

# Analysis and Control of Airport Departure Processes to Mitigate Congestion Impacts

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# Motivation

- Taxi-out times have been steadily increasing in the US airports:
  - 16.7 min in 2007, a 21% increase since 1995
  - the number of flights with taxi-out times larger than 60 min in 2007 increased 21% comparing to 2006
  - Taxi-out times are excessive in several major airports:

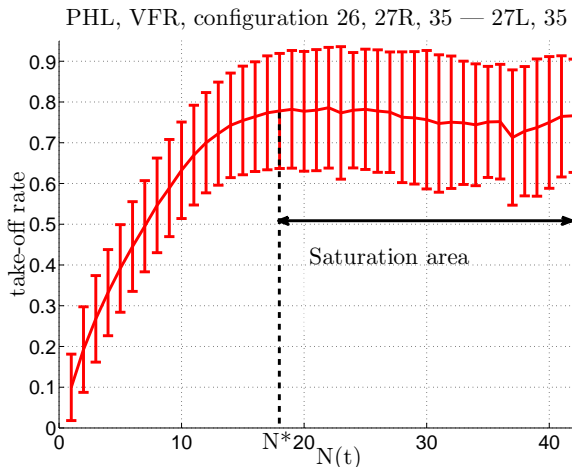
<b>Airport</b>	JFK	EWR	PHL	DTW	BOS
<b>Average taxi-out time (min)</b>	37.1	29.6	25.5	20.8	20.6

- Aircraft taxi out operations contribute significantly to the environmental footprint of airports:
  - An estimated 4,000 tons of HC, 8,000 tons of NO<sub>x</sub> and 45,000 tons of CO were emitted in 2007 from aircraft taxiing out in the US airports

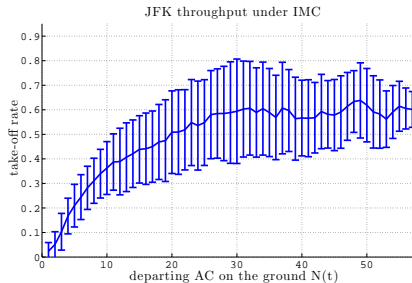
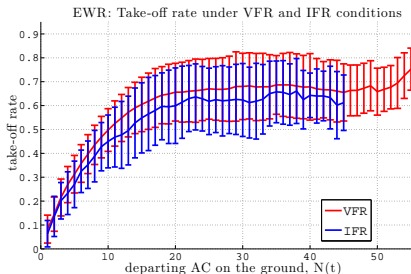
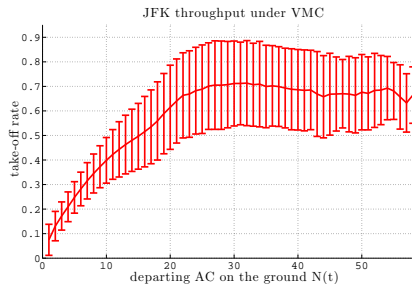
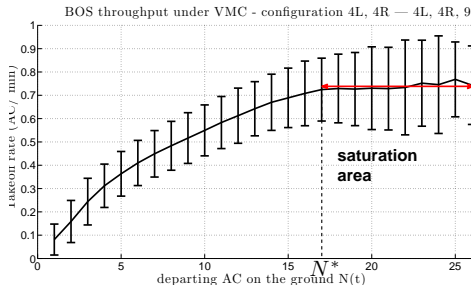
(Balakrishnan et al., 2008)

# Congestion metric: Number of departing aircraft on the ground, $N(t)$

- As  $N$  increases, the airport take-off rate increases until it saturates
- For each runway configuration, we identify the saturation point  $N^*$
- In saturation, the airport operates at its "capacity"



# A consistently observed phenomenon



## Congestion of major airports

- VMC, most frequently used runway configurations

<b>Airport</b>	Total flights	Capacity (AC/hour)	$N^*$	% of time in congestion	% of takeoffs in congestion
<b>JFK</b>	148,829	42	28	17.85	31.15
<b>EWR</b>	165,344	40	25	12.53	20.39
<b>PHL</b>	189,045	46	20	16.30	27.22
<b>BOS</b>	145,417	42	18	6.80	13.50

- IMC, most frequently used runway configurations

<b>Airport</b>	Total flights	Capacity (AC/hour)	$N^*$	% of time in congestion	% of takeoffs in congestion
<b>JFK</b>	24,412	36	27	24.09	40.94
<b>EWR</b>	25,640	37	22	15.17	23.58
<b>PHL</b>	14,228	37	16	31.90	48.75
<b>BOS</b>	15,152	36	15	13.76	22.60

## Taxi time metrics

- The unimpeded taxi-out time is a lower bound
  - A metric for what the taxi-out time of an aircraft could be, if it spent no time in the queues of the departure process
- The saturation taxi time could be an acceptable upper bound
  - An airport needs to have, on average,  $N^*$  aircraft active on the surface so as to reach its capacity
  - If there are fewer than  $(N^* + 1)$  departing aircraft on the surface, the level of traffic and the corresponding taxi times may be characterized as acceptable
  - The taxi time of an aircraft  $i$  having  $N^*$  or more aircraft in its takeoff queue,  $N_Q(i)$ , can be characterized as excessive
- Comparing the observed taxi times with these two metrics enables us to assess the impact of congestion on taxi times

## Taxi time analysis of major airports

- VMC, most frequently used runway configurations

Airport	Unimpeded taxi time	Average taxi time	Saturation taxi time	Flights in congestion	Taxi time in congestion
<b>JFK</b>	16.37	34.99	41.31	33,743	65.40
<b>EWR</b>	13.54	28.13	38.02	27,781	51.90
<b>PHL</b>	11.51	22.51	26.13	48,137	37.53
<b>BOS</b>	12.59	19.87	24.98	16,617	34.45

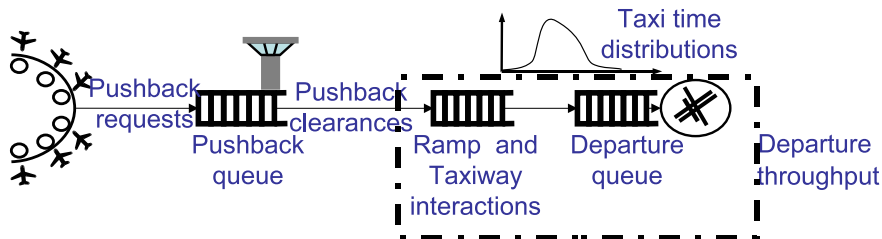
- IMC, most frequently used runway configurations

Airport	Unimpeded taxi time	Average taxi time	Saturation taxi time	Flights in congestion	Taxi time in congestion
<b>JFK</b>	19.00	45.23	47.46	7,866	68.83
<b>EWR</b>	13.84	30.99	35.18	4,501	50.32
<b>PHL</b>	12.36	27.22	25.10	5,434	40.05
<b>BOS</b>	12.58	21.61	25.54	2,876	37.22

# A simple strategy to reduce taxi times: avoid congestion

- Choose a maximum number of departing aircraft on the ground,  $N_{control}$
- For every aircraft that requests to pushback
  - ① If the number of aircraft on the ground exceeds  $N_{control}$
  - ② AND if there is no aircraft waiting to use the occupied gate insert it to the *pushback queue* and clear it for pushback when  $N \leq N_{control}$

(Feron et al., 1997)



## Metrics for the evaluation of the controlled pushback process

- Expected reduction in taxi times, fuel burn and emissions
- $delay_c = (\text{gate holding time} + \text{controlled taxi time}) - (\text{taxi time without control})$

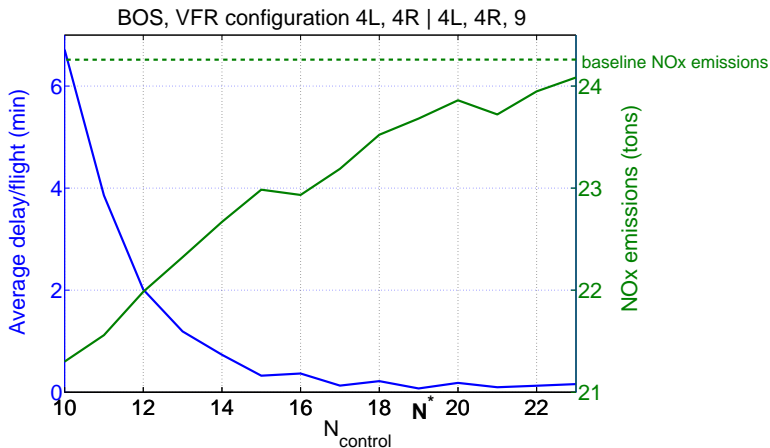
By choosing  $N_{control} = N^*$ , it is possible to achieve emissions reduction with a minimal  $delay_c$ :

Configuration	1	2	3
Total number of flights	32966	23373	16488
Average taxi time without control (min)	19.75	18.72	20.90
Average controlled taxi time (min)	19.16	18.30	20.63
Average $delay_c$ /flight (sec)	1.2	4.4	7.2
Total annual taxi time reduction (hours)	324	165	74
Total annual NOx emissions reduction (kg)	680	585	386

Simulated taxi times and emissions reduction for 3 runway configurations in BOS

## $N_{control}$ tuning

Trade-off between  $delay_c$  and emissions reduction for a runway configuration in BOS<sup>1</sup>



<sup>1</sup>joint work with Indira Deonadan, indira@mit.edu

# Questions-Discussion



Take off Queue in London Heathrow

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