Air Traffic Controller use of Interval Management during Terminal Metering Human-in-the-Loop Simulation

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Presentation Outline

- Background
- Methodology
- Results Summary
- Recommendations
Background
Sponsors of the Work

- This research was conducted with funding from the Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) Human Factors Division (ANG-C1) in support of the Aircraft Certification (AIR) as well as the Flight Standards Service Flight Technologies and Procedures Division (AFS). The Surveillance and Broadcast Services (SBS) Program Office also supported the work.
Overall Operational Environment

▪ Problem: merging, spacing, and sequencing in the terminal
  – Tactical control environment in current terminal airspace leads to vectoring and may keep aircraft from flying optimized routes

▪ Solution
  – For busy Terminal Radar Approach Controls (TRACONs), create and adhere to a schedule that details where aircraft should be at certain times
    ▪ Trajectory predictions from en route down to runway
    ▪ Integrated, de-conflicted arrival schedule

▪ Tools to aid controllers in meeting TRACON schedule
  – Terminal Sequencing and Spacing (TSAS) [Absolute spacing]
  – Interval Management (IM) [Relative spacing]
TSAS

- **Scheduling**
  - Introduces time-based metering in TRACON airspace
  - Creates a sequence and schedule to satisfy minimum spacing and wake separation requirements at defined points

- **Traffic Management**
  - Displays sequence and scheduling information to the controller
  - Provides automated decision support to help the controller achieve the schedule
IM

(early development occurred under other names such as Sequencing and Merging)

- Supports the controller in meeting a spacing goal (e.g., the metering schedule)
- Provides speeds, via avionics, to the flight crew to achieve an Air Traffic Control (ATC)-assigned spacing goal relative to a lead aircraft
- Improves spacing consistency
  - By making more frequent and efficient speed adjustments (than is possible with a ground system and voice communications)
- Increases throughput and reduces delay
  - Through improved inter-aircraft spacing precision
  - Up to approximately 11 more aircraft per hour, as compared to a ground system only
General IM Arrival and Approach Procedure

1. Controller (assisted by ground automation) preconditions the traffic, determines IM aircraft pairs, and the desired spacing goal

2. Controller communicates lead aircraft identification and IM initiation parameters to the trail aircraft

3. Flight crew of trail aircraft confirms then enters the information into IM equipment

4. When IM initiation requirements are met, IM equipment provides IM speeds for flight crew to fly to achieve and/or maintain the assigned spacing goal

5. Flight crew follows the IM speeds and ATC monitors until termination
IM Operations during Terminal Metering

- While the assigned spacing goal is based on the underlying schedule (difference between scheduled times of arrival), a trail aircraft conducting IM is spacing relative to the lead aircraft position
  - Therefore, if the lead aircraft is predicted to be off-schedule, the trail aircraft will be working toward a similar off-schedule position

- **IM determines time-to-achieve at the singular achieve-by point** (e.g., merge point or Final Approach Fix) while TSAS may have a set of “control points”
  - The IM trail aircraft may work toward the schedule slower than would be done by the controller
Methodology
Context

- General acceptance of IM operations has been reported in numerous simulations
- Research on IM in metering environments has been conducted in the past
  - IM in en route metering (e.g., Peterson, Penhallegon, and Moertl, 2012; Rognin et al., 2005)
  - IM and terminal metering with TSAS (e.g., NASA work summarized in Robinson, Thipphavong, and Johnson, 2015)
- However, there were open issues / topics that needed to be addressed based on preparatory activities conducted with the FAA and National Air Traffic Controllers Association (NATCA)
Research Goals and Status

- Further explore and provide data on open topics associated with the integration of absolute (TSAS) and relative (IM) spacing operations from a human factors perspective
  - Feasibility and acceptability (IM aircraft behavior in absolute, time-based spacing environment)
  - Information requirements (for execution and monitoring of IM, avoiding conflicts with TSAS information)
  - Communication requirements
  - Procedures

- Data collection completed in May 2017
  - Final detailed technical report was available in January 2018
  - Results being used to mature ground and flight deck operational and technical requirements and drive follow-on simulation needs
Participants

- Controllers (n = 9)
  - Three sets of controllers participated for 5 days each
    - 2 days of training followed by 3 days of data collection
  - ATC-10 or above Standard Terminal Automation Replacement System (STARS)-equipped TRACON facilities
  - No prior TSAS simulation experience
  - Average years experience 15.4

- Pilots (n = 18)
  - Nine sets of flight crews participated for 1 day each
    - Airline Transport Pilot (ATP)

- Other
  - Two to four pseudo-pilots
Airspace

BRUSR1

IM clearance proposed

EAGUL6

IM clearance proposed

Required Navigation Performance (RNP) Radius-to-Fix (RF) Turn

Achieve-by point / Planned termination point

kt – knot
Traffic – Non-Participant Traffic (i.e., Pseudo-Pilot Aircraft)

- Various aircraft types and categories (e.g., large, heavy)
- Mix of capabilities
  - 100% capable of Area Navigation (RNAV)
    - ~20% capable of flying RNP RF turn
  - ~60% capable of acting as an IM trail aircraft
    - Using IM Sample Algorithm (from RTCA and EUROCAE MOPS)
    - Flying Achieve-by then Maintain or Capture then Maintain clearances
    - “IM-aware” schedule
  - 100% capable of acting as a lead aircraft in IM pair
- Arrival rate of approximately ~40 aircraft per hour
- Aircraft were delivered to the TRACON boundary with a set deviation around the scheduled time
  - Aircraft arrived no earlier than 30 and no later than 15 seconds
  - Simulating the management of aircraft by en route controller
Independent Variables

- **IM awareness information**
  1. TSAS only tools with IM aircraft role (and status) and IM Clearance Window
  2. #1 + Slot marker color change cue to indicate active IM operation
  3. #2 + Prediction of spacing at achieve-by point (ETA differential)

- **IM Lead Aircraft Behavior**
  1. Nominal
  2. Off-nominal
    - Three overtake events per controller that required termination or suspension of IM (one per day per controller)

- **Controller role**
  1. Feeder
  2. Final

  Balanced across 6 scenarios x 3 days = 18 scenarios per controller
Prototype TSAS Tools on STARS Display

Based on Operational Integration Assessment (conducted on 05/2015 at the FAA WJHTC) (Witzberger, Martin, Sharma, and Robinson, 2015)
Prototype IM Tools on STARS Display
(1 of 2)

- IM aircraft role (and status)
- IM Clearance Window
- Change in slot marker color
Prototype IM Tools on STARS Display
(2 of 2)

- IM aircraft role (and status) in data block
  - Trail aircraft (eligible, active, suspended, invalid, no speed)
    - Replaced the TSAS speed advisory and early / late indicator
  - Lead aircraft (active, suspended)

- IM Clearance Window
  - Provided IM clearance and IM status information
    - Color-coded based on status (proposed, active, terminated / rejected, or alerted)
    - IM proposed only after validity and feasibility checks
    - A field for the current TSAS spacing prediction (Trail ETA at FAF – Lead ETA at FAF) in select runs
  - The order of the text was that of the voice clearance

- Change in slot marker color (from white to blue)
  - Quick visual cue for which aircraft were acting as an IM trail aircraft / conducting IM (in select runs)
STARS-Like Implementation

Automated Terminal Proximity Alert (ATPA)

Distance to lead

Cone length / separation minima

Cone
Data Collection

- **Subjective**
  - Paper questionnaires after each run and at the end of simulation
    - Covering topics such as: workload, acceptability of displays, communications and concepts, ideas for improvements, etc.

- **Objective**
  - Automatically collected by simulation environment
    - Ground: e.g., Inputs for initiation, rejection, suspension, resumption, and termination; Initiation delay; Location of initiations, rejections, suspensions, resumptions, and terminations
Results Summary
Controllers ranked the three operations (terminal metering, RNP RF turns, and IM) similarly in terms of how challenging they were, but RNP RF turns may have been more challenging, especially when compared to terminal metering.
IM Operations Conduct - Overall

- 97.2% of the IM clearances were initiated by the controllers
  - Less than 1% of these were suspended
  - 4.2% of these were terminated (at various points along the arrival and approach)
    - 44% were due to a believed potential to increase efficiency
      - Approximately 50% were for one controller
      - Some conditions were made worse upon intervention
IM during Terminal Metering (1 of 2)

- IM and terminal metering are compatible, desirable, and acceptable
  - At times, IM was very similar to the behavior of controllers who transition from an absolute spacing operation to a relative spacing operation in the later stages of approach and landing
  - Controllers reported that it was acceptable to receive aircraft already conducting IM
  - Controllers reported they were confident both IM and non-IM aircraft would be handed off with minimal problems, though non-IM aircraft received higher / more positive ratings
  - Controllers did not appear to have issues with two different IM achieve-by points, nor spacing / separation issues with IM aircraft that were still in the achieve stage when passing the merge point
  - However, controllers noted that this general environment created a relatively low workload environment, and that it could cause controllers to act more as “monitors” and be less engaged
Controllers reported:
- Roles and responsibilities were clear
  - Few, if any, differences between Feeder and Final controller roles
- Overall workload was acceptable
- Traffic awareness for IM and non-IM aircraft was acceptable
- The necessary monitoring of both IM and non-IM aircraft was acceptable
  - Though controllers reported increased monitoring of IM aircraft and responses were variable for non-IM aircraft
- Mixed equipage was acceptable
Traffic Spacing Awareness and Acceptability (1 of 2)

- Controllers reported:
  - They were confident both IM and non-IM aircraft would remain outside their separation requirement
    - Across controller roles, tool sets, and aircraft role
      - Although non-IM aircraft tended to have higher / more positive replies
    - The spacing achieved by IM and non-IM aircraft was acceptable
    - They were able to detect spacing / separation issues developing for IM and non-IM aircraft
      - All designed-in off nominal events where a trail aircraft overtook its lead were detected by the controllers without alerting support
    - It was clear IM aircraft were working toward appropriate spacing
      - Although responses were variable
Several comments were made on the questions related to controller confidence in monitoring and predicting spacing and separation

- Controllers expressed issues with not “knowing what the [IM aircraft / flight crew] is doing” / not knowing the speeds to be flown and when
- Controllers reported trusting the flight crew and letting it “play out,” but feeling out of the loop
- The observers noted that controllers appeared to be comfortable allowing aircraft conduct IM when further from the separation standard and separation was not an issue. However, they appeared to direct more attention to the aircraft when the pair was near the separation standard and separation monitoring became necessary
Aircraft Spacing and Separation (1 of 3)

- IM aircraft (45.9%) were in the slot markers for less time in the feeder’s airspace as compared to non-IM aircraft (54.2%)
  - This is likely because the feeder controller was working to get non-IM aircraft into their slot markers prior to the handoff to the final controller, while the achieve-by aircraft were still working toward the spacing goal at a later point (DERVL and YOKXO) in the final controller’s airspace

- All aircraft had similar amounts of time (approximately 18%) spent in their slot markers in the final controller’s airspace
  - Final controllers appeared to let aircraft run ahead of schedule
Some past work showed controller concerns with IM aircraft being outside their slot markers longer than non-IM aircraft. Controllers in this simulation reported that IM aircraft position and behavior relative to its slot marker was logical.

Although aircraft were often outside of their slot markers and ahead of schedule, the majority of the time the trail aircraft (IM or non-IM) had the same relative position to its slot marker as the lead aircraft did to its slot marker.
Several controllers in this simulation expressed an interest in closing gaps and landing aircraft as soon as possible, regardless of the schedule.

Overall, performance baseline / goals for IM (+/- 10 seconds, 95%; +/- 5 seconds, 68%) and non-IM (+/- 12 seconds, 68%) aircraft were met.

- IM aircraft met the spacing goal with a standard deviation of 4.1 seconds (half that of non-IM aircraft).

There were only five events where the spacing within an aircraft pair was below the separation standard in the feeder or final controller’s airspace. None of the events were for an aircraft actively conducting IM.

IM aircraft remained on their RNAV procedure 98.2% of the time, while non-IM aircraft remained on their RNAV procedure 93.8% of the time.
Displays (1 of 3)

Terminal metering tools did not appear to conflict with IM. They were reported as useful and generally received positive ratings for both IM and non-IM aircraft

- Controllers found the slot markers (without the additional IM color cue) less useful for IM, but the responses had a lot of variability. However, observations indicate the slot markers (without the additional IM color cue) were still important and utilized for IM aircraft
Displays (2 of 3)

- **Data block IM elements**
  - Trial aircraft and lead aircraft status indicators were reported as helpful

- **Blue slot markers received lower and variable responses regarding their usefulness**
  - However, observations and most replies indicate the blue slot markers were still important and utilized for IM aircraft

- **IM clearance window information**
  - Controllers reported the IM status information, the projected spacing, and the no speed alerting were helpful
Controllers agree to the following post-scenario statements and the tool sets had very similar ratings:

- IM aircraft would remain outside their separation requirement (no statistically significant difference)

- They were able to detect spacing / separation issues developing for non-IM aircraft

- They had the necessary display elements (no statistically significant difference)
Recommendations
IM during Terminal Metering – General Acceptability

- The topic of controllers acting as monitors in a Trajectory Based Operations (TBO) environment may require additional study or, at least, continued consideration.

- Initiation geometries different than those examined here (such as opposite corner posts) may be more challenging. The topics examined here could be examined with these more challenging geometries.

- The potential issue of IM aircraft being out of the slot markers for longer periods of time than non-IM aircraft should be further examined to determine whether it really is an issue, including in unusual and complex traffic situations.
Displays

- The terminal metering tools tested did not conflict with IM and there were no results indicating any should be removed, including the slot markers
  - The only terminal metering information that was removed, and is suggested to stay removed, is the speed advisory and early / late indicator

- Additional work should be performed to continue to determine the necessary controller tools and the usefulness of the slot marker IM cue and spacing prediction (to know when separation will be an issue) to support controller trust in and understanding of IM

- Additional work should be performed to see if a display feature would be helpful in overcoming the concern of controllers about not knowing when aircraft conducting IM will change speeds and by how much
Questions?
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