Developing a General Framework for Human Autonomy Teaming

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Problems with Automation

- **Brittle**
  - Automation often operates well for a range of situations but requires human intervention to handle boundary conditions (Woods & Cook, 2006)

- **Opaque**
  - Automation interfaces often do not facilitate understanding or tracking of the system (Lyons, 2013)

- **Miscalibrated Trust**
  - Disuse and misuse of automation have lead to real-world mishaps and tragedies (Lee & See, 2004; Lyons & Stokes, 2012)

- **Out-of-the-Loop Loss of Situation Awareness**
  - Trade-off: automation helps manual performance and workload but recovering from automation failure is often worse (Endsley, 2016; Onnasch, Wickens, Li, Manzey, 2014)
HAT Solutions to Problems with Automation

- **Brittle**
  - *Negotiated decisions* puts a layer of human flexibility into system behavior

- **Opaque**
  - Requires that systems be designed to be *transparent*, present *rationale* and *confidence*
  - Communication should be in terms the operator can easily understand (*shared language*)

- **Miscalibrated Trust**
  - Automation *display of rationale* helps human operator know when to trust it

- **Out-of-the-Loop Loss of Situation Awareness**
  - *User directed interface*; adaptable, not adaptive automation
  - Greater interaction (e.g., *negotiation*) with automation reduces likelihood of being out of the loop
Tenets of HAT

Make the Automation into a Teammate

• Transparency
• Communication of Rationale
• Communication of Confidence
• Shared Language
• Shared Goals
• Shared Plans
• Agreed upon allocation of responsibility
• Minimized Intent Inferencing

Negotiation

Bi-Directional Communication

User Directed Interface

Plays
HAT Agent

Alerts
Context
Responses to Queries
- Alternatives
- Transparency info
- Predicted Outcomes
- Reasoning
- Confidence level

Context
- Time Pressure
- User Info
- more

HAT Agent
- Plays
  - Goals
  - Risks to achieving goals
  - Mitigations
- Transparency Info
- Authority Info
- Scratch Pad

Interface
- Display
- Audio
- Visual

Automation

Requests
Polling for Risks

Queries/Requests
- A v. B
- Why?
- What If?
Implementation

Tenets

Human In The Loop Simulations
Implementation

Tenets → Human In The Loop Simulations

Tenets

Human In The Loop Simulations
Simulated Ground Station
ELP and ACFP

Research prototype software, Intelligent Systems Division, PI: D. Smith

   –  Cockpit decision aid
   –  Route planning for (serious) emergencies
      –  control system failures
      –  physical damage
      –  fires
   –  Time & Safety were dominant considerations

   –  Ground station decision aid
   –  Diversion selection, route planning, route evaluation
      –  weather diversion
      –  medical emergencies
      –  less critical system failures
Find the best landing sites and routes for the aircraft
ELP Approach

Consider all runways within range (150 miles)
Construct “obstacles” for weather & terrain
Search for paths to each runway
Evaluate risk of each path
Present ordered list

< 10 seconds
ELP’s Risk Model

Enroute path
  Distance/time
  Weather

Approach path
  Ceiling & Visibility
  Approach minimums
  Population density

Runway
  Length
  Width
  Surface condition
  Relative wind

Airport
  Density altitude
  Tower
  Weather reporting
  Emergency facilities

\[
P_{\text{stable}} = \text{probability of success} / \text{nm in stable flight}
\]
\[
P_{\text{wx}} = \text{probability of success} / \text{nm in light weather}
\]
\[
P_{\text{leg}} = (P_{\text{stable}} \ast (P_{\text{wx}})^S)^D
\]
\[
P_{\text{route}} = \prod P_{\text{leg}}
\]

\[
P_{\text{appr}} = P_{\text{leg}} \ast P_{\text{ceil}} \ast P_{\text{vis}}
\]

\[
P_{\text{rnwy}} = P_{\text{length}} \ast P_{\text{width}} \ast P_{\text{surf}} \ast P_{\text{speed}} \ast P_{\text{xwind}}
\]
Emergency Page on the CDU

- Runway length
- Airport
- Select
- Principal Risks
- Go to Previous/Next Page
- Page #
- Distance to airport
- Bearing to airport
- Show Airport Info Page
- Update
- Execute the selection
ELP Routes on the Navigation Display
ELP Experiment (2010)

Evaluation of ELP in ACFS
- 3 physical damage scenarios
- 5 pilot teams
- 16 scenarios each

Results
- Decision **quality** somewhat better in adverse weather
- Decision **speed** much better in adverse weather
- Damage Severity not a significant factor

Pilot feedback:
“... your software program alleviates the uncertainty about finding a suitable landing site and also reduces workload so the crew can concentrate on "flying" the aircraft.”
Sample Run

Damage occurred

Decision made

Actual track

Recommended route

Ideal immediate decision

other options considered

KHX 08

KHX 26

KCAO 02

KCAO 20
ACFP differences

Multiple aircraft
Much wider geographic area
Additional optimization criteria
  – medical facilities
  – maintenance facilities
  – passenger facilities
  – connections
Constrained requests
  – runway length
  – distance
Route evaluation
  – current route/destination
  – proposed changes
### Optimization

#### Situations:
- weather reroute
- weather diversion
- systems diversion
  - anti-skid braking
  - radar altimeter
- medical emergency
  - heart attack
  - laceration
- engine loss
- depressurization
- damage
- cabin fire

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Simulated Ground Station
ACFP Before HAT

Recommended airports - rank ordered.
Adding HAT Principles to the Ground Station

With Added Transparency
Adding HAT Principles to the Ground Station
Adding HAT Principles to the Ground Station

- Human-Directed: Operator calls “Plays” to determine who does what

A play encapsulates a plan for achieving a goal. It includes roles and responsibilities of what is the automation going to do and what is the operator going to do.
Adding HAT Principles to the Ground Station

- Transparency: Divert reasoning and factor weights are displayed.
- Negotiation/Dialog: Operators can change factor weights to match their priorities.
- Shared Language/Communication: Numeric output from ACFP was found to be misleading by pilots. Display now uses English categorical descriptions.
HAT Simulation: Tasks

• Participants, with the help of automation, monitored 30 aircraft
  – Alerted pilots when
    • Aircraft was off path or pilot failed to comply with clearances
    • Significant weather events affect aircraft trajectory
    • Pilot failed to act on EICAS alerts
  – Rerouted aircraft when
    • Weather impacted the route
    • System failures or medical events force diversions

• Ran with HAT tools and without HAT tools
HAT Simulation: Results

- Participants preferred the HAT condition overall (rated 8.5 out of 9).

- HAT displays and automation preferred for keeping up with operationally important issues (rated 8.67 out of 9)

- HAT displays and automation provided enough situational awareness to complete the task (rated 8.67 out of 9)

- HAT displays and automation reduced the workload relative to no HAT (rated 8.33 out of 9)
HAT Simulation: Results

- HAT workload reduction was marginally significant (HAT mean 1.7; No HAT mean 2.3, p = .07)
HAT Simulation: Debrief

• Transparency
  − “This [the recommendations table] is wonderful…. You would not find a dispatcher who would just be comfortable with making a decision without knowing why.”

• Negotiation
  − “The sliders was [sic] awesome, especially because you can customize the route…. I am able to see what the difference was between my decision and [the computer’s decision].”

• Human-Directed Plays/Shared Plans
  − “Sometimes [without HAT] I even took my own decisions and forgot to look at the [paper checklist] because I was very busy, but that didn’t happen when I had the HAT.”
HAT Simulation: Summary

• Participants liked where we were headed with the HAT concept
  – Increased Situation Awareness
  – Reduced Workload

• Things we didn’t get quite right
  – Annunciations: People liked them but thought there were too many
  – Voice Control: Did not work well. Need a more complete grammar, better recognition
  – Participants didn’t always understand what the goal of a play was

• Things we didn’t get to
  – Airlines hate divers. We need to put in support to help avoid them
  – Plays need more structure (branching logic)
  – Roles and responsibilities need to be more flexible
  – Limited ability to suggest alternatives
Where we are and planned FY17 work

- Trust repair with automated system part-task
  Now (Transparency Part Task)

- Implementing HAT features on the flight deck
  Spring ’17 (Flight Deck)

- Developing a software framework for creating HAT Agents

- Updating ground station re-routing tool
  Summer ’17 (Ground Station Agent)

- UX testing
Generalization

- Tenets
- Thought Experiments
- Human In The Loop Simulations
HAT in Photography
HAT in Photography
HAT in Photography
HAT in Photography
HAT in Photography
HAT in Navigation

To The Fencing Center
From My Location

23 min
14 mi - Guadalupe Pkwy S
Fastest route
12 mi
Take exit 144B onto CA-134

Faster Route Available
Save 11 min using US-101 N

Cancel
GO
HAT in Navigation

Centerwide Announcement

UPDATE - Main Gate Reopening Monday, April 4, 2016
To: Recipient List Suppressed

TO: Resident Staff

FROM: Janice Fried, Director, NASA Research Park Office

SUBJECT: UPDATE - Main Gate Reopening Monday, April 4, 2016

The Main Gate to NASA Ames Research Center will reopen ** at 6

You will notice that the Main Gate intersection has changed. The
gate need to present identification at the Arnold Avenue gate. Because
badges at the visitor badging office before approaching the Arnold

gate will return to the same operating hours as before the close
- The Moffett Blvd./Main gate and Arnold Avenue gate will be oper
- The Ellis Street gate will operate seven days a week, from 5 a.m
- The Mark Avenue gate will operate from Monday through Friday,

- The King Road/Gate 18 will be closed.

Construction will continue in the area of the Main gate. There may
during this period of construction. Please allow additional travel tin
advance of known delays.
Lessons

• Seems applicable to a wide variety of automation
• Plays are a big part of the picture
  – Provide a method for moving negotiation to less time critical periods
  – Provide a mechanism for creating a shared language
Design Patterns

• Looking at a variety of situations, we see common problems with common solutions
  – Bi-Directional Communication solves a problem of keeping the human in the loop with potential problems in the current plan and reduces brittleness by opening up the system to operator generated solutions
  – Plays solve the problem allowing the system to adopt to different conditions without having the system infer the operator’s intent
• In other domains, people have attempted to capture similar problem-solution pairs using “design patterns”
  – Architecture (Alexander, et al., 1977)
    • E.g., Raised Walkways solve the problem of making pedestrians feel comfortable around cars
  – Computer Programming (Gamma, et al., 1994)
    • E.g., Observers solve the problem of maintaining keeping one object aware of the state of another object
Design Patterns for HAT

• Working with the NATO working group on Human Autonomy Teaming (HFM-247) to develop design patterns for HAT

• Original Conception was to identify relationships between different agents (after Axel Schulte, Donath, & Lange, 2016)
Design Patterns for HAT

- Working with Gilles Coppin from the NATO Working Group on a Bi-Directional Communication pattern
- Modeled after Gamma et al specifications:
  - Intent: Support generation of input from all relevant parties and its integration into decisions
  - Motivation: Reduce brittleness of the system by consolidating information and skills
  - Applicability: May not be applicable in urgent situations or with automation that lacks structure (e.g., neural networks)
HAT Agent

Alerts
- Context
- Responses to Queries
  - Alternatives
  - Transparency info
    - Predicted Outcomes
    - Reasoning
    - Confidence level

Context
- Time Pressure
- User Info
- more

Queries/Requests
- A v. B
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Automation

HAT Agent
- Plays
  - Goals
  - Risks to achieving goals
  - Mitigations
- Transparency Info
- Authority Info
- Scratch Pad

Interface
- Display
- Audio
- Visual

Etiquette Rules/Contextual Sensitivity

Requests
- Polling for Risks

Operator

Queries/Requests
- A v. B
- Why?
- What If?
Thank you!

Three papers to appear in the proceedings of at the 8th International Conference on Applied Human Factors and Ergonomics (AHFE 2017).

- Shively, R. J., Lachter, J., Brandt, S. L., Matessa, M., Battiste, V., & Johnson, W. W., Why Human-Autonomy Teaming?
- Lachter, J., Brandt, S. L., Sadler, G., & Shively, R. J., Beyond Point Design: General Pattern to Specific Implementations.