Towards Autonomous Airport Surface Operations: NextGen Flight Deck Implications

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URL: http://humansystems.arc.nasa.gov/groups/HCSL
Mission:
- Develop **principled and robust procedures** and user interfaces with appropriate human-automation function allocation

- Develop **safe and efficient systems** that minimize pilots’ cognitive/visual **workload** and increase **situation awareness**

Research Focus Areas:
- Flight Deck Human Factors
- NextGen surface operations and departure concepts (25+ years)
- KCLT ATD-2 Integrated Arrival, Departure & Surface (IADS) demonstration project
OVERVIEW

• Airport Surface Operations: Taxi-out/Departures and **Surface Trajectory-Based Operations** (STBO: taxi with time requirements)

• Continuum of Surface Operations:
  Manual → Aided → Autonomy

• Current-day; near-term and far-term STBO

• Research on Pilot/Flight deck STBO

• 4DT STBO: A candidate for autonomous operations
  - Research Issues
OVERVIEW
Surface Trajectory-Based Operations (STBO)

STBO = Adding time component to Surface Operations (taxi/departure)

- Current Day Surface Operations
- Current Day (EDCT – APREQ/CFR)
- Near-term (e.g., FAA STBO/NASA ATD2) - without flight deck component
- Future 4DT Surface Trajectory-based Operations (STBO) Vision (NASA/DLR) - with flight deck component
Continuum of Surface Operations Manual ➔ Autonomy

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## Continuum of Surface Operations Manual → Autonomy

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Current Day Surface Operations

- Pilots manage pushback time to meet:
  - Scheduled departure/take-off time

Flight Deck:
1. Pushback Time

ATC:
1. Manage departure sequence
Current Day (EDCT – APREQ/CFR)

**Flight Deck:**
1. Pushback Time

**ATC:**
1. Manage “wheels-up” time (EDCT - APREQ/CFR)

- Flight deck/pilots manage pushback time to meet:
  - “Wheels-up time”
- Flight deck/pilots have no information about:
  - Expected taxi time
  - Surface congestion
  - Departure queue size
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Near-term (e.g., FAA STBO/NASA ATD2) - without flight deck component

Flight Deck:
1. Pushback

ATC/Ramp manages (with Decision Support Tools, DSTs):
1. Pushback (re: gate holds) – Target Off-Block Time (TOBT)
2. Target Airport Movement Area entry time (TMAT)
3. Target/Calculated Take-Off Time (TTOT/CTOT) re: Departure time or “wheels-up” time, EDCT - APREQ/CFR)

- Pilots manage pushback time to meet:
  - “Wheels-up time” (at KCLT, about 10% of flights)
- Pilots have no information about:
  - Expected taxi time
  - Surface congestion
  - Departure queue size
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**Controller**: Manual/voice ops, manual sequencing/scheduling aids, manual deconfliction

**Pilot**: Controls manually, info/displays for 4DT STBO

**Controller**: Auto-routing, auto-deconfliction, auto-sequencing/scheduling, position timing

**Pilot**: Controls manually, info/displays for 4DT STBO
Future 4DT Surface Trajectory-based Operations (STBO) Vision (NASA/DLR) - with flight deck component


• Requirement to be at locations at specific time; defined \( (x_t, y_t) \) with certain tolerance
• DLR TRACC Surface Management System dynamically creates conflict-free routes
• Coordination between Flight Deck – ATC/Ramp re: location and times

Transition from “first-come, first-served” operations
Future 4DT Surface Trajectory-based Operations (STBO) Vision (NASA/DLR) - with flight deck component

- Enables dynamic surface flow re-planning
- Enables increasingly precise taxi routing plans for improved surface traffic flow efficiency
- Flight deck component allows for coordination with ATC re: schedule issues (e.g., maintenance, FMS, weights/balances, RWY changes, etc.)
- Extension of FAA/NASA STBO concept
- Would enable aircraft traffic to continue rolling through Active RWY Crossings, instead of stopping aircraft and requiring ATC to do “batch” crossings of arrivals
- Facilitate timed runway take-off window conformance (+/- 5 min EDCTs, -2/+1 min APREQ/CFRs)
### 4DT STBO: Taxi Clearances w/ Speed Commands: Taxi Time-based Conformance


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<th>Taxi Clearance</th>
<th>Required time of Arrival (RTA) Performance</th>
<th>Safety</th>
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<td>• Non-specified acceleration/deceleration speed profile (n = 8 pilots)</td>
<td>Not able to achieve accurate RTAs</td>
<td>Slightly increased visual demand, as compared to baseline</td>
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| • Specified acceleration/deceleration profile (1kt/sec) | Good RTA performance | • Increased workload and visual demand  
• 14/18 pilots rated “unsafe” |
| • Speed-conformance bound (+/- 1.5 kts) (n = 18 pilots) | | |

- Taxiing Captain cannot “tightly control/track” speed, navigate, and maintain separation.

**ConOps Implications:**
- Incorporating speed into the taxi clearance alone is not sufficient for the performance/safety balance
- There is a requirement for human-centered flight deck display algorithms

“NASA 227, Taxi to RWY 17L via A, B, C at 14 kts”
4DT STBO: Flight Deck Display Design/Philosophy

Bakowski, Hooey, Foyle, & Wolter, 2015, AHFE
Bakowski, Hooey, & Foyle, 2017

- **Status-at-a-glance** display to maximize ‘eyes-out’ time

- Enable **strategic use** – pilots do not need to track speed continuously (anywhere in pink band is ‘in conformance’)

- **Display expected position with tolerance** and allow pilots to use expertise to control aircraft (e.g., “human/pilot-centered”)
Two allowable conformance deviation sizes were used:

+/- 164 ft and +/- 405 ft

HITL Simulation: Bakowski, Hooey, & Foyle, 2017
4DT Surface Trajectory-Based Operations (STBO)

HITL Sim: Bakowski, Hooey, & Foyle, 2017 (Preliminary Analysis)

- Emulated DLR TRACC 4DT STM system
  - Taxi Routes for Aircraft: Creation and Controlling” Surface Management System
  - Creates conflict free routes/re-routes
  - Non-Conformance within 50 m (164 ft) of deviation from expected x, y position
  - Dynamic, multiple speed changes (up to 5) along taxi route
- Flight Deck/Pilot Manual Control:
  Steering (tiller/rudder), Navigation, speed (thrust/brakes), other flight deck tasks (checklists, callouts, 2nd engine start)
- Map Display with Route and Allowable Deviation
- Position/time \((x_t, y_t)\) Conformance >90% but decrease with smaller allowable deviation (+/- 164 ft)
- “Eyes-in” time higher, but rated “safe” and “acceptable”

% Time in Conformance

- “Eyes-in” time: 37% for +/- 164 ft
  35% for +/- 405 ft
  29%* for Speed Clearances & Map
  19%* with Map

*HITL Sim: Bakowski, Hooey, Foyle, & Wolter, AHFE, 2015

- Safety rating: 4.7 (out of 5) for +/- 164 ft
  4.9 (out of 5) for +/- 405 ft
- Acceptability rating: 4.2 (out of 5) for +/- 164 ft
  4.3 (out of 5) for +/- 405 ft

\(p < .05\)
4DT Surface Trajectory-Based Operations (STBO)

HITL Sim: Bakowski, Hooey, & Foyle, 2017 (Preliminary Analysis)

Robustness:
- Flight deck interruptions, off-nominals, FMS/equipment problems, etc
- System/integration implications -- speed changes, dynamic updates
- Candidate for automation/autonomous aircraft control during taxi operations

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**Automation/Autonomy in 4DT Surface Trajectory-Based Operations (STBO)**

**TRACC**: “Taxi Routes for Aircraft: Creation and Controlling” Surface Management System – Germany’s DLR

- Creates conflict free routes/re-routes
- Non-Conformance within 50 m (164 ft) of deviation from expected x, y position
- Dynamic, multiple speed changes (up to 5) along taxi route

**Autonomous Surface Operations:**

- Enables 4DT STBO efficiencies
- Distributed architecture (Airport/Tower/Aircraft)
- Surface traffic manager
  - 4DT STBO operations (i.e., times at AMA entry, taxi merge points, rolling runway crossings, runway departure queue)
  - Routing/re-routing
  - Traffic de-confliction
- Candidate Auto-taxi propulsion
  - Wheel-bots
  - Electric tugs
  - Auto-taxi aircraft
**TRACC**: “Taxi Routes for Aircraft: Creation and Controlling” Surface Management System – Germany’s DLR
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**Autonomous Surface Operations:**
Candidate initial architecture (NASA/DLR Concept):
- Ground/Tower: Surface Traffic Management
  - Issue STBO Clearances (Routes w/ times)
  - Re-routing for efficiency or non-conformance
  - Traffic deconfliction
- Aircraft:
  - Aircraft navigation
  - Aircraft movement (steering, speeds, turns)
  - Additional On-board Conflict Detection and Resolution (CD&R)

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### STBO with Autonomous flight deck component

Pilot(s) responsible for aircraft/crew & passenger safety

Enabling Pilots/Flight deck Situation Awareness
Need for “status-at-a-glance” awareness and intent displays

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STBO with Autonomous flight deck component
Pilot(s) responsible for aircraft/crew & passenger safety
Enabling Pilots/Flight deck Situation Awareness and Flight Deck workflow/procedure integration

Research issues, re: Pilot roles:
• Taxi clearance (how to load? pilot approve if auto-load?)
• 4DT STBO – speed/time updates (approve? Auto-load?)
• Departing Runway (changes, FMS, weights, temps, etc)
• Runway crossings, “wheels-up” times
• Braking – hot brakes (take-off abort)
  - Airports are not flat; KCLT, DFW varies 50ft
  - 747-8 1 Million lbs fully loaded
• Monitoring: - Traffic (aircraft, pedestrian, vehicle) – Separation assurance
  - Ownship aircraft intent (stopping, turning, waiting to cross active runway)
• (Non) Conformance: - Mid-taxi stopping / abort – FMS, passengers, weights
  - For 4DT STBO – interactions re: dynamic STM system; # updates
• Pilot Intervention? Revert to manual or abort taxi, or unable to make time b/c of flight deck, equipment, passenger, baggage, etc. issues
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