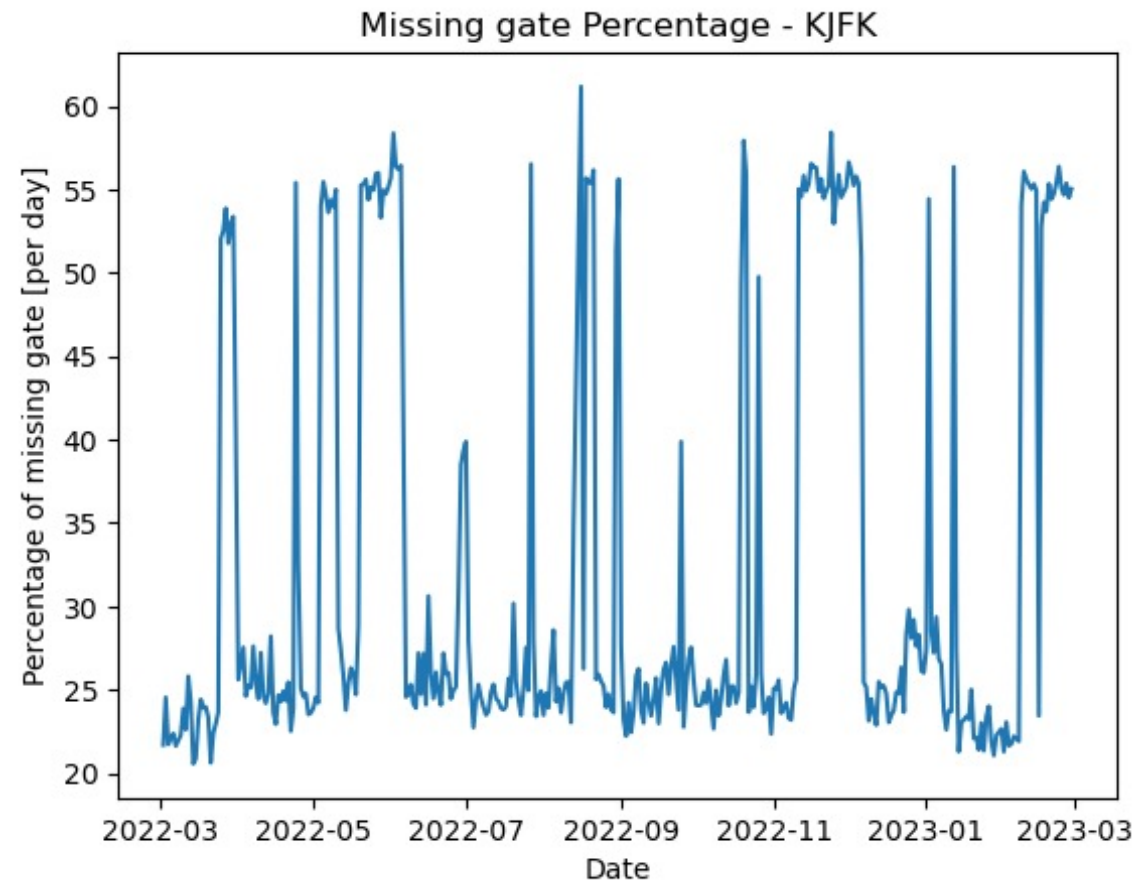


KJFK Unimpeded Taxi-Out Models



```
taxi_out.pipelines.data_engineering.nodes - INFO - 96.6% of departures were selected in the date range
kedro.runner.sequential_runner - INFO - Completed 10 out of 29 tasks
kedro.runner.sequential_runner - INFO - Completed 11 out of 29 tasks
taxi_out.pipelines.data_engineering.nodes - INFO - Kept 51.6% of flights when filtering to keep only departures
kedro.runner.sequential_runner - INFO - Completed 12 out of 29 tasks
taxi_out.pipelines.data_engineering.nodes - INFO - Kept 67.5% of departures when filtering to keep only departures with non-null departure stand|
taxi_out.pipelines.data_engineering.nodes - INFO - Kept 98.6% of departures when filtering to keep only departures with non-null departure runway
kedro.runner.sequential_runner - INFO - Completed 13 out of 29 tasks
taxi_out.pipelines.data_engineering.nodes - INFO - Kept 99.2% of departures when filtering to keep only departures with valid actual_departure_full_taxi_time taxi time
taxi_out.pipelines.data_engineering.nodes - INFO - Kept 97.5% of departures when filtering to keep only departures with value within 3.0 +-IQR/QUANTILE for actual_departure_full_taxi_time
kedro.runner.sequential_runner - INFO - Completed 14 out of 29 tasks
taxi_out.pipelines.data_engineering.nodes - INFO - Kept 83.2% of flights when filtering to keep only departures with non-nulls for all required actual times
kedro.runner.sequential_runner - INFO - Completed 15 out of 29 tasks
taxi_out.pipelines.data_engineering.nodes - INFO - Matched 100.0% of departures when joining fraction of taxi-out trajectory with speed greater than or equal to threshold
kedro.runner.sequential_runner - INFO - Completed 16 out of 29 tasks
taxi_out.pipelines.data_engineering.nodes - INFO - No filtering from surface counts
kedro.runner.sequential_runner - INFO - Completed 17 out of 29 tasks
taxi_out.pipelines.data_engineering.nodes - INFO - 19.9% of departures were unimpeded in the AMA (because fraction of trajectory measurements with speed above threshold >= 0.9)
kedro.runner.sequential_runner - INFO - Completed 18 out of 29 tasks
taxi_out.pipelines.data_engineering.nodes - INFO - train group has 95045 instances
taxi_out.pipelines.data_engineering.nodes - INFO - test group has 23560 instances
```

MLFlow logging: identified missing gate data at KJFK



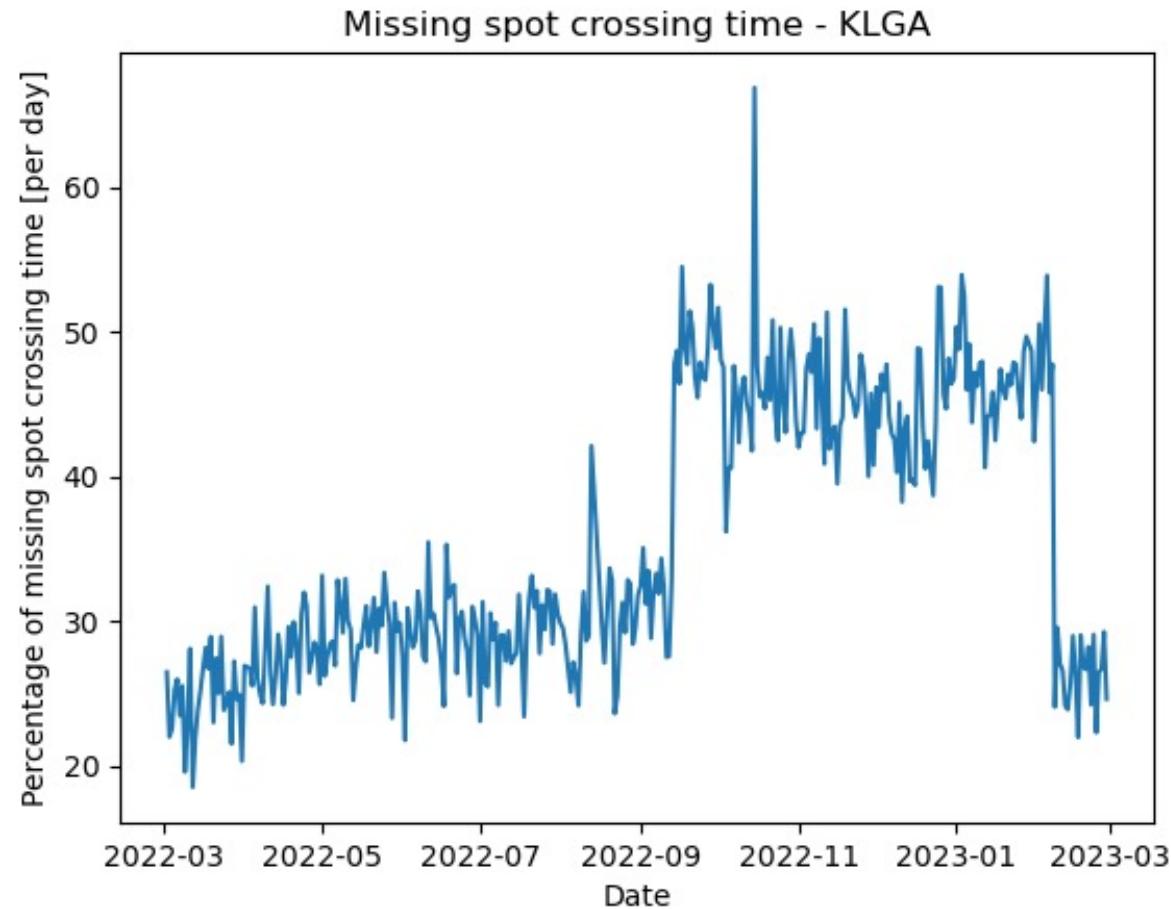
KJFK missing gate data spikes on particular days indicating technical issue



KLGA Unimpeded Taxi-Out Models

```
- taxi_out.pipelines.data_engineering.nodes - INFO - 99.5% of departures were selected in the date range
- kedro.runner.sequential_runner - INFO - Completed 10 out of 29 tasks
- kedro.runner.sequential_runner - INFO - Completed 11 out of 29 tasks
- taxi_out.pipelines.data_engineering.nodes - INFO - Kept 50.0% of flights when filtering to keep only departures
- kedro.runner.sequential_runner - INFO - Completed 12 out of 29 tasks
- taxi_out.pipelines.data_engineering.nodes - INFO - Kept 72.6% of departures when filtering to keep only departures with non-null departure stand
- taxi_out.pipelines.data_engineering.nodes - INFO - Kept 99.0% of departures when filtering to keep only departures with non-null departure runway
- kedro.runner.sequential_runner - INFO - Completed 13 out of 29 tasks
- taxi_out.pipelines.data_engineering.nodes - INFO - Kept 99.4% of departures when filtering to keep only departures with valid actual_departure_full_taxi_time taxi time
- taxi_out.pipelines.data_engineering.nodes - INFO - Kept 100.0% of departures when filtering to keep only departures with value within 0, 1 +-IQR/QUANTILE for actual_departure_full_taxi_time
- kedro.runner.sequential_runner - INFO - Completed 14 out of 29 tasks
- taxi_out.pipelines.data_engineering.nodes - INFO - Kept 63.0% of flights when filtering to keep only departures with non-nulls for all required actual times
- kedro.runner.sequential_runner - INFO - Completed 15 out of 29 tasks
- taxi_out.pipelines.data_engineering.nodes - INFO - Matched 100.0% of departures when joining fraction of taxi-out trajectory with speed greater than or equal to threshold
- kedro.runner.sequential_runner - INFO - Completed 16 out of 29 tasks
- taxi_out.pipelines.data_engineering.nodes - INFO - No filtering from surface counts
- kedro.runner.sequential_runner - INFO - Completed 17 out of 29 tasks
- taxi_out.pipelines.data_engineering.nodes - INFO - 20.7% of departures were unimpeded in the AMA (because fraction of trajectory measurements with speed above threshold >= 0.7)
- kedro.runner.sequential_runner - INFO - Completed 18 out of 29 tasks
```

MLFlow logging: identified missing actual spot crossing times at KLGA



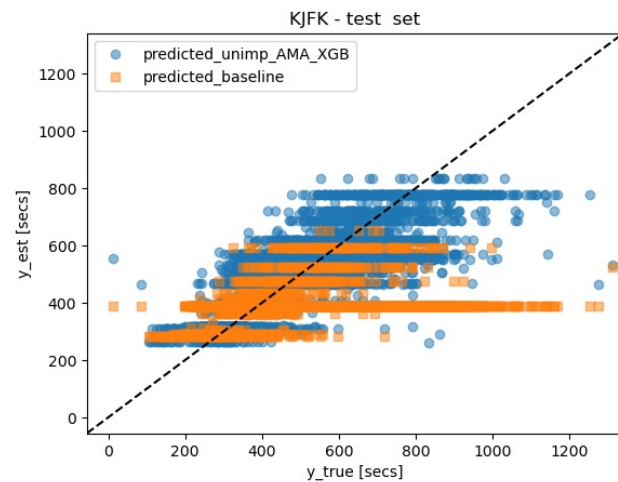
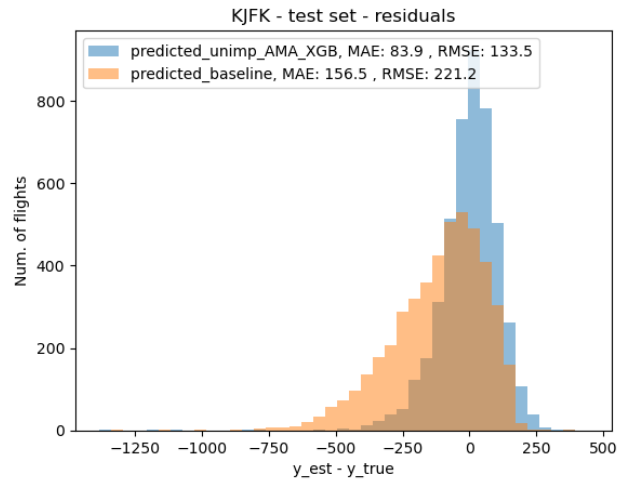
KLGA missing spot crossing times indicate technical issue between October 2022 and February 2023



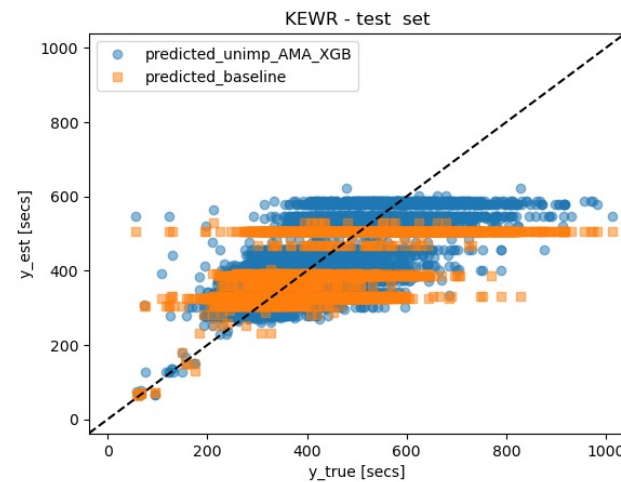
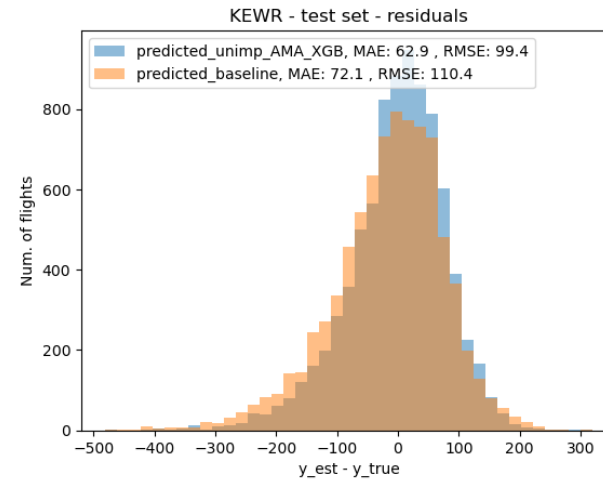
Unimpeded AMA Taxi Out Models



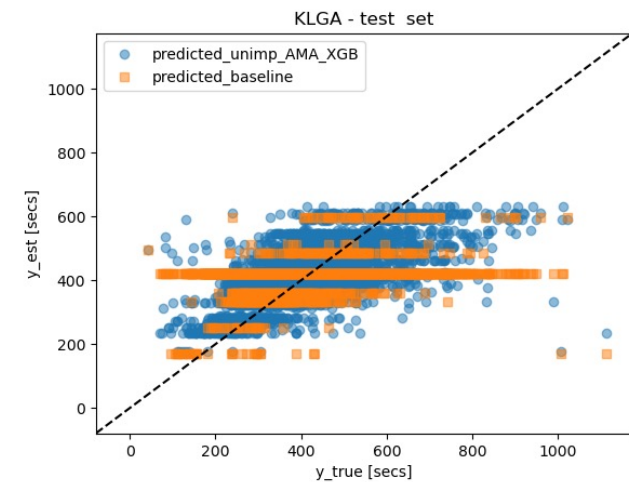
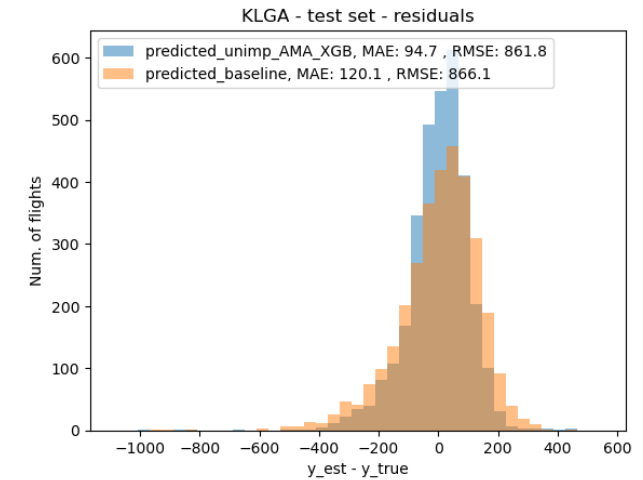
KJFK



KEWR



KLGA



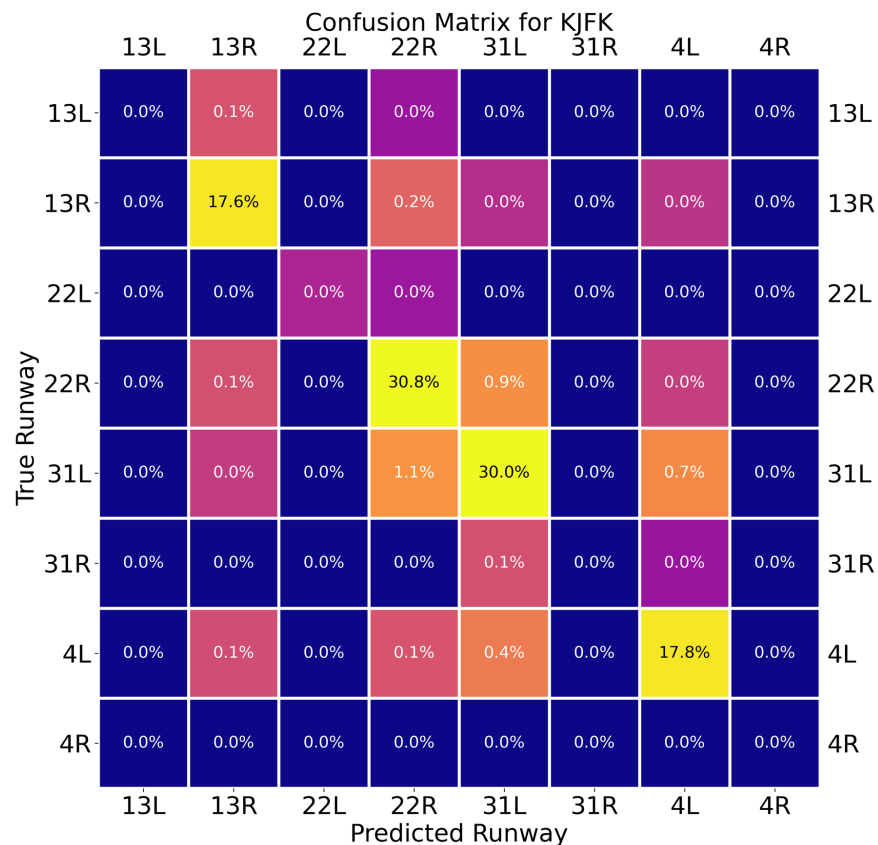
- “Truth” data collected by identifying aircraft which maintain AMA taxi above pre-defined threshold value
- ML models show improved performance compared to benchmark (average across terminal/runway group)



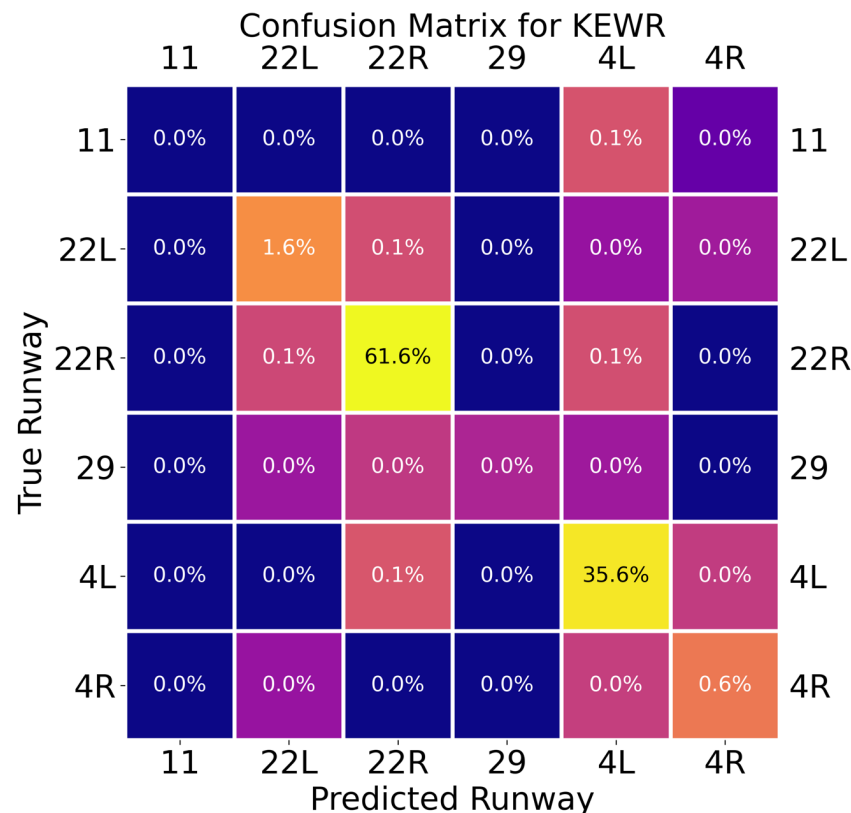
Departure Runway Models



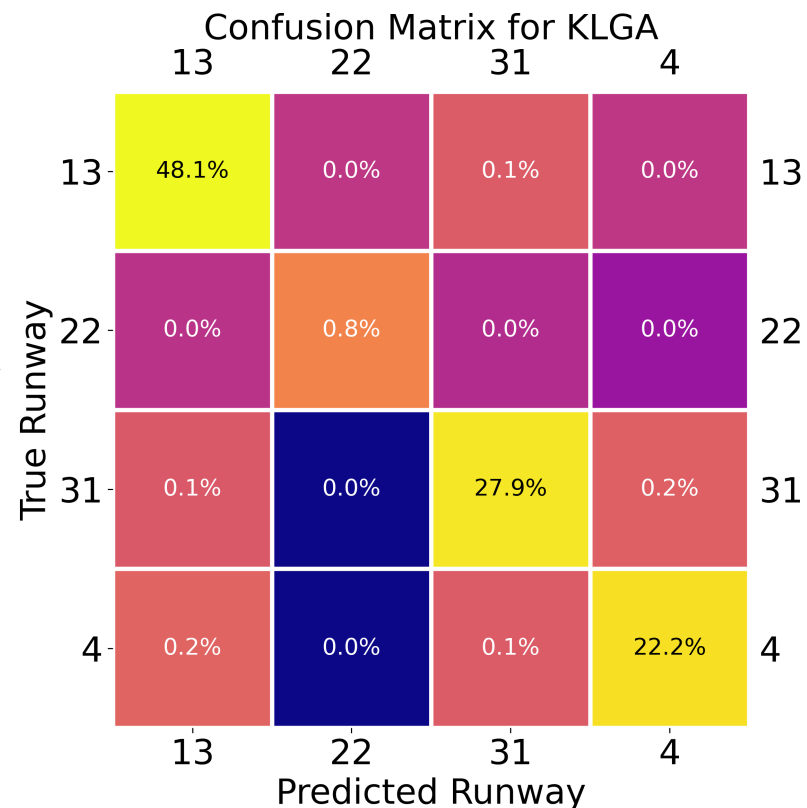
Accuracy ~ 96.2%



Accuracy ~ 99.4%



Accuracy ~ 99.1%



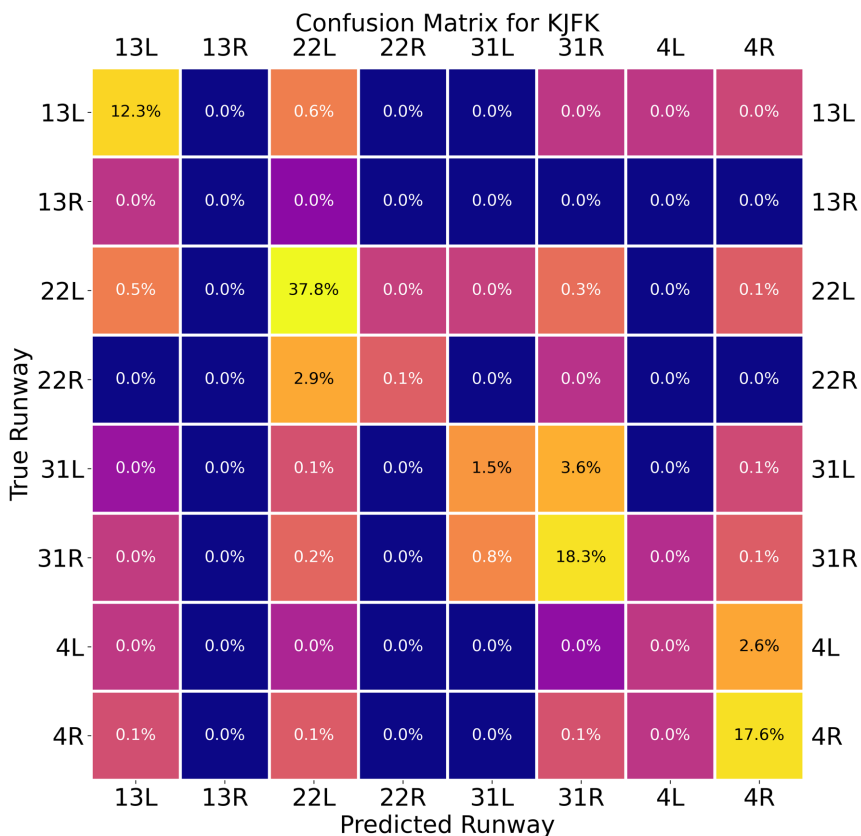
Departure runway prediction mostly determined by D-ATIS configuration



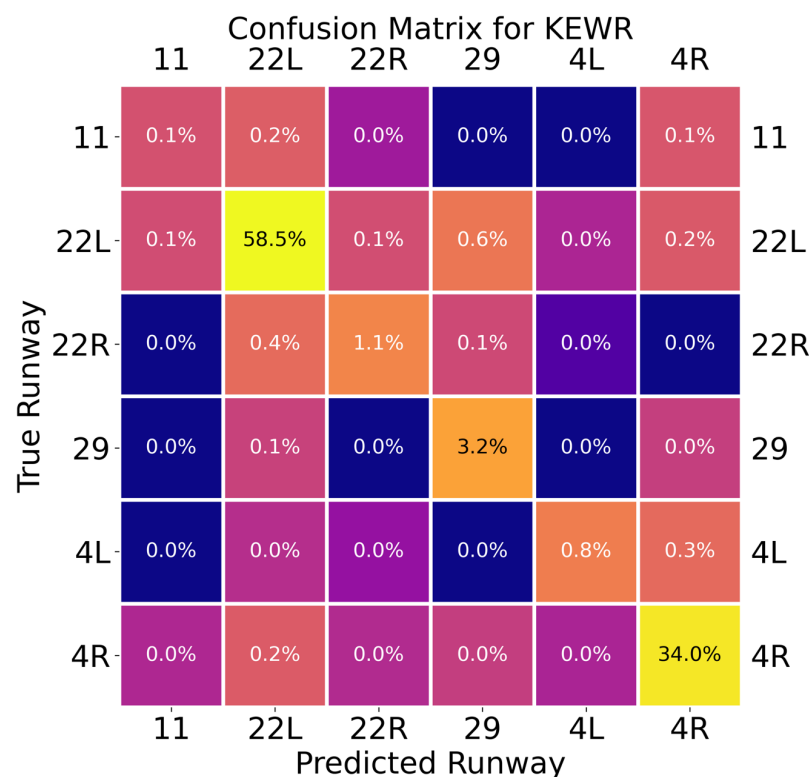
Arrival Runway Models



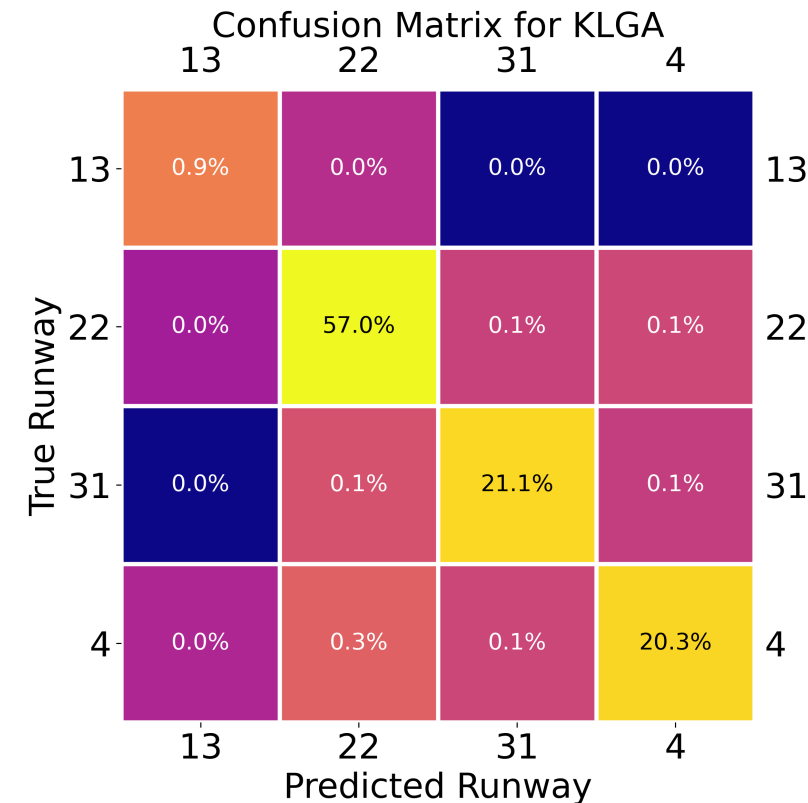
Accuracy ~ 87.6%



Accuracy ~ 97.6%

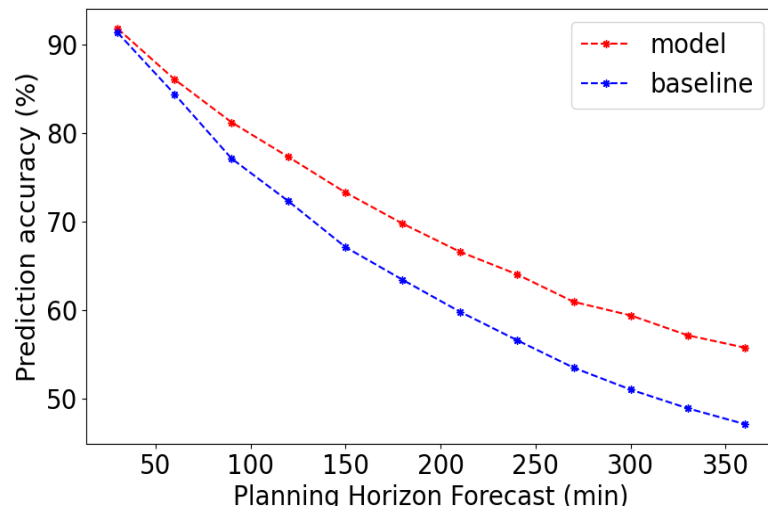


Accuracy ~ 99.3%



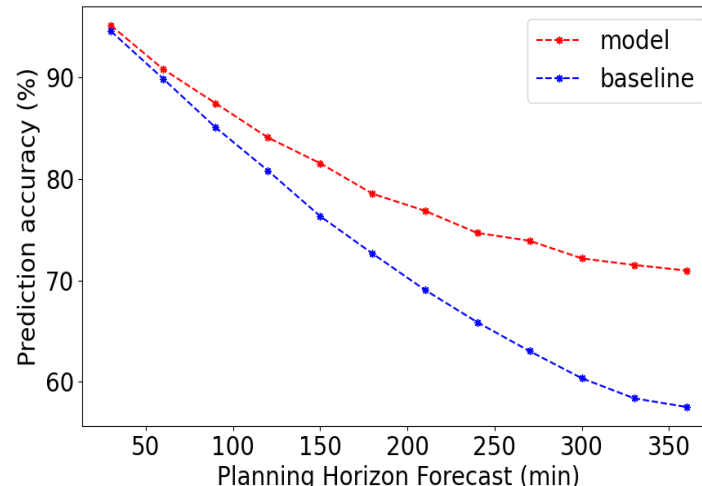
- Arrival runway prediction is mostly determined by D-ATIS configuration
- With departure/arrival runway determined by current configuration, the focus shifts to configuration prediction

KJFK



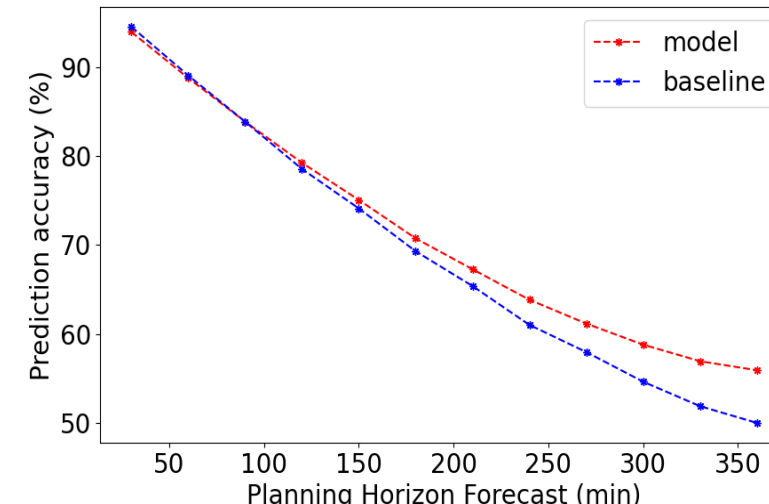
- INFO - Kept 96.88% of rows when removing configurations active less than 1 percent
- INFO - Kept 8 configurations from 37

KEWR



- INFO - Kept 99.70% of rows when removing configurations active less than 1 percent
- INFO - Kept 10 configurations from 20

KLGA

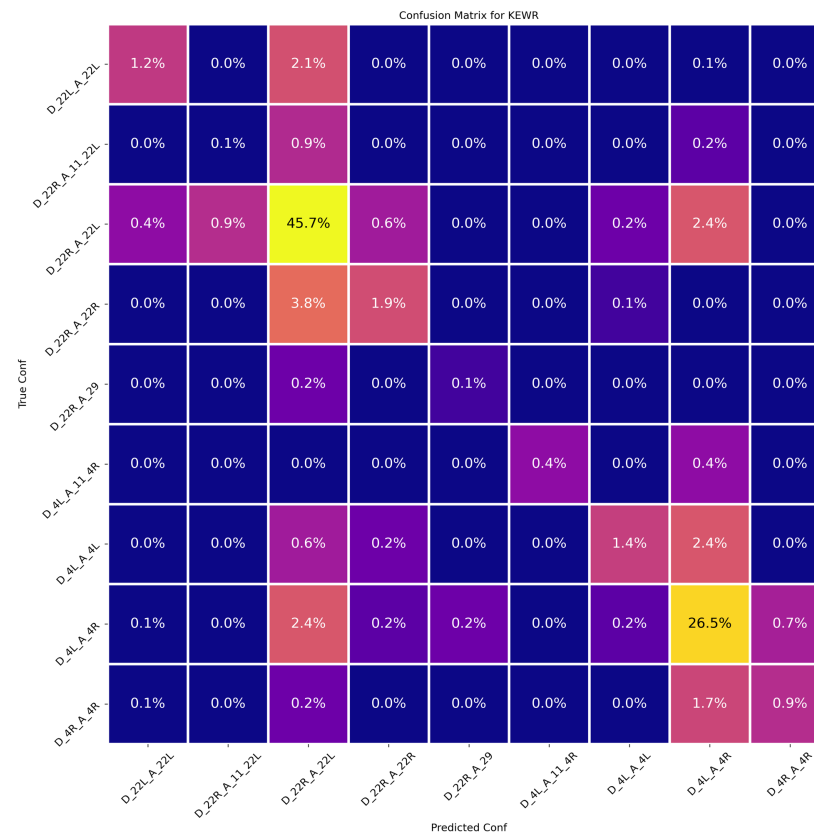
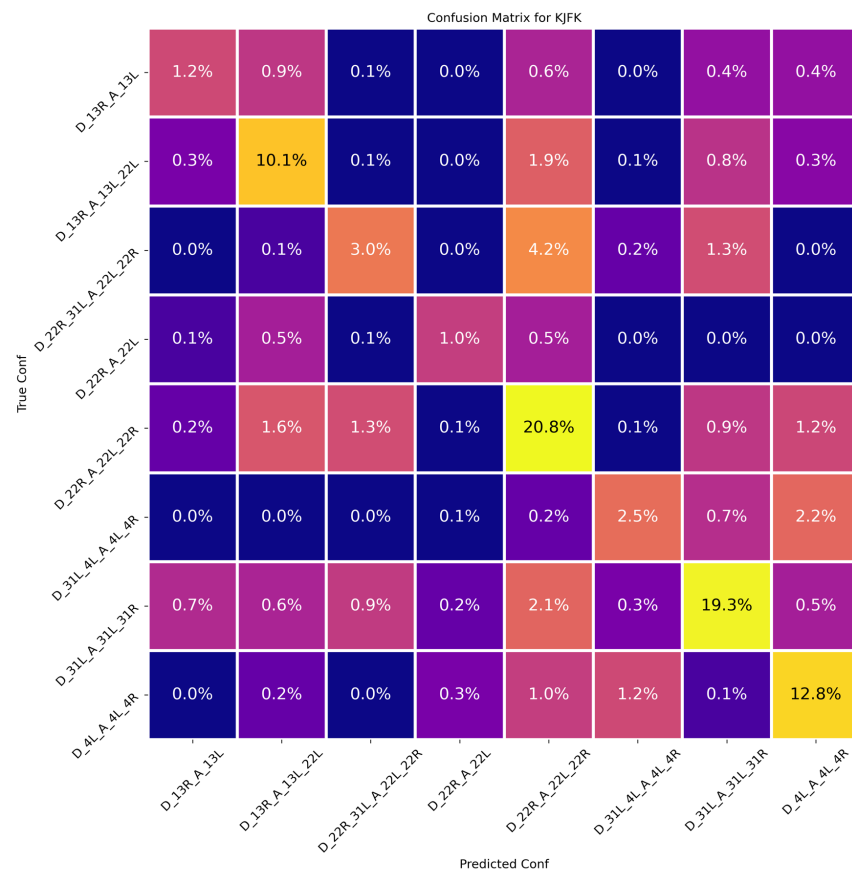


- INFO - Kept 99.32% of rows when removing configurations active less than 1 percent
- INFO - Kept 9 configurations from 14

Configuration prediction shows improvement over baseline (predict current config) but more research is needed to understand model performance

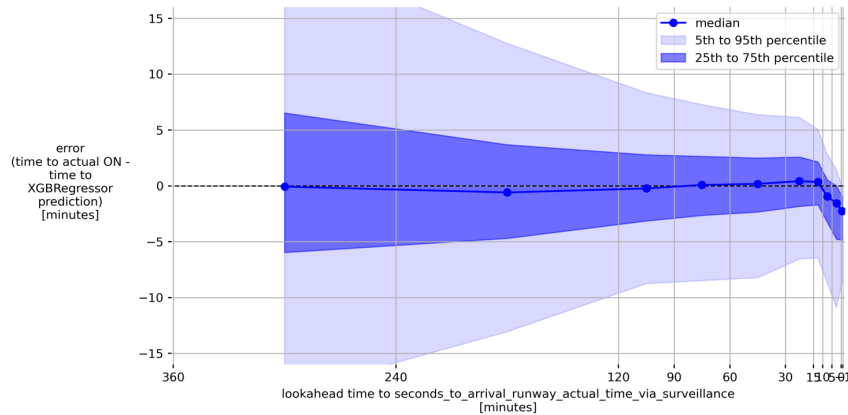


Config Prediction Accuracy at 3 Hour Lookahead

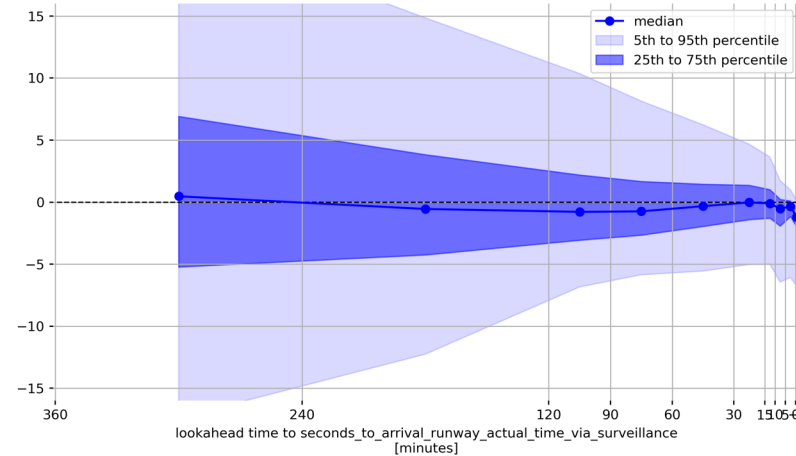


Predicted configuration values show diversity in predictions
(not just predicting the most dominant configuration)

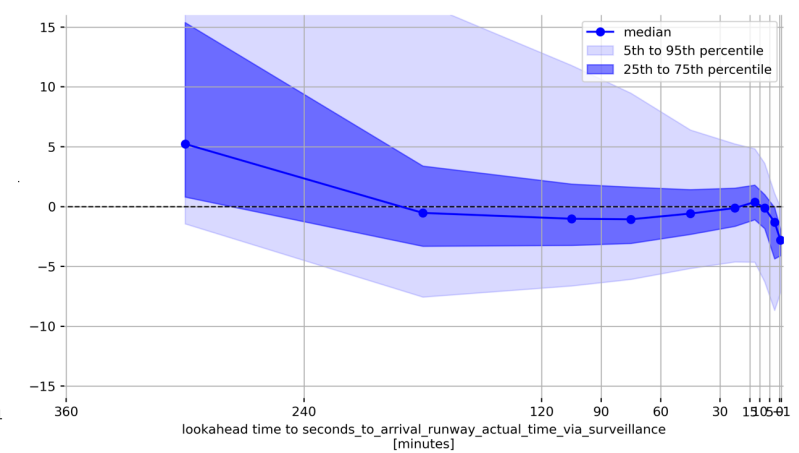
KJFK



KEWR



KLGA



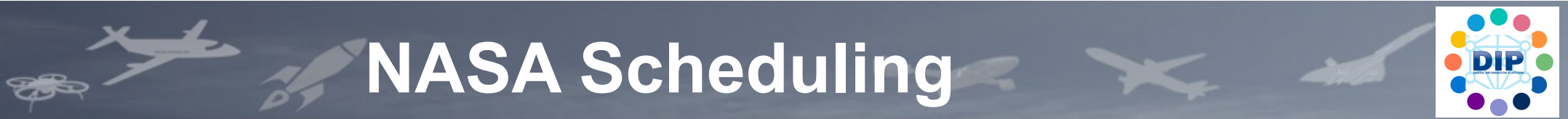
Actual ON prediction shows some bias as the flight approaches the ON event and requires additional investigation



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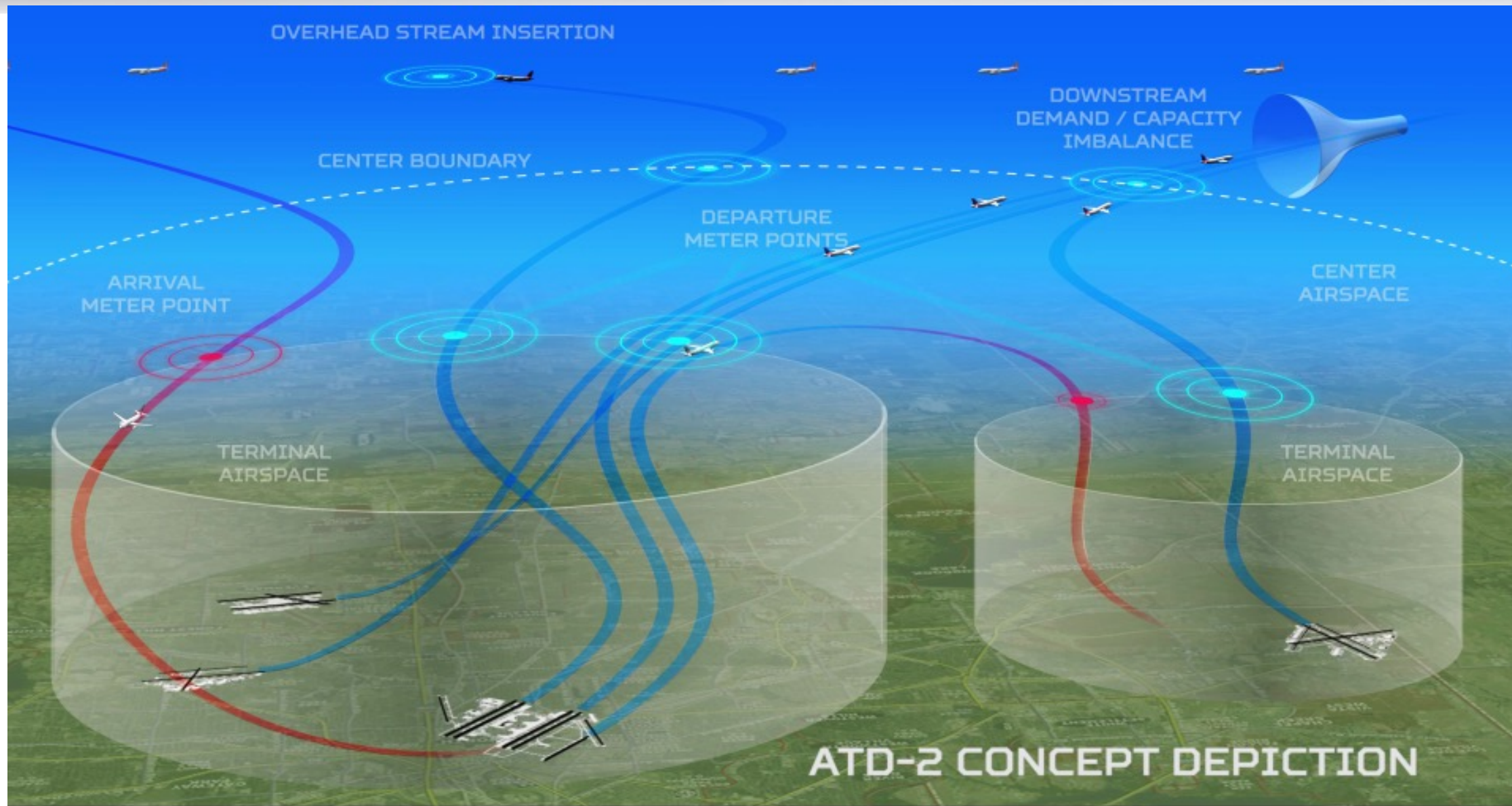


NASA Scheduling

- Center TRACON Automation System / Traffic Management Advisor* (CTAS/TMA/**TBFM**)
- Surface Management System (SMS)
- Final Approach Spacing Tool (FAST)
- Precision Departure Release Capability (PDRC)
- Spot and Runway Departure Advisor (SARDA)
- Terminal Sequencing and Scheduling* (TSAS)
- Integrated Arrival Departure Surface^ (IADS/**TFDM**)

* NASA software of the year

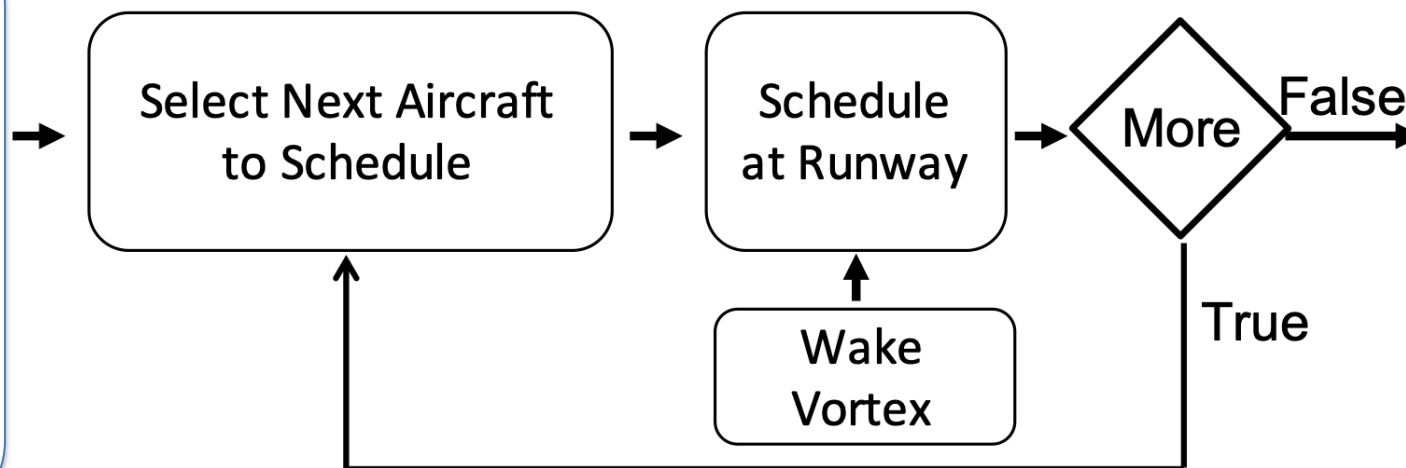
^ NASA first runner up software of the year



Scheduling Algorithm

ML Model Output

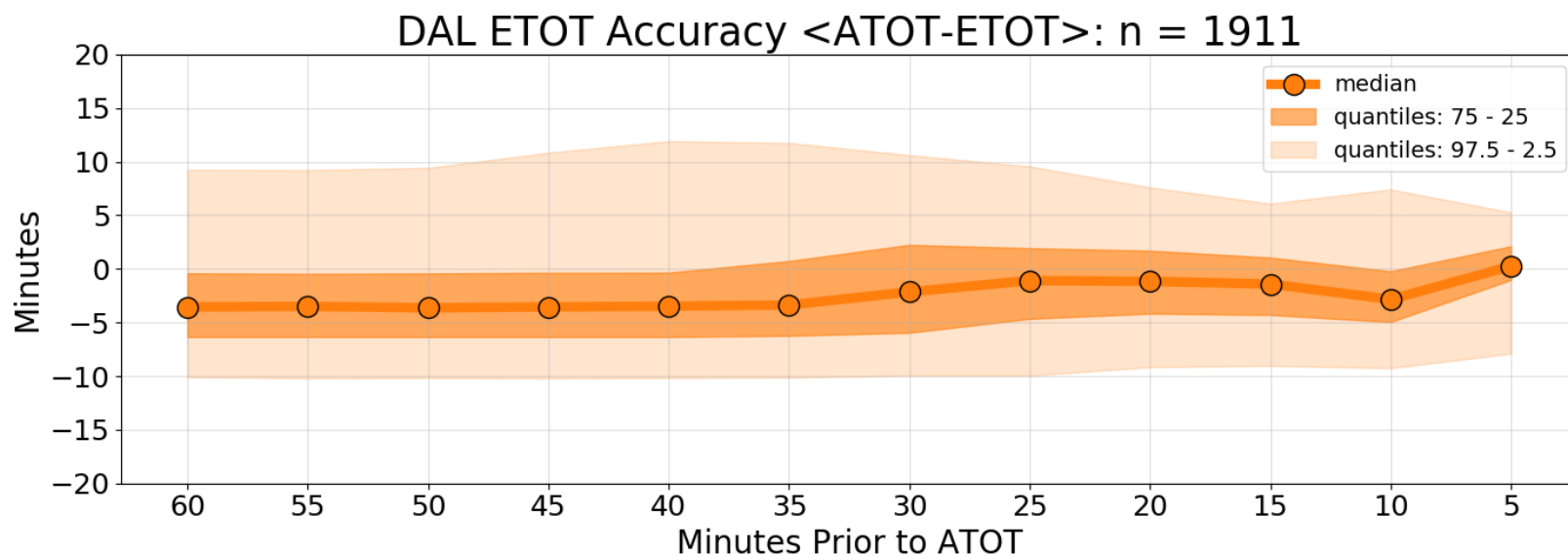
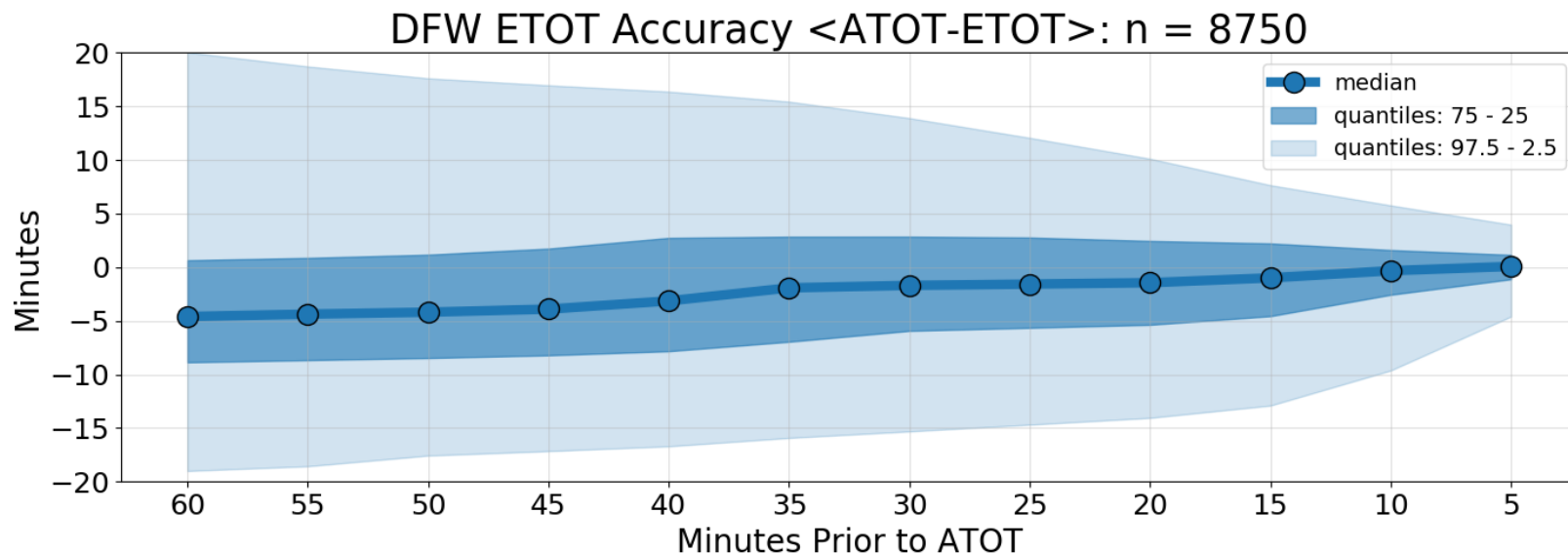
Predicted Runways
Predicted Unimpeded
Take Off Time (UTOT)
Predicted Landing
Time
Terminal Constraints
Scheduling Groups



Scheduler Output

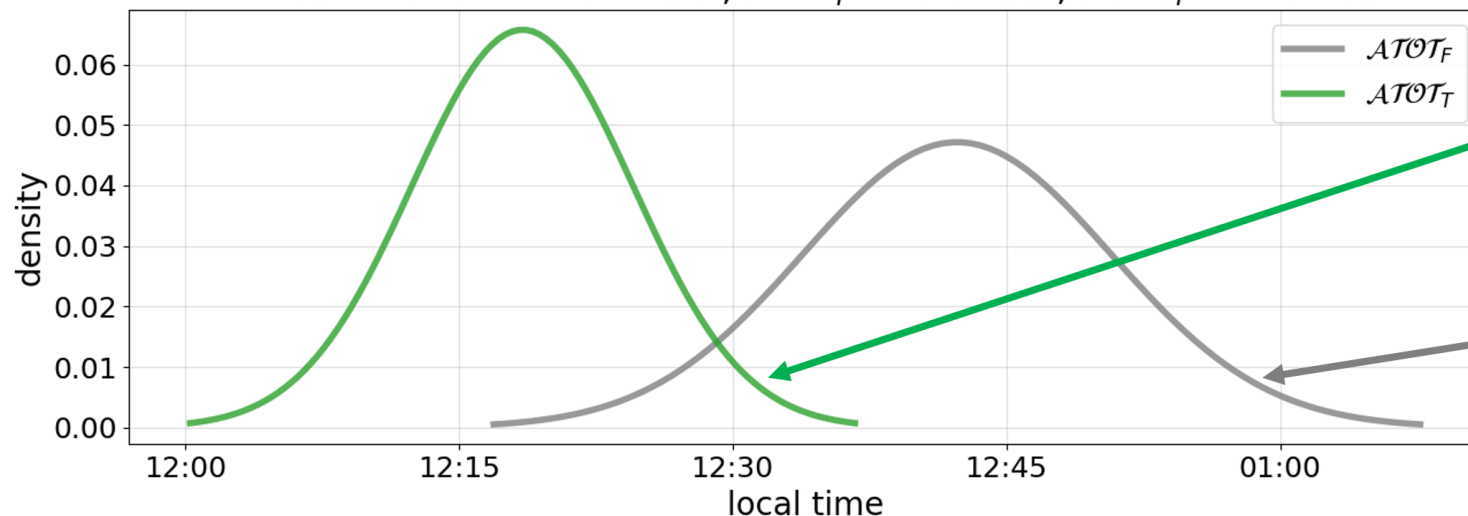
Estimated Take Off
Time (ETOT)
Target Landing Time

**Scheduler output provides prediction of OFF time and delay for departures accounting for:
combined demand + surface constraints + terminal constraints**



- Accuracy of Estimated Take Off Time (ETOT) is measured as a function of time prior to the Actual Take Off Time (ATOT)
- ETOT accuracy is stored in a lookup table and will be used to calculate the probability of delay savings on the TOS alternative routes

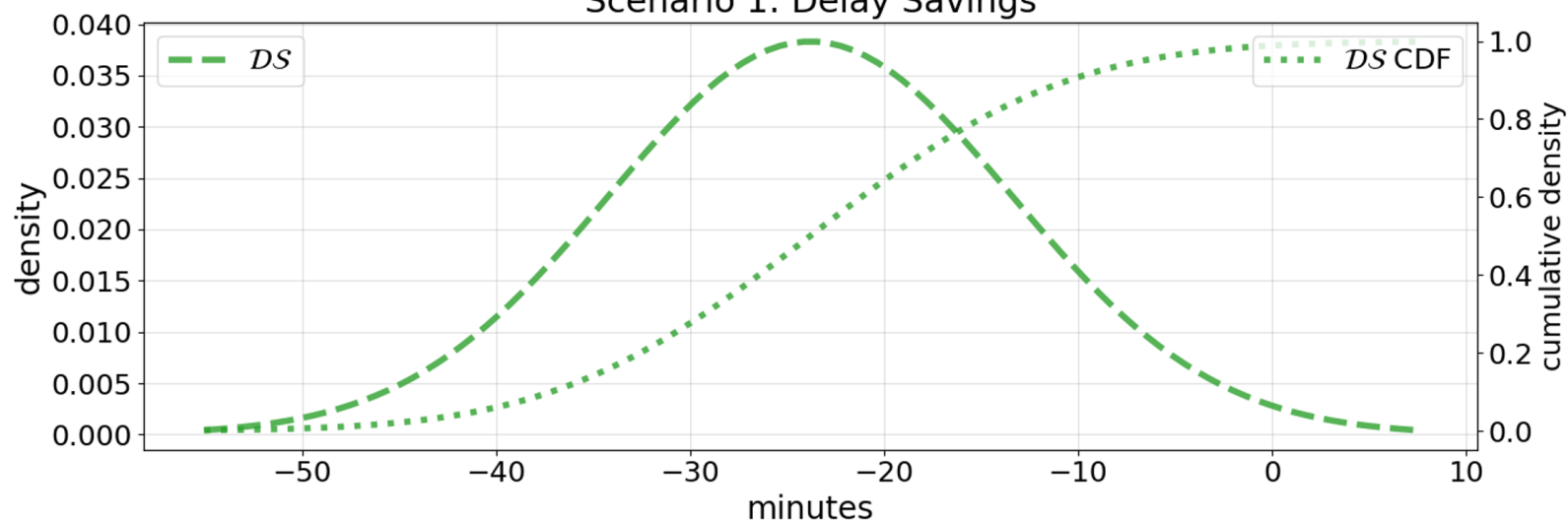
Scenario 1: Time = 12:00PM, $ETOT_F = 12:45PM$, $ETOT_T = 12:20PM$



$ATOT_T$: probability density function (pdf) representing the take off time on the TOS route

$ATOT_F$: probability density function (pdf) representing the take off time on the Filed route

Scenario 1: Delay Savings



Delay savings distribution:
 $DS = ATOT_T - ATOT_F$

Delay savings Cumulative Distribution Function (CDF)



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Performance Monitoring

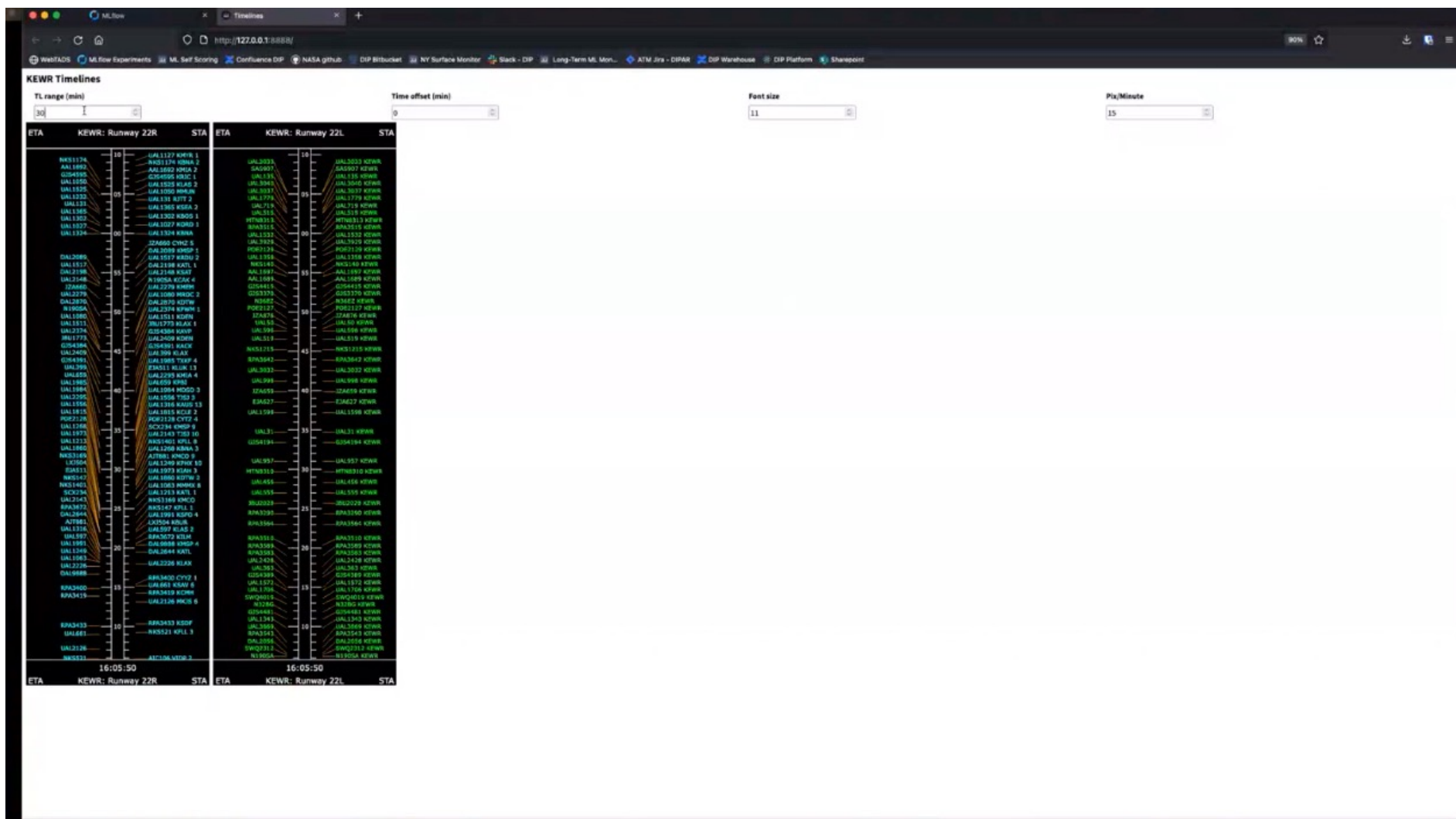


N90 Timeline Demo



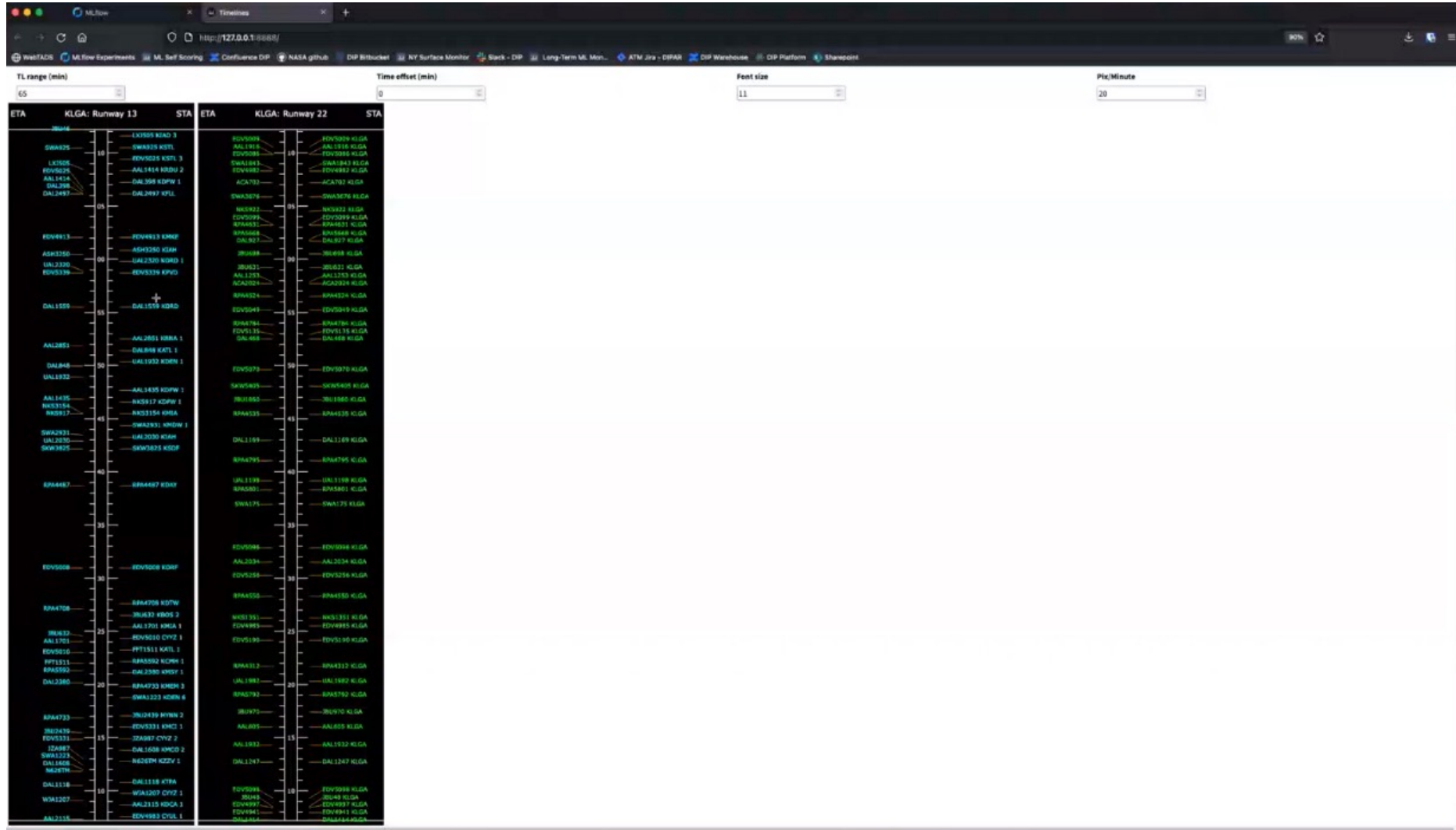


Timeline - KEWR





Timeline - KLGA

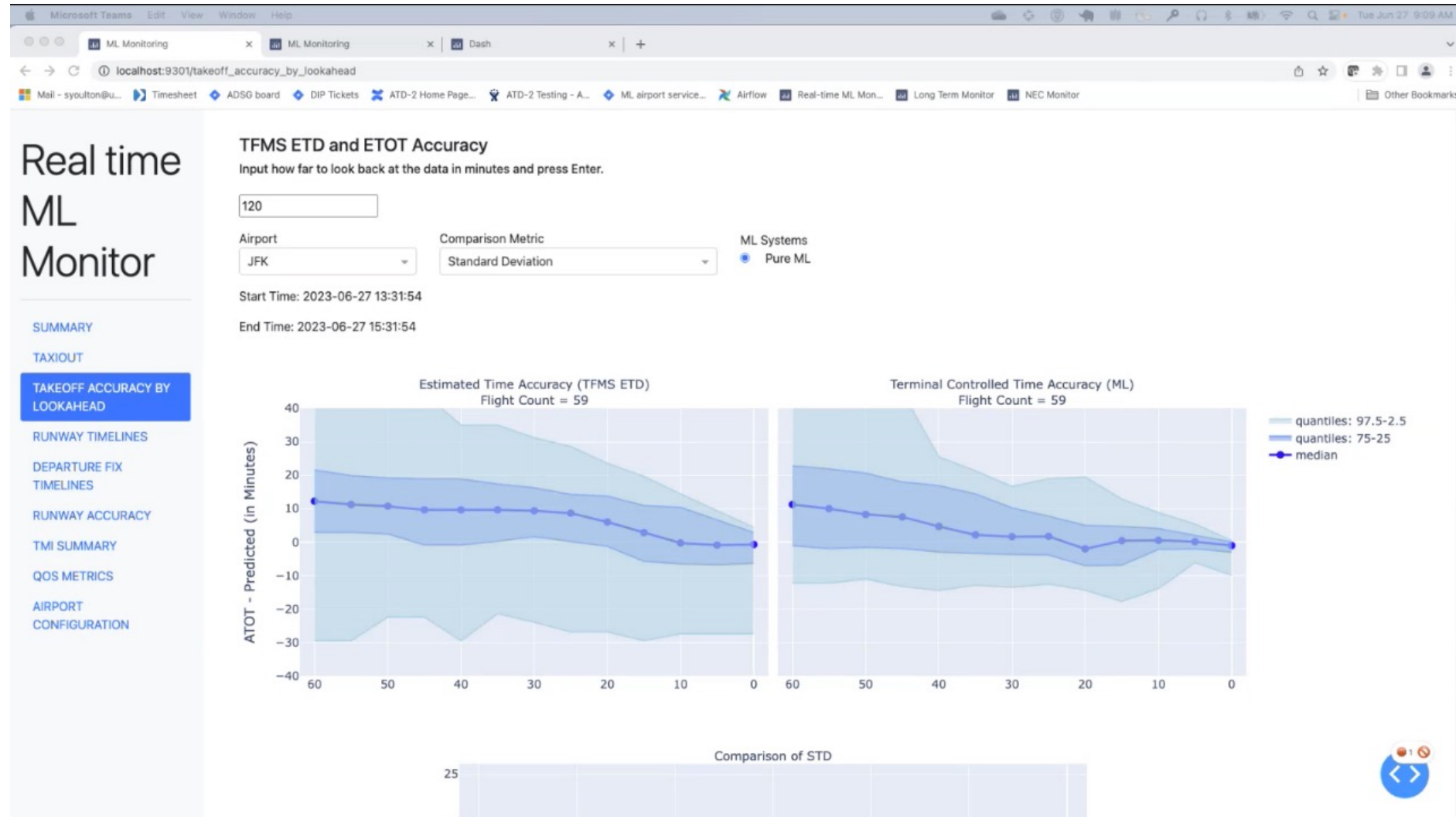




Real-time ML Monitor Demo

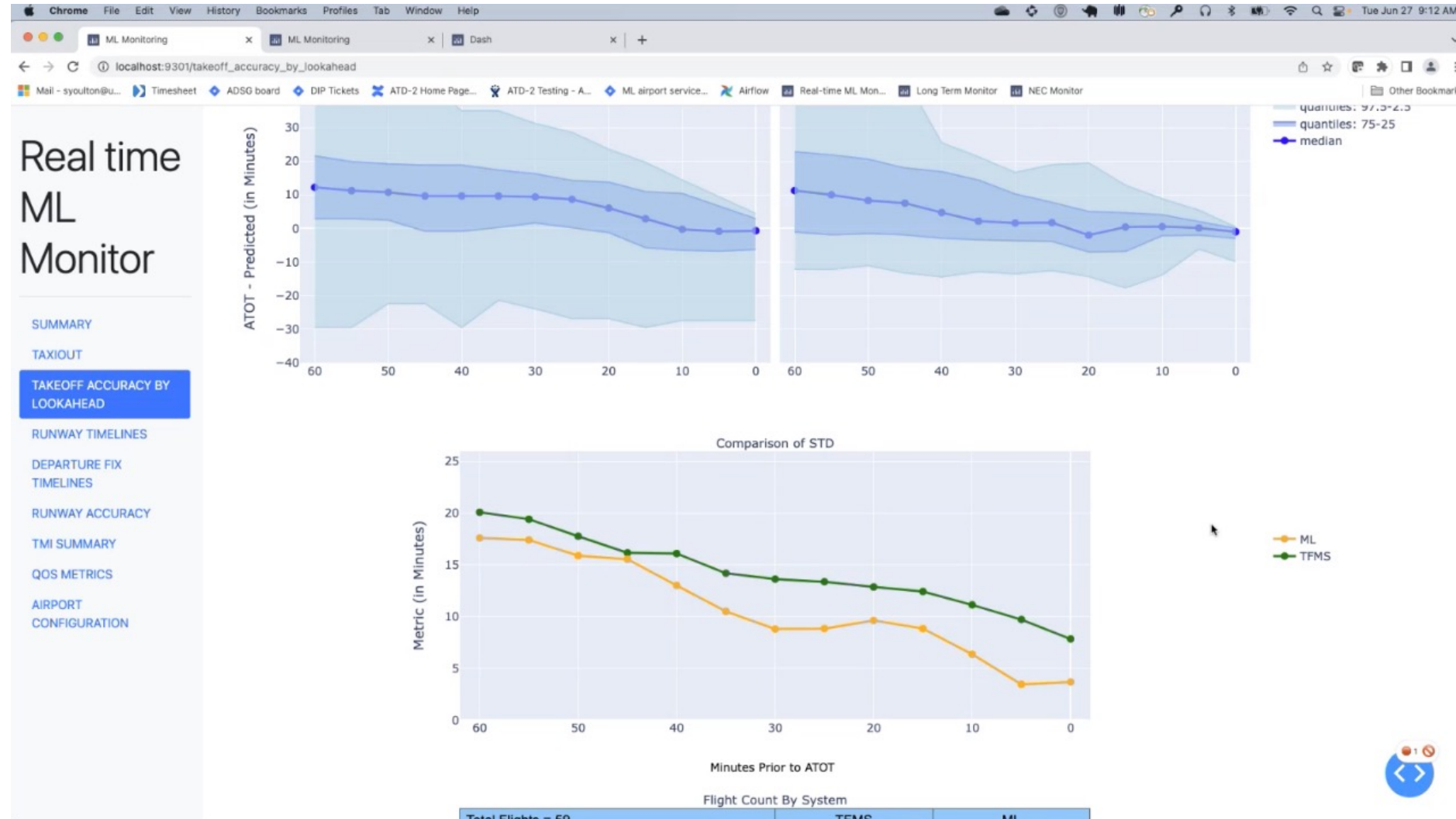


Real time ML Monitor – TFMS ETD and ETOT Accuracy





Real time ML Monitor – TFMS ETD and ETOT Accuracy





Real time ML Monitor – TMI Summary



Real time ML Monitor

- SUMMARY
- TAXIOUT
- TAKEOFF ACCURACY BY LOOKAHEAD
- RUNWAY TIMELINES
- DEPARTURE FIX TIMELINES
- RUNWAY ACCURACY
- TMI SUMMARY**
- QOS METRICS
- AIRPORT CONFIGURATION

DATA Configuration

Airport	Start Time	Configuration
KEWR	2023-06-27 10:19:00	D_22R_A_22L
KJFK	2023-06-26 13:55:00	D_22R_A_22L_22R
KLGA	2023-06-27 04:42:00	D_13_A_22

Summary of Restrictions

Restriction	Unique Flight Count (ML)	Multiple Restrictions (ML)
APREQ	11	0
EDCT	5	-
MIT	140	10
Fix Closure	0	0
Ground Stop	0	0
Ground Delay Program	0	0

APREQ

Flight Type	Resource	Type	Flight Count ML
Arrival	LGA	AIRPORT	10
Departure	DFW	AIRPORT	1

Fix Closure

Flight Type	Resource	Type	Flight Count ML
No CLOSURE			0



Real time ML Monitor – TMI Summary

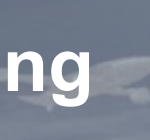


Real time ML Monitor

- SUMMARY
- TAXIOUT
- TAKEOFF ACCURACY BY LOOKAHEAD
- RUNWAY TIMELINES
- DEPARTURE FIX TIMELINES
- RUNWAY ACCURACY
- TMI SUMMARY**
- QOS METRICS
- AIRPORT CONFIGURATION

Arrival	LGA	AIRPORT	10	NO CLOSURE			0
Departure	DFW	AIRPORT	1				

Flight Type	Resource	Type	Miles	Minutes	Flight Count ML
Arrival	EWR	AIRPORT	25	0	17
Arrival	JFK	AIRPORT	25	0	28
Arrival	LGA	AIRPORT	25	0	24
Arrival	NOBBI	FIX	15	0	1
Arrival	VALRE	FIX	15	0	1
Departure	BIGGY	FIX	0	5	6
Departure	BIGGY	FIX	10	0	2
Departure	NEWEL	FIX	15	0	2
Departure	RBV	FIX	10	0	26
Departure	WAVEY	FIX	20	0	18
Departure	WHITE	FIX	0	5	12
Departure	WHITE	FIX	0	7	1
Departure	ZIMMZ	FIX	0	5	12

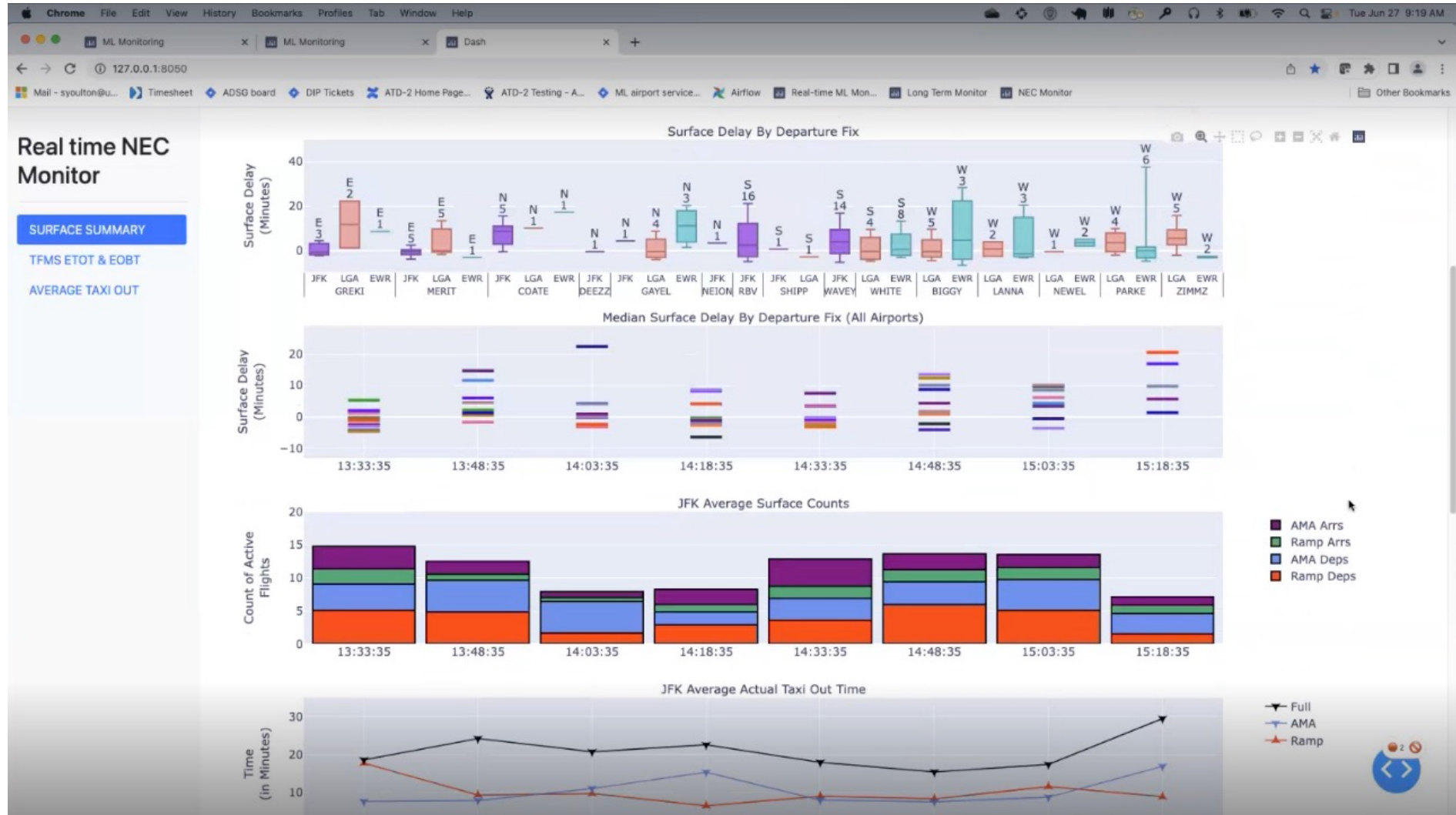


Surface Traffic Monitor Demo





Real time NEC Monitor





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Daily Data Digest

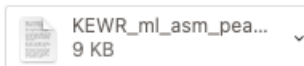


TEST DIP Daily Data Digest for EWR 2023-06-23



o alerts@clt-warehouse.ntx.org <alerts@clt-warehouse.ntx.org>

To: Lin, Melody I. (ARC-AFS)[SimLabs III Contract Management & Technical Services]; Cc: Coupe, William Jeremy (ARC-AFH); greg.juro@cavansolution



[Download All](#) • [Preview All](#)

Times are in local Eastern unless otherwise specified.

Off Peaks

Peak Start	All Flights	Major/regional	GA/BA/cargo
2023-06-23 01:00	6	6	0
2023-06-23 02:00	7	7	0
2023-06-23 03:00	10	10	0
2023-06-23 04:00	12	12	0
2023-06-23 05:00	6	6	0
2023-06-23 06:00	40	39	1
2023-06-23 07:00	53	52	1
2023-06-23 08:00	47	46	1
2023-06-23 09:00	53	53	0
2023-06-23 10:00	49	47	2

EOBT Provision & Accuracy

Group	Flights	Flights with EOBT @ AOBT	% with EOBT @ AOBT	Median num updates
	22	22	100.0%	3.5
	22	22	100.0%	3.5
	0	0	0.0%	
	361	361	100.0%	1
	25	24	96.0%	1
	22	22	100.0%	0.5
	48	7	14.6%	1

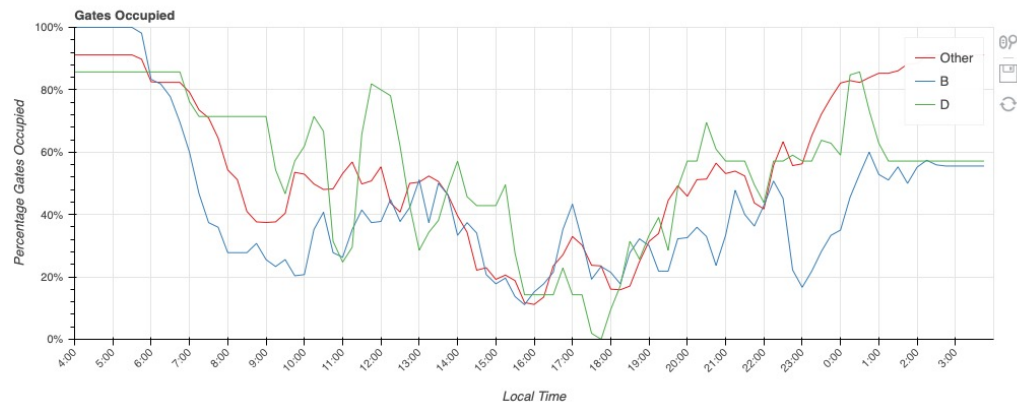
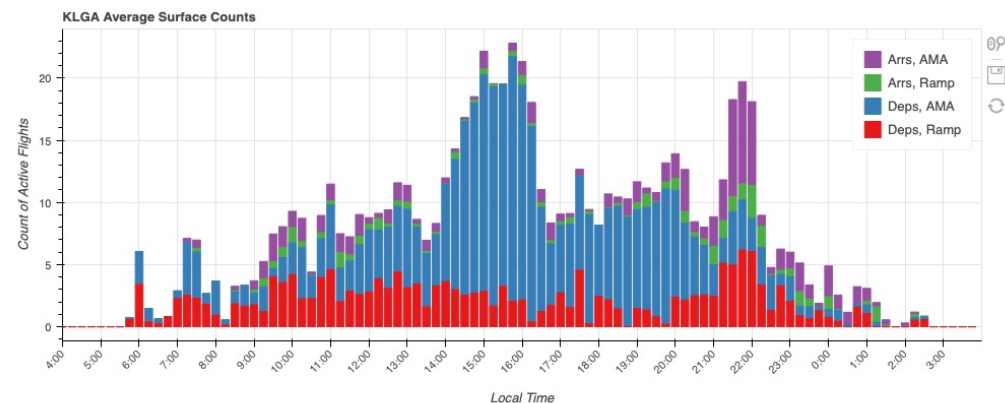
Daily Data Digest (DDD) provides email summary of daily operations



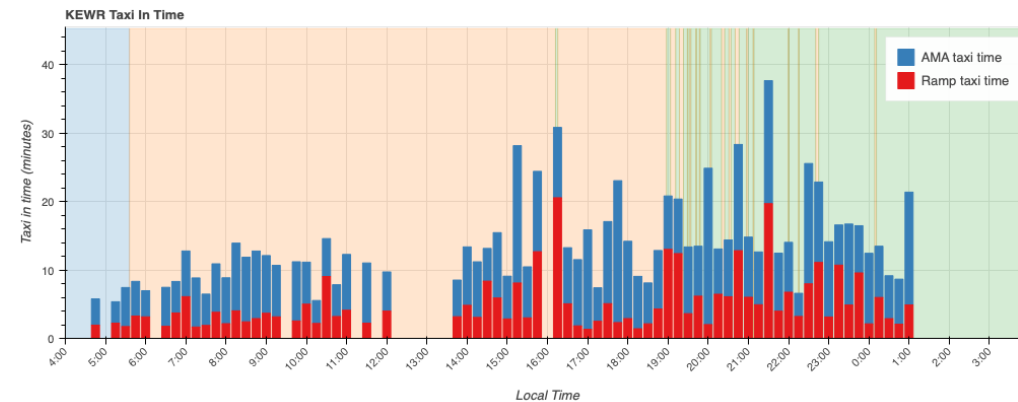
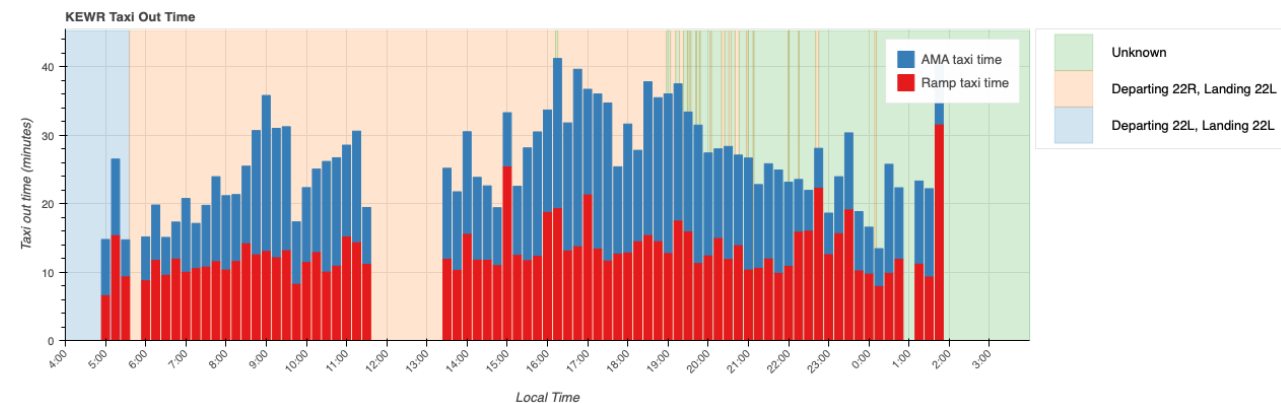
Daily Data Digest



KLGA Surface Counts



KEWR Taxi Time



DDD email summary includes analysis attachments



TMI Summary



TEST N90 TMI Summary for 2023-06-25



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Times are in local Eastern unless otherwise specified.

TMI Activity

Departure Fix Closures

Creation Time	Start Time	End Time	Actual End Time	End Reason	Duration	Fix	Gate	Alt Fix	Alt Gate	Requesting Facility	Facility	Reason/Impacting conditions	Source	Inclusions	Exclusions	Creating User
2023-06-25 13:20	2023-06-25 13:20	2023-06-25 16:00	2023-06-25 16:00	EXPIRED	02:40	PARKE	WEST			N90	EWR	WX:Thunderstorms	TFM			
2023-06-25 13:20	2023-06-25 13:20	2023-06-25 16:00	2023-06-25 16:00	EXPIRED	02:40	PARKE	WEST			N90	LGA	WX:Thunderstorms	TFM			
2023-06-25 19:38	2023-06-25 19:36	2023-06-25 20:30	2023-06-25 20:15	CANCELLED	00:39	GREKI	EAST			DCC	N90	WX:Thunderstorms	TFM	JETS		

Departure MIT/MINIT Restrictions

Creation Time	Start Time	End Time	Actual End Time	End Reason	Duration	Fix	Gate	Miles in Trail	Minutes in Trail	Requesting Facility	Facility	Reason/Impacting conditions	Source	Inclusions	Exclusions	Creating User
2023-06-25 10:25	2023-06-25 10:15	2023-06-25 13:30	2023-06-25 13:13	CANCELLED	02:58	BIGGY	WEST	0	5	N90	EWR	VOL:RERTES	OIS		MET	
2023-06-25 11:05	2023-06-25 10:15	2023-06-25 13:30	2023-06-25 13:13	CANCELLED	02:58	BIGGY	WEST	0	5	N90	LGA	VOL:RERTES	TFM			
2023-06-25 09:43	2023-06-25 10:15	2023-06-25 13:30	2023-06-25 13:11	CANCELLED	02:56	BIGGY	WEST	10		ZNY	N90	VOL:Volume	TFM			
2023-06-25 11:05	2023-06-25 11:00	2023-06-25 13:30	2023-06-25 13:13	CANCELLED	02:13	LANNA	WEST	0	5	N90	EWR	VOL:RERTES	TFM			
2023-06-25 11:05	2023-06-25 11:00	2023-06-25 13:30	2023-06-25 13:13	CANCELLED	02:13	LANNA	WEST	0	5	N90	LGA	VOL:RERTES	TFM			
2023-06-25 10:59	2023-06-25 11:00	2023-06-25 13:30	2023-06-25 13:11	CANCELLED	02:11	LANNA	WEST	10		ZNY	N90	VOL:RERTES	TFM			
2023-06-25 11:09	2023-06-25 11:30	2023-06-25 14:00	2023-06-25 12:50	CANCELLED	01:20	WHITE	SOUTH	0	8	N90	EWR	WX:Thunderstorms	TFM			
2023-06-25 11:09	2023-06-25 11:30	2023-06-25 14:00	2023-06-25 12:50	CANCELLED	01:20	WHITE	SOUTH	0	8	N90	LGA	WX:Thunderstorms	TFM			
2023-06-25 11:07	2023-06-25 11:30	2023-06-25 14:00	2023-06-25 12:50	CANCELLED	01:20	WHITE	SOUTH	20		DCC	N90	WX:Thunderstorms	TFM			
2023-06-25 13:21	2023-06-25 13:15	2023-06-25 18:00	2023-06-25 18:00	EXPIRED	04:45	ZIMMZ	WEST	0	7	N90	EWR	WX:Thunderstorms	TFM			
2023-06-25 13:21	2023-06-25 13:15	2023-06-25 18:00	2023-06-25 18:00	EXPIRED	04:45	ZIMMZ	WEST	8	9	N90	HPN	WX:Thunderstorms	TFM			
2023-06-25 13:21	2023-06-25 13:15	2023-06-25 18:00	2023-06-25 18:00	EXPIRED	04:45	ZIMMZ	WEST	5	7	N90	LGA	WX:Thunderstorms	TFM			

Email summary of restrictions in airspace (potential to expose as API)



TMI Summary



Arrival Fix Closures

Creation Time	Start Time	End Time	Actual End Time	End Reason	Duration	Fix	Cornerpost	Requesting Facility	Facility	Reason/Impacting conditions	Source	Inclusions	Exclusions
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Arrival MIT/MINIT Restrictions

Creation Time	Start Time	End Time	Actual End Time	End Reason	Duration	Fix	Cornerpost	Miles in Trail	Minutes in Trail	Requesting Facility	Facility	Reason/Impacting conditions	Source	Inclusions	Exclusions
2023-06-25 07:00	2023-06-25 06:00		2023-06-25 07:00	CANCELLED	01:00	CAMRN		10		N90	ZNY	VOL:Compacted Demand			
2023-06-25 07:00	2023-06-25 06:00		2023-06-25 07:00	CANCELLED	01:00	LENDY		10		N90	ZNY	VOL:Compacted Demand			
2023-06-25 10:05	2023-06-25 11:00	2023-06-25 12:00	2023-06-25 12:00	EXPIRED	01:00	LIZZI		15		DCC	ZNY	VOL:Arrival Demand	TFM		
2023-06-25 11:14	2023-06-25 12:00	2023-06-25 22:00	2023-06-25 22:00	EXPIRED	10:00	CAMRN		10		N90	ZNY	VOL:Compacted Demand	TFM		
2023-06-25 11:14	2023-06-25 12:00	2023-06-25 22:00	2023-06-25 22:00	EXPIRED	10:00	LENDY		10		N90	ZNY	VOL:Compacted Demand	TFM		
2023-06-25 11:16	2023-06-25 12:00	2023-06-25 22:00	2023-06-25 22:00	EXPIRED	10:00	OWENZ		15		DCC	ZNY	VOL:Compacted Demand	TFM		

Contains both departure and arrival TMI restrictions



Flight Summary

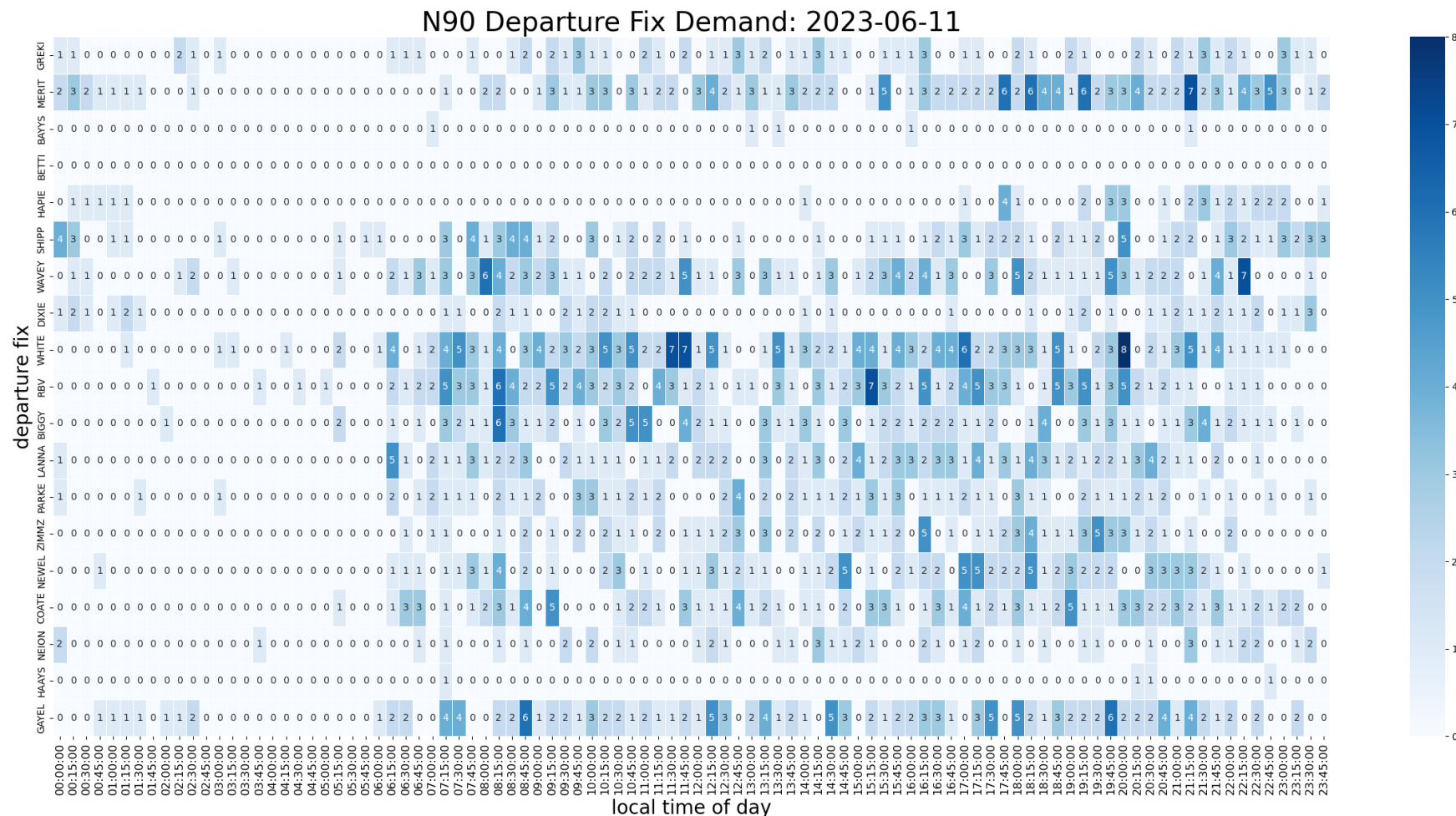


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	acid	gufi	isArrival	isDepartu	departure	arrival_a	departure	arrival_st	aircraft_a	aircraft_e	aircraft_r	aircraft_t	wake_tur	altitude	beacon_c	cancelled	cancelled	carrier	departure_s	departure_r	departure_r	departure_f	departure_s	departure_s
2	ELY001	ELY1.TLV.JFK	TRUE	FALSE	LLBG	KJFK			7569605	JET		B789	B	12000	7304			ELY					6/24/23 22:00	
3	DAL157	DAL157.ACC.	TRUE	FALSE	DGAA	KJFK			10548300	JET	N1602	B763	C	32000	7276			DAL	6/24/23 22:06				6/24/23 22:10	
4	JBU679	JBU679.JFK.I	FALSE	TRUE	KJFK	KMKE			10701176	JET	N3102J	BCS3	D	14000	6642			JBU	6/25/23 18:24	6/25/23 18:35	6/25/23 19:13	6/25/23 19:23	6/25/23 18:30	6/25/23 18:
5	MSR986	MSR986.JFK.	FALSE	TRUE	KJFK	HECA			65876	JET	65876	B77W	B	31000	2641			MSR	6/25/23 16:26	6/25/23 16:40	6/25/23 16:40	6/25/23 16:50	6/25/23 16:00	6/25/23 16:
6	JBU780	JBU780.MBJ	TRUE	FALSE	MKJS	KJFK			10594990	JET	N2060J	A21N	D	9000	6766			JBU	6/26/23 1:14				6/25/23 17:00	
7	DAL669	DAL669.JFK.I	FALSE	TRUE	KJFK	KLAS			10910664	JET	N517DN	A21N	D	10000	1511			DAL	6/25/23 21:13	6/25/23 21:54	6/25/23 22:31	6/25/23 22:40	6/25/23 21:10	6/25/23 21:
8	JBU137	JBU137.JFK.S	FALSE	TRUE	KJFK	MDST			10593228	JET	N2044J	A21N	D	15000	3062			JBU	6/25/23 10:46	6/25/23 10:57	6/25/23 11:07	6/25/23 11:15	6/25/23 10:17	6/25/23 10:
9	AAL1077	AAL1077.SFO	TRUE	FALSE	KSFO	KJFK			10492032	JET	N105NN	A321	D	19000	1615			AAL	6/25/23 20:30	6/25/23 20:44	6/25/23 20:51		6/25/23 20:35	6/25/23 20:
10	DAL528	DAL528.SEA.	TRUE	FALSE	KSEA	KJFK			11226859	JET	N828DN	B739	D	20000	1677			DAL	6/25/23 22:53	6/25/23 23:08	6/25/23 23:08		6/25/23 22:55	6/25/23 22:
11	EDV5424	EDV5424.JFK	FALSE	TRUE	KJFK	KCLE			10563787	JET	N176PQ	CRJ9	E	10000	1537			EDV	6/25/23 14:16	6/25/23 14:23	6/25/23 14:31	6/25/23 14:42	6/25/23 13:20	6/25/23 13:
12	DAL2861	DAL2861.JFK	FALSE	TRUE	KJFK	KBOS			10490862	JET	N104DU	BCS1	D	11000	3050			DAL	6/26/23 2:48	6/26/23 2:57	6/26/23 3:09	6/26/23 3:20	6/26/23 0:55	6/26/23 2:
13	CAL012	CAL12.TPE.JF	TRUE	FALSE	RCTP	KJFK			9015329	JET		B77W	B	20000	1713			CAL					6/25/23 9:30	
14	SKW3975	SKW3975.OF	TRUE	FALSE	KORD	KJFK			10644408	JET	N255SY	E75L	E	19000	6273			SKW	6/25/23 12:01	6/25/23 12:07	6/25/23 12:15		6/25/23 11:59	6/25/23 11:
15	JBU1105	JBU1105.JFK	FALSE	TRUE	KJFK	KORD			10718418	JET	N328JB	E190	D	32000	3355			JBU	6/25/23 12:44	6/25/23 12:50	6/25/23 12:59	6/25/23 13:15	6/25/23 11:30	6/25/23 11:
16	ASA42	ASA42.SFO.J	TRUE	FALSE	KSFO	KJFK			11367985	JET	N967AK	B39M	D	11000	3306			ASA		6/25/23 6:17	6/25/23 6:37		6/25/23 6:15	6/25/23 6:
17	RPA4306	RPA4306.INC	TRUE	FALSE	KIND	KJFK			10795522	JET	N403YX	E75S	E	6000	3744			RPA	6/25/23 16:31				6/25/23 16:36	6/25/23 16:
18	JBU161	JBU161.JFK.S	FALSE	TRUE	KJFK	KSMF			10592452	JET	N2039J	A21N	D	30000	1020			JBU	6/25/23 22:20	6/25/23 22:29	6/25/23 22:49	6/25/23 23:12	6/25/23 22:26	6/25/23 22:
19	AAL1524	AAL1524.MIA	TRUE	FALSE	KMIA	KJFK			11297861	JET	N898NN	B738	D	11000	6660			AAL	6/26/23 3:06	6/26/23 3:13	6/26/23 3:23		6/25/23 22:24	6/26/23 3:
20	DAL707	DAL707.PHX.	TRUE	FALSE	KPHX	KJFK			11251486	JET	N852DN	B739	D	11000	4121			DAL	6/25/23 19:24		6/25/23 20:14		6/25/23 17:30	6/25/23 20:
21	AAL198	AAL198.JFK.I	FALSE	TRUE	KJFK	LIMC			11175628	JET	N778AN	B772	B	35000	4025			AAL	6/25/23 23:20	6/25/23 23:26	6/25/23 23:44	6/25/23 23:53	6/25/23 22:15	6/25/23 22:
22	DAL429	DAL429.JFK.I	FALSE	TRUE	KJFK	KLAX			10558780	JET	N171DN	B763	C	36000	1031			DAL	6/26/23 2:36	6/26/23 3:00	6/26/23 3:05	6/26/23 3:13	6/25/23 23:05	6/26/23 1:
23	DAL451	DAL451.DFW	TRUE	FALSE	KDFW	KJFK			10490862	JET	N104DU	BCS1	D	11000	2311			DAL	6/25/23 12:15	6/25/23 12:23	6/25/23 12:33		6/25/23 12:15	6/25/23 12:
24	DAL446	DAL446.JFK.I	FALSE	TRUE	KJFK	KLAS			10914110	JET	N520DE	A21N	D	10000	1152			DAL	6/26/23 1:57		6/26/23 2:21	6/26/23 2:31	6/26/23 1:10	6/26/23 1:
25	DAL861	DAL861.JFK.S	FALSE	TRUE	KJFK	KSFO			11101559	JET	N704X	B752	D	11000	1532			DAL	6/25/23 19:53	6/25/23 20:03	6/25/23 20:12	6/25/23 20:31	6/25/23 19:59	6/25/23 19:
26	DAL613	DAL613.JFK.A	FALSE	TRUE	KJFK	TNCA			11219251	JET	N820DN	B739	D	33000	2706			DAL	6/25/23 12:08		6/25/23 12:31	6/25/23 12:39	6/25/23 12:10	6/25/23 12:
27	DAL226	DAL226.GRU	TRUE	FALSE	SBGR	KJFK			11231459	JET	N832MH	B764	C	26000	6607			DAL	6/25/23 0:14				6/25/23 0:15	6/25/23 0:
28	AAR221	AAR221.JFK.	FALSE	TRUE	KJFK	RKSI			7455617	JET		A359	B	40000	1157			AAR		6/25/23 17:25	6/25/23 17:40	6/25/23 17:59	6/25/23 16:55	6/25/23 16:
29	DAL208	DAL208.JFK.I	FALSE	TRUE	KJFK	EGPH			10583757	JET	N196DN	B763	C	33000	2620			DAL	6/26/23 2:01	6/26/23 2:10	6/26/23 2:34	6/26/23 2:45	6/26/23 2:05	6/26/23 2:
30	CJT1246	CJT1246.JFK.	FALSE	TRUE	KJFK	CYHM			12593270	JET		B763	C	30000	3375			CJT		6/26/23 5:59	6/26/23 6:19	6/26/23 6:33	6/26/23 5:00	6/26/23 5:
31	RAM201N	RAM201.JFK	FALSE	TRUE	KJFK	GMMN			131388	JET		B789	B	37000	7141			RAM		6/26/23 1:28	6/26/23 1:49	6/26/23 1:56	6/26/23 0:40	6/26/23 0:
32	JBU509	JBU509.JFK.S	FALSE	TRUE	KJFK	MDSD			11349873	JET	N949JT	A321	D	27000	1156			JBU	6/26/23 5:22	6/26/23 5:29	6/26/23 5:37	6/26/23 5:45	6/26/23 2:56	6/26/23 3:

One row per flight with processed metrics generated by nightly queries against our internal databases (fuser, scheduler, TMI, ...)



Flight Summary



Processed metrics (e.g. `departure_fix_undelayed_time_at_out`) create common metrics across the team and simplify downstream analysis tasks



Outline



- Objectives for N90 workshop series
- Initial validation of ML models
- Overview of scheduling algorithm
- Real-time performance monitoring tools
- Post-operations analysis reports available
- **Discussion**



Questions





Discussion Topics



- Objectives for N90 workshop series
- Topics for next workshop (early August)
- Additional use cases for predictive engine
- Real-time displays/dashboards to support N90 decision making
- Current limitations of predictive engine in N90



Backup Slides

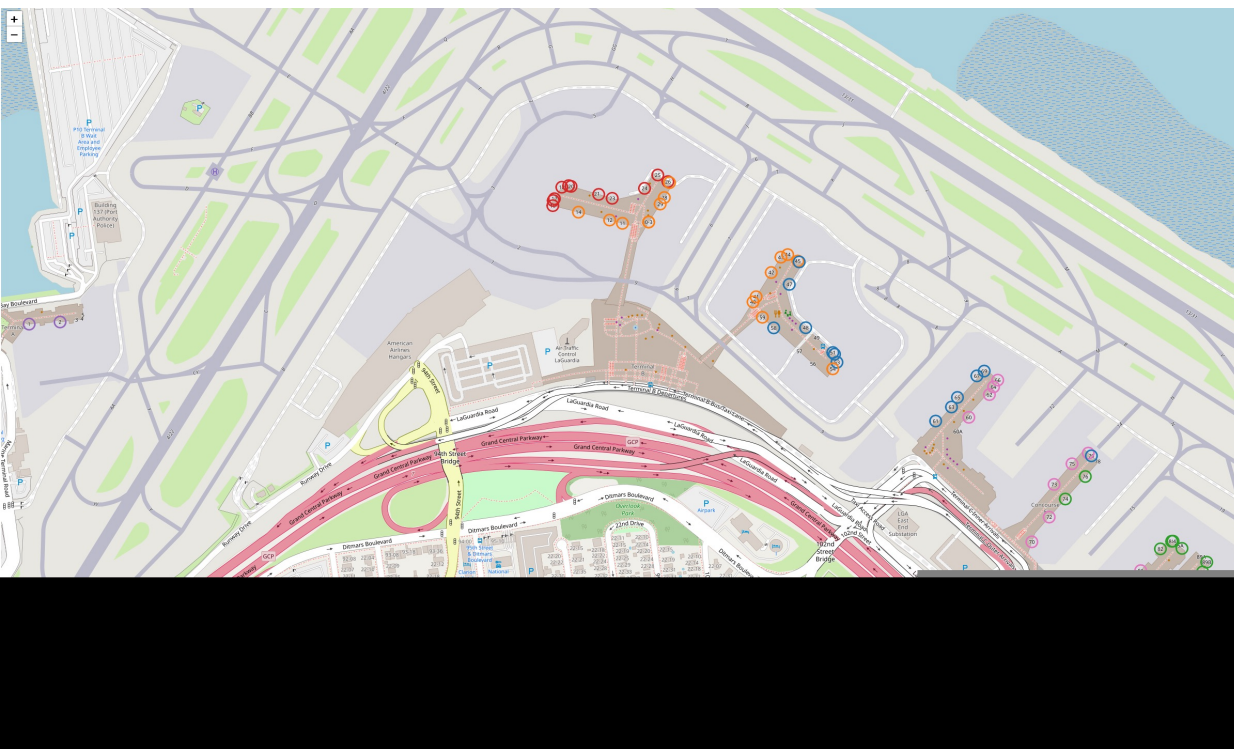


INFO - Gate Clustering : 93.9% of flights and 74.1% of gates covered
 INFO - Gate Clustering transform : 0.1% of flights with unknown gate in the fit
 INFO - Gate Clustering : 94.2% of flights and 75.0% of gates covered
 INFO - Gate Clustering transform : 0.8% of flights with unknown gate in the fit
 INFO - Gate Clustering : 93.9% of flights and 74.5% of gates covered
 INFO - Gate Clustering transform : 0.1% of flights with unknown gate in the fit
 INFO - Gate Clustering : 94.2% of flights and 75.5% of gates covered
 INFO - Gate Clustering transform : 0.9% of flights with unknown gate in the fit
 INFO - Gate Clustering : 94.4% of flights and 74.5% of gates covered
 INFO - Gate Clustering transform : 0.8% of flights with unknown gate in the fit
 INFO - Gate Clustering : 94.8% of flights and 76.2% of gates covered
 INFO - Gate Clustering transform : 0.1% of flights with unknown gate in the fit
 INFO - Gate Clustering : 93.5% of flights and 73.5% of gates covered
 INFO - Gate Clustering transform : 0.9% of flights with unknown gate in the fit
 INFO - Gate Clustering : 95.0% of flights and 75.9% of gates covered
 INFO - Gate Clustering transform : 0.8% of flights with unknown gate in the fit
 INFO - Gate Clustering : 94.9% of flights and 75.3% of gates covered
 INFO - Gate Clustering transform : 0.8% of flights with unknown gate in the fit
 INFO - Gate Clustering : 94.1% of flights and 74.5% of gates covered
 INFO - Gate Clustering transform : 0.8% of flights with unknown gate in the fit

- ```
- INFO - Gate Clustering : 84.4% of flights and 53.5% of gates covered
- INFO - Gate Clustering transform : 0.4% of flights with unknown gate in the fit
- INFO - Gate Clustering : 83.0% of flights and 53.0% of gates covered
- INFO - Gate Clustering transform : 0.5% of flights with unknown gate in the fit
- INFO - Gate Clustering : 85.3% of flights and 53.9% of gates covered
- INFO - Gate Clustering transform : 0.4% of flights with unknown gate in the fit
- INFO - Gate Clustering : 84.2% of flights and 53.3% of gates covered
- INFO - Gate Clustering transform : 0.4% of flights with unknown gate in the fit
- INFO - Gate Clustering : 83.0% of flights and 52.1% of gates covered
- INFO - Gate Clustering transform : 0.4% of flights with unknown gate in the fit
- INFO - Gate Clustering : 85.1% of flights and 52.9% of gates covered
- INFO - Gate Clustering transform : 0.4% of flights with unknown gate in the fit
- INFO - Gate Clustering : 84.3% of flights and 54.2% of gates covered
- INFO - Gate Clustering transform : 0.4% of flights with unknown gate in the fit
- INFO - Gate Clustering : 84.3% of flights and 53.6% of gates covered
- INFO - Gate Clustering transform : 0.3% of flights with unknown gate in the fit
- INFO - Gate Clustering : 83.8% of flights and 53.0% of gates covered
- INFO - Gate Clustering transform : 0.4% of flights with unknown gate in the fit
- INFO - Gate Clustering : 83.2% of flights and 53.6% of gates covered
- INFO - Gate Clustering transform : 0.4% of flights with unknown gate in the fit
```



# KLGA Departure Gate Clustering



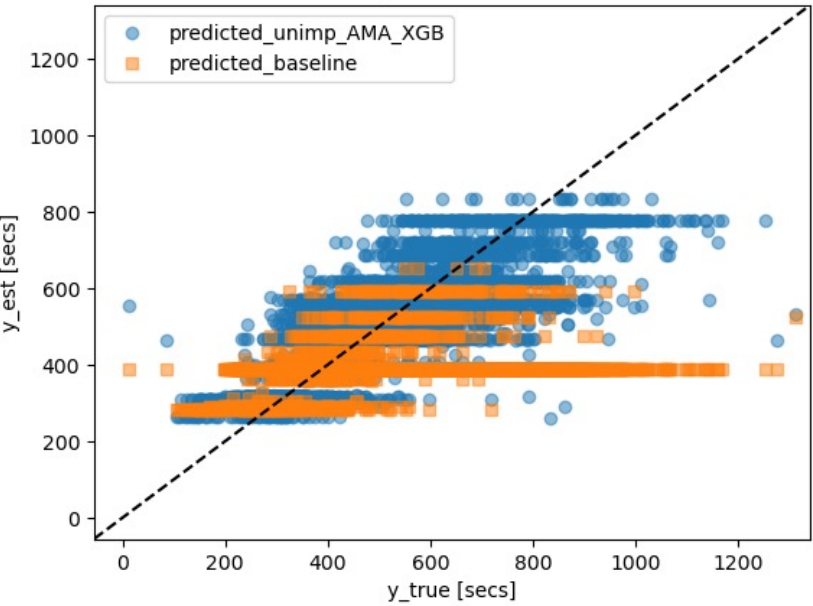
- INFO - Gate Clustering : 93.9% of flights and 71.8% of gates covered
- INFO - Gate Clustering transform : 0.5% of flights with unknown gate in the fit
- INFO - Gate Clustering : 95.6% of flights and 73.1% of gates covered
- INFO - Gate Clustering transform : 0.8% of flights with unknown gate in the fit
- INFO - Gate Clustering : 94.1% of flights and 70.5% of gates covered
- INFO - Gate Clustering transform : 0.7% of flights with unknown gate in the fit
- INFO - Gate Clustering : 94.6% of flights and 71.2% of gates covered
- INFO - Gate Clustering transform : 0.6% of flights with unknown gate in the fit
- INFO - Gate Clustering : 95.6% of flights and 71.8% of gates covered
- INFO - Gate Clustering transform : 0.7% of flights with unknown gate in the fit
- INFO - Gate Clustering : 95.8% of flights and 71.8% of gates covered
- INFO - Gate Clustering transform : 0.6% of flights with unknown gate in the fit
- INFO - Gate Clustering : 94.0% of flights and 71.0% of gates covered
- INFO - Gate Clustering transform : 0.6% of flights with unknown gate in the fit
- INFO - Gate Clustering : 94.3% of flights and 71.0% of gates covered
- INFO - Gate Clustering transform : 0.6% of flights with unknown gate in the fit
- INFO - Gate Clustering : 93.6% of flights and 69.5% of gates covered
- INFO - Gate Clustering transform : 0.5% of flights with unknown gate in the fit
- INFO - Gate Clustering : 95.6% of flights and 72.0% of gates covered
- INFO - Gate Clustering transform : 0.8% of flights with unknown gate in the fit



KJFK :

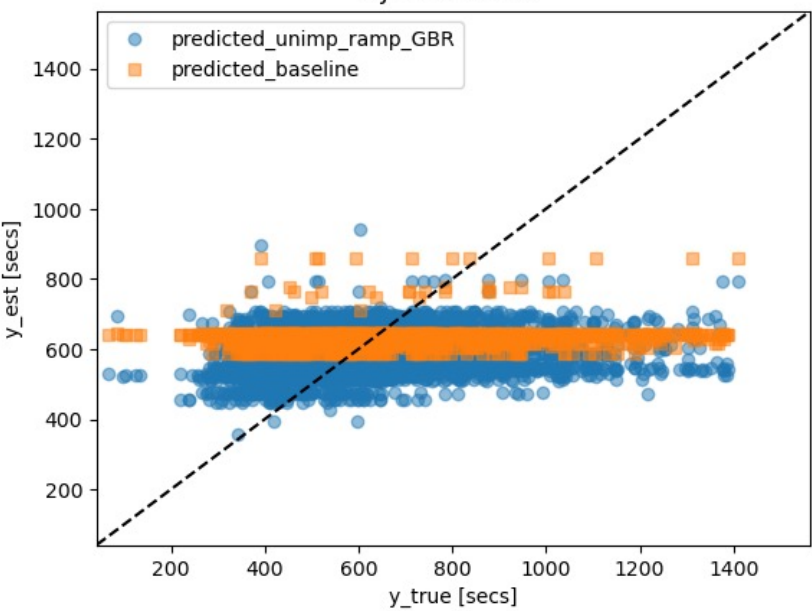
AMA (MAD=92s ~1'30")

KJFK - test set



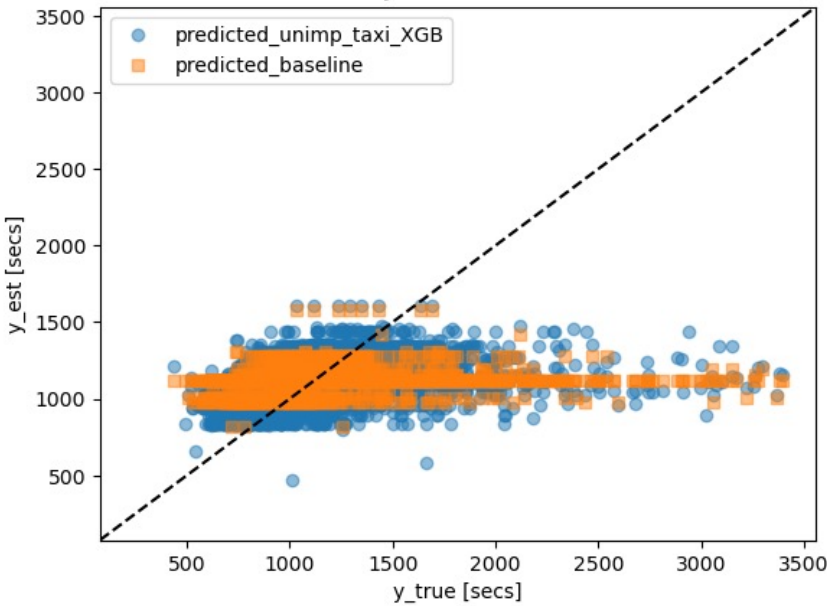
Ramp (MAD=138s ~2')

KJFK - test set



Total (MAD=196s ~ 3')

KJFK - test set



(MAD : median absolute deviation x 1.48 ~ 1  $\sigma$ )

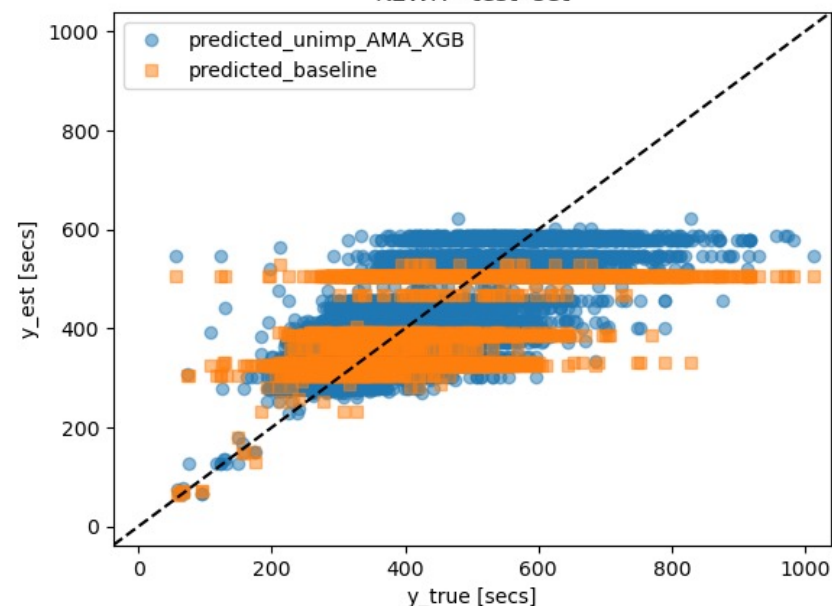


# KEWR Taxi-Out Models

KEWR:

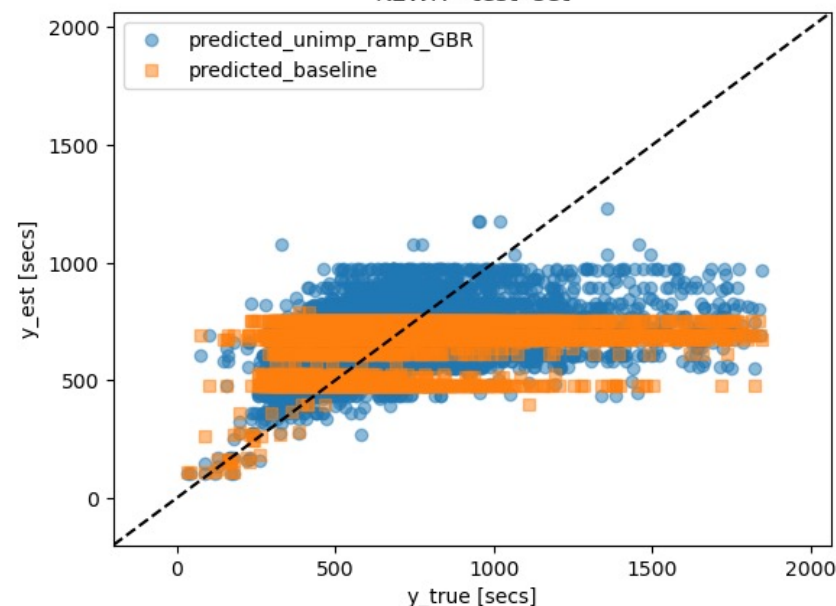
AMA (MAD = 71s ~ 1')

KEWR - test set



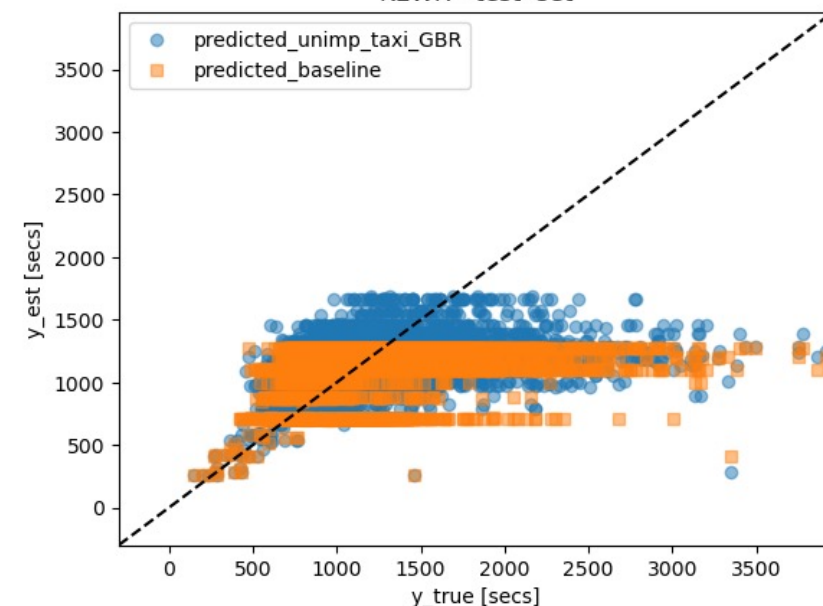
Ramp (MAD=171s ~ 3')

KEWR - test set



Total (MAD = 231s ~ 4')

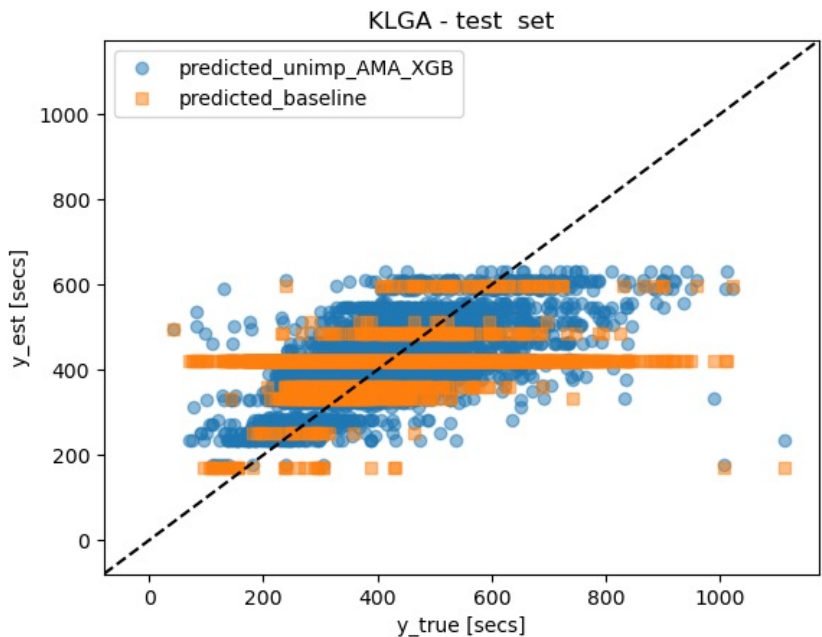
KEWR - test set



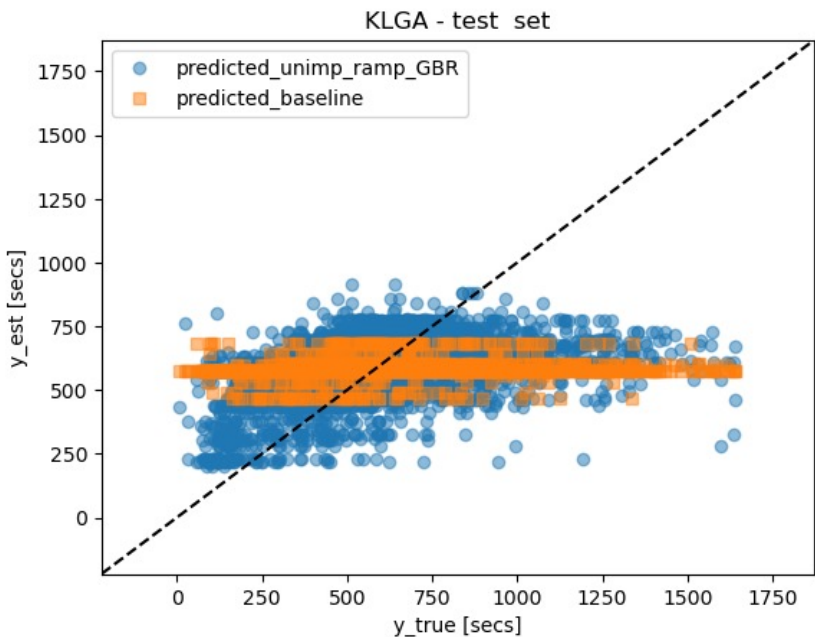


KLGA :

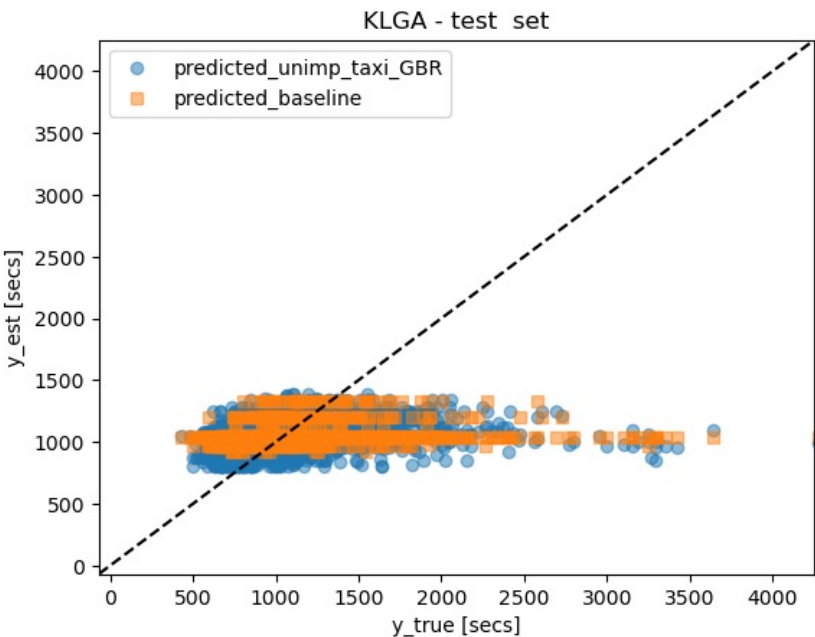
AMA (MAD=86s ~ 1'30")



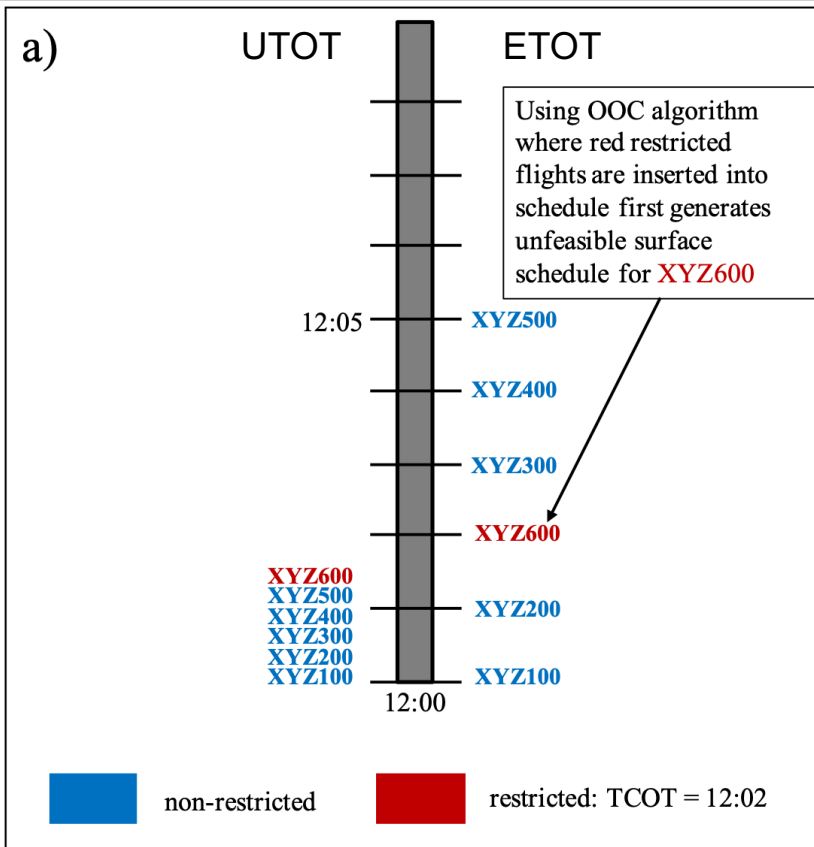
Ramp (MAD=176s ~ 3' )



Total (MAD=215s~3'30")

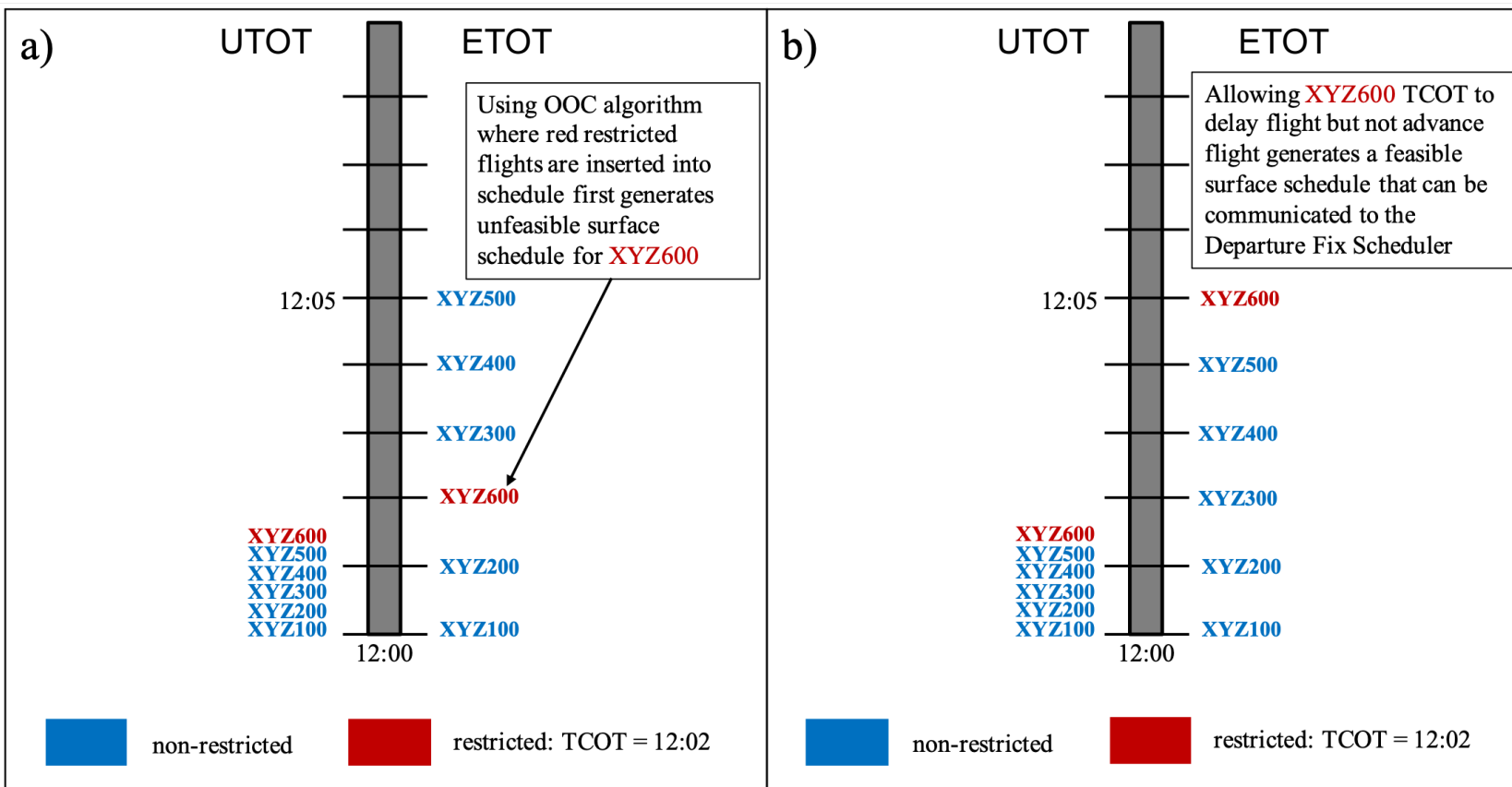


UTOT = Unimpeded Take Off Time, ETOT = Estimated Take Off Time, TCOT = Terminal Controlled Off Time



a) Hierarchical Order of Consideration

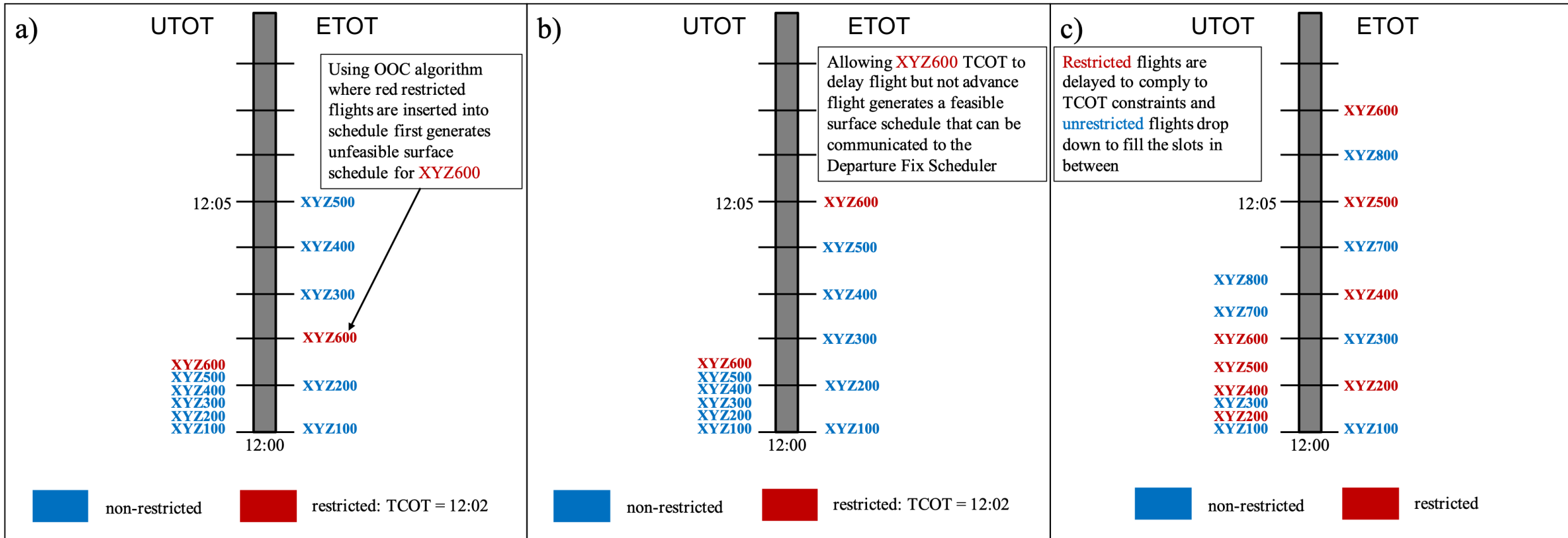
UTOT = Unimpeded Take Off Time, ETOT = Estimated Take Off Time, TCOT = Terminal Controlled Off Time



a) Hierarchical Order of Consideration

b) NASA heuristic allowing TMI constraint to delay flight but not advance flight in UTOT sequence

UTOT = Unimpeded Take Off Time, ETOT = Estimated Take Off Time, TCOT = Terminal Controlled Off Time



a) Hierarchical Order of Consideration

b) NASA heuristic allowing TMI constraint to delay flight but not advance flight in UTOT sequence

c) NASA heuristic allowing TMI constraint to delay flight but not advance flight in UTOT sequence