A Human Performance Model of Commercial Jetliner Taxiing

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Abstract

There is a critical gap in attempting to predict aviation system performance between large-scale engineering-oriented simulations and human-in-the-loop experiments. In order to bridge this gap, we have constructed a model of a human pilot taxiing a commercial jetliner using ACT-R, a computational theory of human cognition and performance. The model was constructed on the basis of a task analysis that was synthesized from a mixture of prior literature, official procedures, and consultations with SMEs. The model taxis a simulated 737 in the X-Plane flight simulation environment. Our approach to validation, which we believe to be unique, will be to validate the model against actual taxi trajectories recorded by real pilots at DFW airport in actual operations. The model can ultimately be used to provide higher-fidelity pilots in large simulations or used to populate the environment in human-in-the-loop experiments.

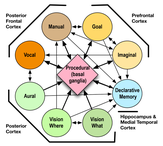
Motivation

- Surface traffic management is a critical concern for NextGen
- Goal: optimize timing and route for each plane
  - Too computationally difficult for human controllers
  - Exacerbated by increasing amount of surface traffic
- FAA and NASA developing algorithms to calculate optimal routes
  - However, testing these algorithms is challenging
- Human-in-the-loop (HITL) experiments on ground controllers
  - Expensive
  - Difficult to explore much of the design space
  - Require many participants to act as "pilots" to ensure simulation fidelity
- Large-scale computer simulations
  - No dynamic models of human pilots
  - Simulated pilots react in zero time, perfectly predictably
  - Also do not detect and correct for off-nominal situations
  - Lack of human element raises serious fidelity concerns

Approach

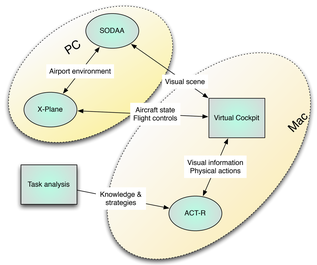
- Construct computational cognitive models of pilots taxiing
- Validate model. Two prongs:
  - Compare with extensive data taken from real operations at DFW airport (SODAA data)
    - Many issues still to be resolved in exactly how to do this comparison.
    - What is "good enough" performance on what metrics?
  - "Turing test": Can an SME discriminate model performance from real pilot performance?
- Deploy validated model
  - In place of human pseudopilots in HITL simulations
  - Use to populate database of human pilot response time distributions for use in large-scale simulations

ACT-R



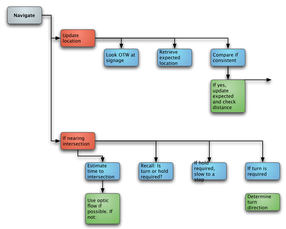
- ACT-R is a general-purpose theory and simulation architecture for developing models of human cognition and performance
- Inputs:
  - Knowledge
  - Task environment
  - Parameter settings
- Output:
  - Timstamped behavior sequence
  - Can run in real time

Simulation Platform



Task Analysis

- Knowledge included in the model is based on a detailed task analysis of taxiing
- Two primary sources:
  - Airline and FAA procedural documentation
  - Consultations with SMEs
- Initial analysis has been refined during implementation
- Example piece:



Model's Primary Tasks

- Steering
  - Corrective steering
    - Small steering adjustments to keep aircraft on centerline
    - Based on Salvucci's (2006) model of automobile driving
  - Turning
    - Examined real-world turn trajectories
    - Used those to compute steering adjustments model would need to make
    - Model gradually adjusts yoke setting to steer through turn
- Navigation
  - Model maintains a representation in memory of current location on taxi surface
  - Model scans for signage, compares expected location to what signage says
  - Updates position
  - Must take corrective action in cases of disagreement
- Scanning the taxiway
  - Look for incursions
  - Currently limited to looking for other aircraft, but will be expanded in scope in the future
- Maintain Speed
  - Make throttle/brake adjustments to keep speed in desired bounds

Model's Environment

- 737-800 jetliner in highly authentic environment
- DFW Airport
  - X-Plane representation of DFW is good, but not complete
  - Augmented with complete signage
- Surface Operations Data Analysis and Adaptation (SODAA) tool (Brinton, Lindsey, & Graham, 2010)
  - Records surface position of every aircraft on the DFW taxi surface over time
  - We have access to several segments of these recordings
- SODAA data integrated with X-Plane flight simulation platform
  - Single plane removed from the data stream
  - Replaced by ACT-R model
  - Model then taxis in real-time environment populated by planes that moved as they did in real DFW environment

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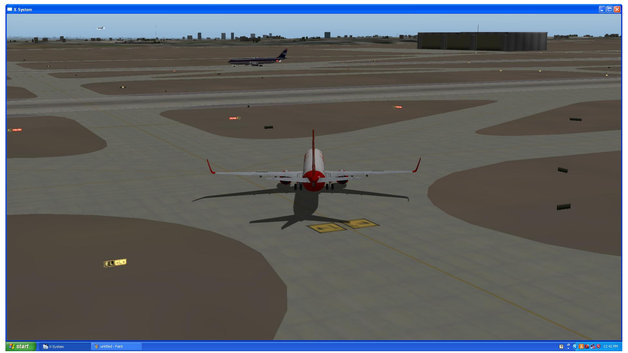
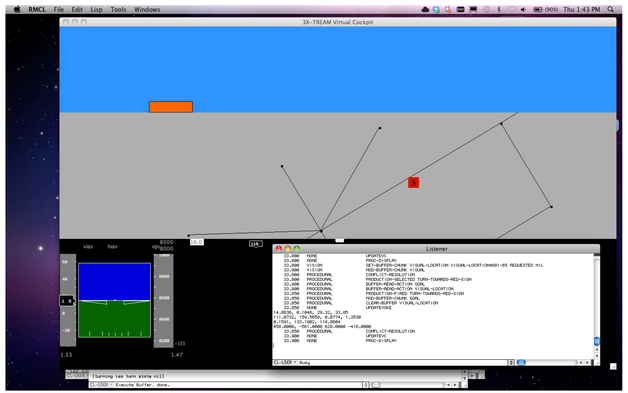
X-Plane view while taxiing



ACT-R model at the same point in time

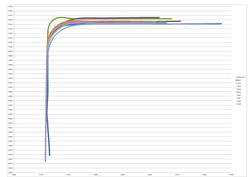


Validation: SODAA Data

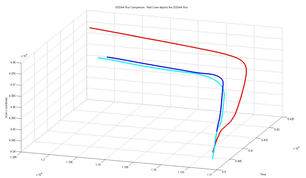
- Preliminary development is complete
  - Now refining and extending the model
  - Near-term changes to model to be based on validation efforts
- Validation of human performance models is not straightforward
  - Data for validation is frequently sparse
  - HITL simulations not always high fidelity
- Unique opportunity: SODAA data
  - Full time and position data from actual DFW operations
    - Not HITL simulation data, thus limiting fidelity concerns
  - Significant volume of data
- However, there are still issues
  - Position data only; no communications information
  - Do not know which trajectories are errors
- Raises important questions
  - What are the appropriate performance metrics?
  - What are the criteria for those metrics?
- Preliminary comparisons already useful
  - Qualitative mismatches immediately evident

Issues Identified

- Model generally matches spatial trajectories well
  - Dark blue line is human data; others are model runs



- However, model is too fast
  - Red is human data, blue are model runs



Validation: "Turing Test"

- Will use a second validation approach
- A "Turing test" for the model
- Multiple movies will be recorded showing out-the-window (OTW) view as ACT-R taxis
- Interspersed will be movies showing OTW as the plane follows the SODAA trajectory
- Can an SME reliably discriminate model-generated runs from human-generated runs?
- If so, will debrief SME on what cues gave model away
  - Direct future refinements toward correcting those mismatches

Future Directions and Applications

- Extending model
  - Address more task complexity
    - More complete knowledge for off-nominal situations
    - Natural language communications with ground control
  - Widen range of taxi tasks
    - Full set of different clearances
    - Different equipment (e.g., 747s)
    - Taxi in after landing
  - Possibly expand to other team members
    - Pilot not flying
    - Ground controllers
- Applications
  - Replace human "pseudopilots" in HITL simulations of ground controller activities
  - Evaluate impacts of changes in displays or other cockpit technology
    - Virtual HITL simulations
  - Inform database of pilot response time distributions
    - DB being developed by Aptima as part of the same project
    - Literature is often incomplete; model can fill holes
  - Perhaps eventually, participate in large-scale NASA/FAA fast-time simulations of metroplex air/ground traffic

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