Assessment of Fuel Burn and Emissions Impacts of Surface Traffic Optimization Concepts

Hamsa Balakrishnan
Massachusetts Institute of Technology
hamsa@mit.edu
Motivation

• In 2007, aircraft in the U.S. spent over **63 million minutes** taxiing in to their gates, and over **150 million minutes** taxiing out for departure [FAA ASPM data]

• Taxiing aircraft **burn fuel**, and contribute to **surface emissions** of CO$_2$, hydrocarbons, NOx, SOx and particulate matter
  − An estimated 6 million tons of CO$_2$, 45,000 tons of CO, 8,000 tons of NOx and 4,000 tons of hydrocarbons are emitted annually by aircraft taxiing out for departure

• In Europe, aircraft are estimated to spend 10-30% of their time taxiing [Airbus]

• A short/medium range A320 expends as much as 5-10% of its fuel on the ground [Airbus]
Evaluation of fuel burn and emissions performance of various airports

- Percentage of (domestic) departures from the top 20 airports vs. percentage of the taxi-out fuel burn from these flights

[ASPM, ICAO data]
CO performance

- Percentage of (domestic) departures from the top 20 airports vs. percentage of taxi-out CO emissions from these flights

[ASPM, ICAO data]
NOx performance

• Percentage of (domestic) departures from the top 20 airports vs. percentage of taxi-out NOx emissions from these flights

[ASPM, ICAO data]
HC performance

- Percentage of (domestic) departures from the top 20 airports vs. percentage of taxi-out HC emissions from these flights

[ASPM, ICAO data]
A queuing model of the taxi-out process

- Model inputs (ASPM database)
  - Pushback schedules
  - Gate assignments
  - Runway configurations
  - Weather conditions

- Desired outputs
  - Taxi-out time for each flight
  - Level of congestion on airport surface
  - Loading on departure queues
Estimating taxi-out time

- Taxi-out time expressed as

\[ \tau = \tau_{\text{unimpeded}} + \tau_{\text{taxiway}} + \tau_{\text{dep.queue}} \]

- Unimpeded taxi-out time (\( \tau_{\text{unimpeded}} \)) dominates when the number of aircraft on the surface is low
- Departure queue wait time (\( \tau_{\text{dep.queue}} \)) dominates when the number of departures on the surface is high
- Taxiway congestion term (\( \tau_{\text{taxiway}} \)) is important under medium traffic conditions

- Parameter extraction:
  - Unimpeded taxi-out time
  - Departure throughput saturation
  - Runway service process
Improvement through including taxiway congestion term

- Assume $\tau_{\text{taxiway}} = \alpha R(t)$
- $R(t)$ is the number of aircraft on ramps and taxiways
- Choose $\alpha$ for best parameter fit
Model validation: departure throughput

- Model validated on 2008 data

Without taxiway congestion term

With taxiway congestion term

[4L, 4R|4L, 4R, 9; VMC]
Taxi times as a function of congestion

BOS taxi-out times in segment (VMC ; 4L, 4R | 4L, 4R, 9)

- High ($N \geq 17$)
- Medium ($9 \leq N \leq 16$)
- Low ($N \leq 8$)
Prediction of taxi-out times

Departures, Taxitime and Queue size comparison, Jul 22, 2007, BOS

[Graph showing departures, taxi times, and queue size over hours]
Model can be used to evaluate surface traffic management strategies

- One potential strategy: “N-Control”

- Conceptually simple: Limit the buildup of queues on the airport surface by controlling the pushback times of aircraft
  - If number of aircraft in movement area > $N_{ctrl}$
    - Add any departing aircraft that requests clearance to a virtual departure queue, unless
    - There is an aircraft waiting to use the gate, in which case, clear departure for pushback
  - If number of aircraft in movement area ≤ $N_{ctrl}$
    - Clear aircraft in virtual departure queue for pushback in FCFS order, unless
    - There is a flight waiting to use the gate of an aircraft in the virtual departure queue, in which case, clear departure for pushback
Evaluating delay-emissions tradeoffs

BOS segment (VMC ; 22L, 27 l 22L, 22R)

Baseline NOx emissions
Other procedures: tow-outs

- Type of tug makes a big difference

Percentage reduction in fuel burn and emissions from diesel tugs

% decrease from baseline emissions
Operational challenges to tow-outs

• Return trips of tugs have not been considered
• Impact on aircraft nose landing gear
• Impact on airport throughput
• Ambiguity about control authority during towing operations
• Communication issues, including
  – Tug operators need to be trained in radio operations
  – Currently, chain of communication is often tower-aircraft-tug operator
  – Difficult during active runway crossings
Effect of stopping and starting while taxiing

- Potential fuel burn impact from stopping on the surface

No significant impact
Effect of stopping and starting while taxiing

- Impact depends on pilot actions

No significant change in throttle setting

Throttle setting (%) vs. Time
Using CFDR data to estimate impact of different taxi profiles

- ICAO emissions databank assumes that aircraft taxi at a constant thrust setting of 7%

- Using CFDR data (from Swiss Air) corresponding to taxi profiles of various aircraft, we
  - Developed a regression model for fuel burn, that considers the baseline fuel burn and the impact of stop-start events
    • Stop-start impact: Estimate of the form
      “The extra fuel burn from a start-stop event is equivalent to $x$ additional minutes of taxi time”

\[
\text{Fuel burn} = \text{Baseline fuel burn rate} \times (\text{taxi time}) + (\text{Stop-start impact}) \times (\# \text{ of stop-start events})
\]

- Developed a (linear) regression model between fuel burn and thrust settings
- Conducted above analysis for 9 aircraft types
CFDR vs. ICAO fuel burn estimates

Impact of a stop-start event

Labels indicate thrust settings

Preliminary results: please do not cite
Assessing the impact of taxi trajectories

- Use the estimates of baseline fuel burn and emissions to accurately assess the impact of taxi trajectories
- Refine objective functions in surface traffic optimization
Summary

• Developed a queuing model of departure taxi processes
• Model can be used to estimate benefits of various surface traffic management strategies
• Model can be refined by incorporating daily/seasonal demand variations, different analytical runway models, ASDE-X data, etc.
• Estimated baseline fuel burn and emissions using ICAO engine data bank
• Investigated benefits of operational strategies such as single-engine taxiing and tow-outs
• Refinement of fuel burn (and emissions) estimates using CFDR data
• Ultimately, models can be used to assess NextGen surface traffic management concepts