SARDA HITL #6 Simulation: System Performance Analysis

NASA Ames Research Center/ American Airlines
January 20-21, Fort Worth, TX
SARDA Concept

- Goal: A collaborative decision support tool for airlines and tower controllers to enhance the efficiency of surface traffic.

  - Airline Operator Advisory
    - Provide gate push-back times and MC use to the ramp controllers (CLT)

  - Ground Controller Advisory
    - Provide spot/ramp release schedule to reduce taxi delay while maintaining runway throughput

  - Local Controller Advisory
    - Provide take-off and crossing sequence for efficient and safe runway usage
HITL #6 Simulation Objectives

› Evaluate effects of the SARDA ramp controllers tool by comparing the two types of runs:
  › Baseline runs as current day operations (e.g., <15 in queue)
  › Advisory runs with SARDA scheduler

› SARDA advisories
  › Pushback advisories provide hold time
  › MC advisories provide advisory to indicate the flights that should be given the MC bypass option
Simulation Details [1]

› Two scenarios based on actual traffic data (5/16/2013)

› Departure push with the first part of the next arrival push overlapping

› Each scenario is about 1 hour long

› South-flow configuration (Departing: 18L, 18C; arriving: 23, 18R) with the Arrival-Departure Window (ADW) rule enforced

› Clear weather - VFR

› TMI (MIT @ MERIL 15 nm, EDCT) in effect
Traffic Scenarios

- Two one-hour long scenarios
  - based on actual recorded traffic data from CLT (May 16, 2013)
  - compressed slightly in time
- Departure push followed by arrival push
- Scenario 1:
  - 96 departures & 80 arrivals
- Scenario 2:
  - 84 departures & 72 arrivals
Simulation Details [2]

- 3 weeks – total of 48 scenario runs
- 4-sector configuration for ramp area
- 4 ramp controllers (2 from CLT)
- 1 ramp traffic manager by a NASA researcher
- 3 ATC controllers (2 Local and 1 Ground)
- 9 pseudo-pilots
4-Sector Ramp Configuration
MC Bypass Taxiway
Simulation Details [3]

- Ramp controllers were asked to follow pushback advisory as much as possible.
- Ramp controllers were asked to consider to follow MC advisory through coordination with ramp traffic manager.
Ramp Traffic Console (RTC)

Pushback advisories
- Pushback
- Gate hold
- Holding time

MC bypass route advisories
Data Collected

› Aircraft tracks
› Scheduler inputs and outputs
› ATC controller inputs
› Ramp controllers inputs
› Voice/video recordings
› Workload measurements
› Post run & post study surveys
Simulation Observations

- Did SARDA hold back aircraft at the gate?
- Was there any loss in runway usage due to holding?
- What are the observed benefits?
  - Reduced congestion on ramp and taxiways
  - Taxi times
  - Fuel and emission
  - TMI Conformance
Gate Hold

gate_delay = actual_out_time - scheduled_pushback_time

Departures are held at gates longer in Advisory runs

1.53 min increase in Scenario 1 (99.7%)
1.29 min increase in Scenario 2 (75.4%)
Runway Usage

No observable reduction in runway usage with advisory
Simulation Observations

✓ Did SARDA hold back aircraft at the gate?

✓ Was there any loss in runway usage due to holding?

› What are the observed benefits?
  › Reduced congestion on ramp and taxiways
  › Taxi times
  › Fuel and emission
  › TMI Conformance
Surface Congestion

Number of departures in ramp area

- Baseline
- Advisory

Simulation time (minutes)
Surface Congestion

Number of departures in movement area

Number of aircraft taxiing on the ground reduced (up to 4)
Taxi Times

taxi-out_time = actual_off_time - actual_out_time

taxi-in_time = actual_in_time - actual_on_time

Arrivals
0.3 min reduction in Scenario 1 (3.1%)
0.1 min reduction in Scenario 2 (1.0%)

Departures
1.1 min reduction in Scenario 1 (10.5%)
0.8 min reduction in Scenario 2 (8.3%)
Fuel & Emissions Calculation

- Engines are off if aircraft is held at the gate
- Engine thrust level: 7% during all the taxi phases
- Two engines are running while taxiing

<table>
<thead>
<tr>
<th>AC Type</th>
<th>Assumed AC Model</th>
<th>Assumed Engine Type</th>
<th>El HC (g/kg)</th>
<th>El CO (g/kg)</th>
<th>El NOx (g/kg)</th>
<th>Fuel Flow (kg/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>B772</td>
<td>Trent 892</td>
<td>1.59</td>
<td>29.62</td>
<td>8.88</td>
<td>0.57</td>
</tr>
<tr>
<td>B757</td>
<td>B752</td>
<td>RB211-535E4</td>
<td>0.56</td>
<td>19.40</td>
<td>7.33</td>
<td>0.34</td>
</tr>
<tr>
<td>Large</td>
<td>A319</td>
<td>CFM56-5A5</td>
<td>3.47</td>
<td>41.92</td>
<td>7.15</td>
<td>0.19</td>
</tr>
</tbody>
</table>
Fuel Savings

Departures
12.7 kg/flight saved in Scenario 1 (10.5%)
11.8 kg/flight saved in Scenario 2 (9.3%)
1.3 tonnes saved in Scenario 1 (12%)
1.1 tonnes saved in Scenario 2 (10.4%)
TMI Conformance

- Each scenario included five departures that had an assigned TMI.
- Tower controllers were asked to release TMI departures within a 1-minute window.
- The observed take-off time was compared to the assigned TMI.
TMI Conformance

Advisory runs resulted in smaller variances in the TMI deviations than Baseline runs.
HITL #6 - Summary

- Aircraft were held at the gate longer with advisories.
- No significant differences in runway usage.
- Number of aircraft taxiing on the ground reduced (up to 4)
- Taxi-out times were reduced (8-10%)
- Fuel savings for departures:
  - 1.3 tonnes in Scenario 1,
  - 1.1 tonnes in Scenario 2
- Better TMI conformance.
Other Performance Metrics

More performance metrics will be available later:

- Pushback advisory compliance
- MC route advisory compliance
- Takeoff sequence advisory compliance
- Stop-and-go frequency
- Emissions
Backup Slides
Taxi Times Distribution

Arrival

Scenario 1

Baseline
Advisory

Departure

Scenario 2

Baseline
Advisory
Taxi Delay

- Taxi-Delay = Actual_Taxi_Time – Unimpeded_Taxi_Time

- Unimpeded taxi time: time to travel on that route (gate-spot-runway combination) at 17 knots (8.75 m/s) without stops
Taxi Delay

Departures:
- 1.1 min reduction in Scenario 1 (14.7%)
- 0.8 min reduction in Scenario 2 (12.9%)

Arrivals:
- 0.5 min reduction in Scenario 1 (23.1%)
- 0.2 min reduction in Scenario 2 (8.7%)
Total Delay

\[
\text{total\_delay} = \text{taxi\_delay} + \text{gate\_delay}
\]
Total Delay (no MIT)

total_delay = taxi_delay + gate_delay

All flow constraint aircraft (including terminal A) should be under SARDA advisory
Analysis - by terminals
Gate Delay

- Scenario 1
  - A: Baseline Advisory
  - B: Baseline Advisory
  - C: Baseline Advisory
  - D: Baseline Advisory
  - E: Baseline Advisory

- Scenario 2
  - Baseline Advisory
  - Baseline Advisory
  - Baseline Advisory
  - Baseline Advisory
  - Baseline Advisory
Gate Delay (no TMI)
Total Delay

![Bar chart showing total delay for different scenarios and conditions](chart.png)
Total Delay (no MIT)
Total Delay (no MIT/TMI)
Analysis - by terminals and runways
Taxi Times

![Bar Chart](chart.png)
Gate Delay

The bar chart shows the gate delay (in seconds) for different categories labeled A, B, C, D, and E. The categories are Baseline Advisory for each section. The chart indicates the variability in gate delay across these categories.
Gate Delay (no TMI)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Gate delay (seconds)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Baseline vs. Advisory

Baseline  | Advisory
----------|----------

18C       | 18L
Total Delay

Departures: Total delay (seconds)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Advisory</td>
<td>Baseline</td>
<td>Advisory</td>
<td>Baseline</td>
</tr>
<tr>
<td>Delay (seconds)</td>
<td>800 ± 100</td>
<td>700 ± 90</td>
<td>600 ± 80</td>
<td>700 ± 90</td>
<td>600 ± 80</td>
</tr>
</tbody>
</table>

18C

18L

NASA
Total Delay (no TMI/MIT)
Data Analysis
HITL6 and HITL5

NASA Ames Research Center/ American Airlines
Fort Worth, TX
January 20-21, 2015
HITL6: Human Factors Analysis of Results

Research Question
How does management of ramp traffic affect user workload and usability ratings under the following conditions:
- SARDA advisories (pushback & MC advisories)
- NO SARDA advisories (Baseline condition)

Method
- Post Run and Post Study questionnaire data were gathered to assess controller workload and usability ratings
- Post Study Questionnaire asked a series of specific questions regarding use of Pushback and MC Advisories
Workload

• Workload for HITL6 was defined by four components similar to NASA-TLX (Task Load Index):

  • Mental Demand (Thinking, deciding, calculating, searching, etc.)
  • Temporal Demand (Time pressure)
  • Frustration (Stress, annoyance, irritation)
  • Communication Demand (exchanging information, discussion, negotiation, etc.)
Workload Questions

• Controllers were asked to rate each of the four components of their workload after every run on a scale of 1-10

• For example, see the “mental demand” question response format below:

1. Mental Demand (Thinking, deciding, calculating, remembering, searching, etc.)

   Low                     Moderate                      High
## HITL6 Workload Summary

Workload Responses, Weeks 1-3, All Sectors

**Means (SE)**

<table>
<thead>
<tr>
<th>Week</th>
<th>Mental Demand</th>
<th>Temporal Demand</th>
<th>Frustration</th>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Advisory</td>
<td>Baseline</td>
<td>Advisory</td>
<td>Baseline</td>
</tr>
<tr>
<td>One</td>
<td>4.37 (1.87)</td>
<td>4.43 (1.92)</td>
<td>2.53 (.64)</td>
<td>2.99 (.89)</td>
</tr>
<tr>
<td>Two</td>
<td>3.78 (2.05)</td>
<td>3.78 (2.06)</td>
<td>2.00 (.74)</td>
<td>2.12 (.86)</td>
</tr>
<tr>
<td>Three</td>
<td>4.24 (2.19)</td>
<td>4.56 (2.07)</td>
<td>2.28 (1.04)</td>
<td>2.45 (1.04)</td>
</tr>
</tbody>
</table>

No significant differences between the advisory and baseline conditions. Differences between weeks shows individual differences.
Pushback Advisories were easy to use, stable, useful and meaningful
Mike-Charlie Advisories reduced workload, reasonable, and improved communications
HITL6 Summary

• Similar workload was reported for the Advisory and Baseline Conditions

• Further statistical analysis showed that
  • In the Advisory condition, the South sector controller Frustration ratings were significantly lower
  • In the Advisory condition, the non CLT Coordination ratings were significantly lower

• Pushback: CLT controllers felt that the gate-hold times or pushback advisories were in a reasonable range more frequently towards the end of each week suggesting a learning effect

• M-C Advisory: The CLT controllers felt the MC advisories were stable more frequently towards the end of the week again suggesting a learning effect
HITL5
RTC vs. Paper Strips
HITL5: Human Factors Analysis of Results

Research Question
How does the management of ramp traffic affect user workload and usability ratings under the following conditions:

• Paper Strips
• Ramp Traffic Console (RTC)

Method
• Post Run questionnaire data were gathered to assess controller workload and usability ratings
• Post Study Questionnaire asked a series of specific questions regarding preference for RTC versus Paper on a number of different parameters
Workload

- Workload for HITL5 is defined by four components of the NASA-TLX (Task Load Index):
  - Mental Demand (Thinking, deciding, calculating, searching, etc.)
  - Physical Demand (Hands and arm movement, force)
  - Temporal Demand (Time pressure)
  - Frustration (Stress, annoyance, irritation)
HITL5 Workload Results Summary
Mean Response (SE)
All Sectors

<table>
<thead>
<tr>
<th>Condition</th>
<th>Paper</th>
<th>RTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Demand</td>
<td>5.68 (.82)</td>
<td>3.94 (1.92)</td>
</tr>
<tr>
<td>Time Pressure</td>
<td>4.87 (.57)</td>
<td>2.41 (.50)</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>4.58 (1.32)</td>
<td>2.78 (1.43)</td>
</tr>
<tr>
<td>Frustration</td>
<td>3.63 (.31)</td>
<td>1.28 (.34)</td>
</tr>
</tbody>
</table>

* Significant results

Higher Workload experienced with paper strips versus RTC
HITL 5 Post Study Questionnaire Results

Mean Controller Preference for Paper vs. RTC on a scale of 1 to 7

Ramp Traffic Console was preferred over the paper strips
HITL5 Summary

• Trend shows that workload ratings were lower in the RTC condition for all four aspects of workload,
  • Significantly lower results for Temporal Demand and Frustration aspects of workload
• Post Study question responses showed preference for RTC over paper strips
In Summary

• Post Run questionnaire Results
  • indicate lower workload ratings for RTC condition
  • Usability ratings for Traffic management performance questions are lower in the RTC condition than in the paper condition showing a preference for RTC over Paper
  • Usability ratings for Resources and efficiency questions show mixed results

• Post study Questions show preference for RTC over paper strips