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

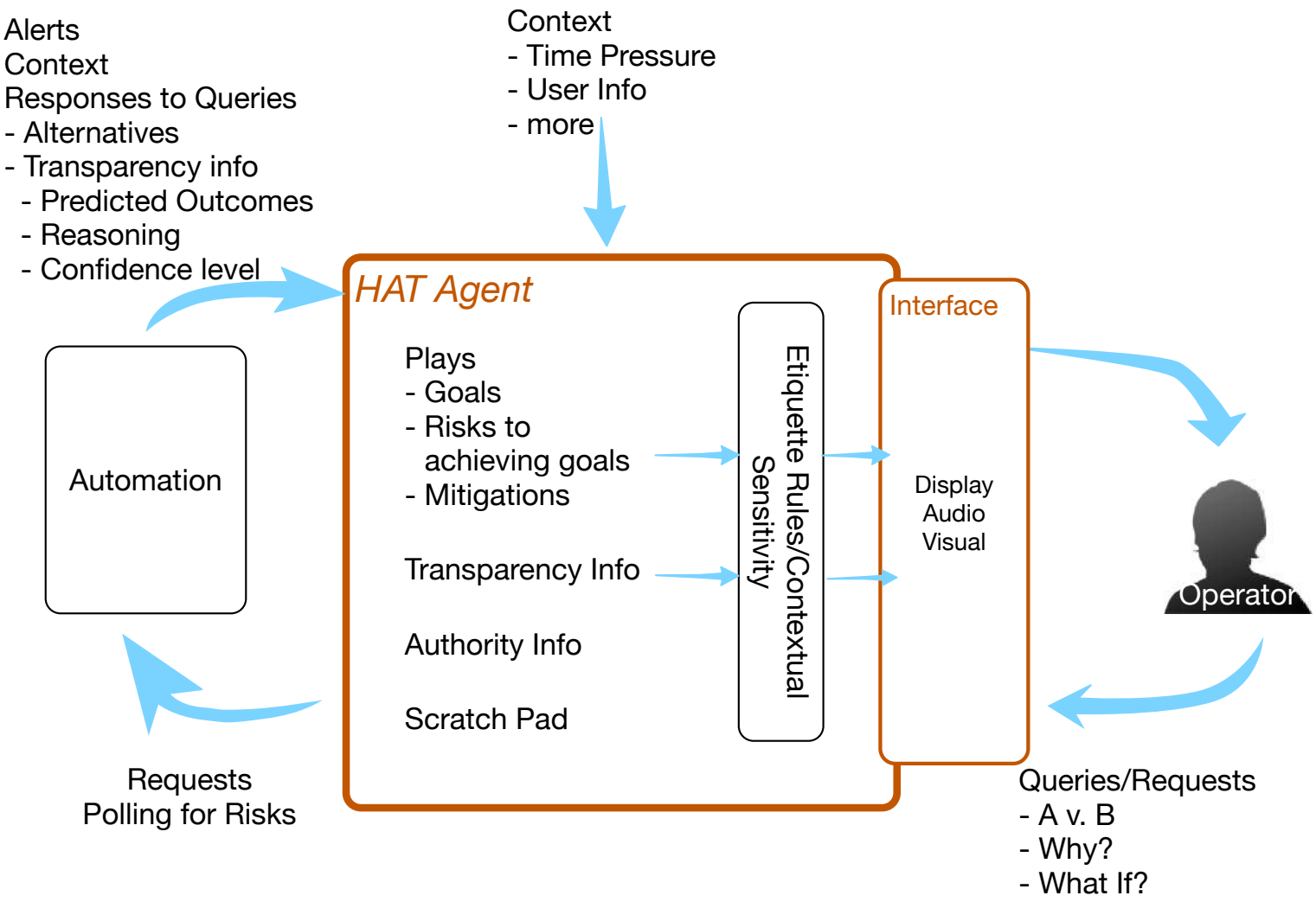
Make the Automation into a Teammate

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

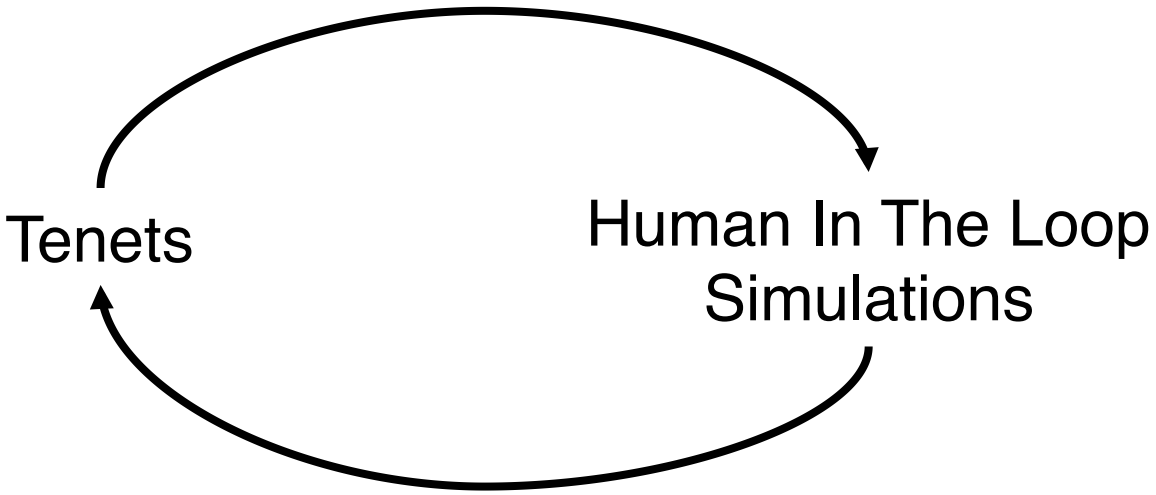
Negotiation
Bi-Directional Communication

User Directed Interface
Plays

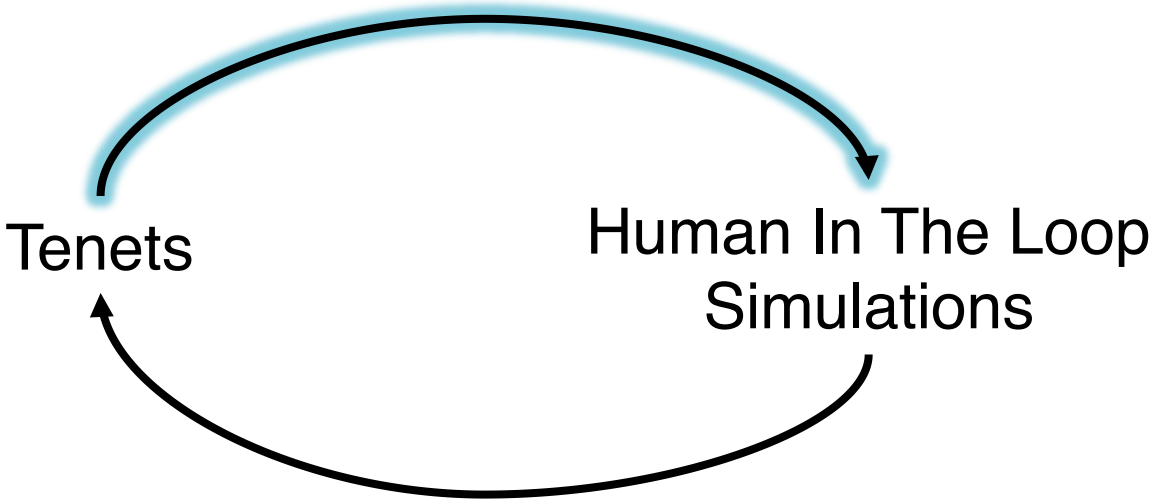
HAT Agent


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
Etiquette Rules/Contextual Sensitivity
Interface
Display
Audio
Visual
Automation
Operator
Requests
Polling for Risks
Queries/Requests
- A v. B
- Why?
- What If?

Implementation



Implementation



Simulated Ground Station

ELP and ACFP

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

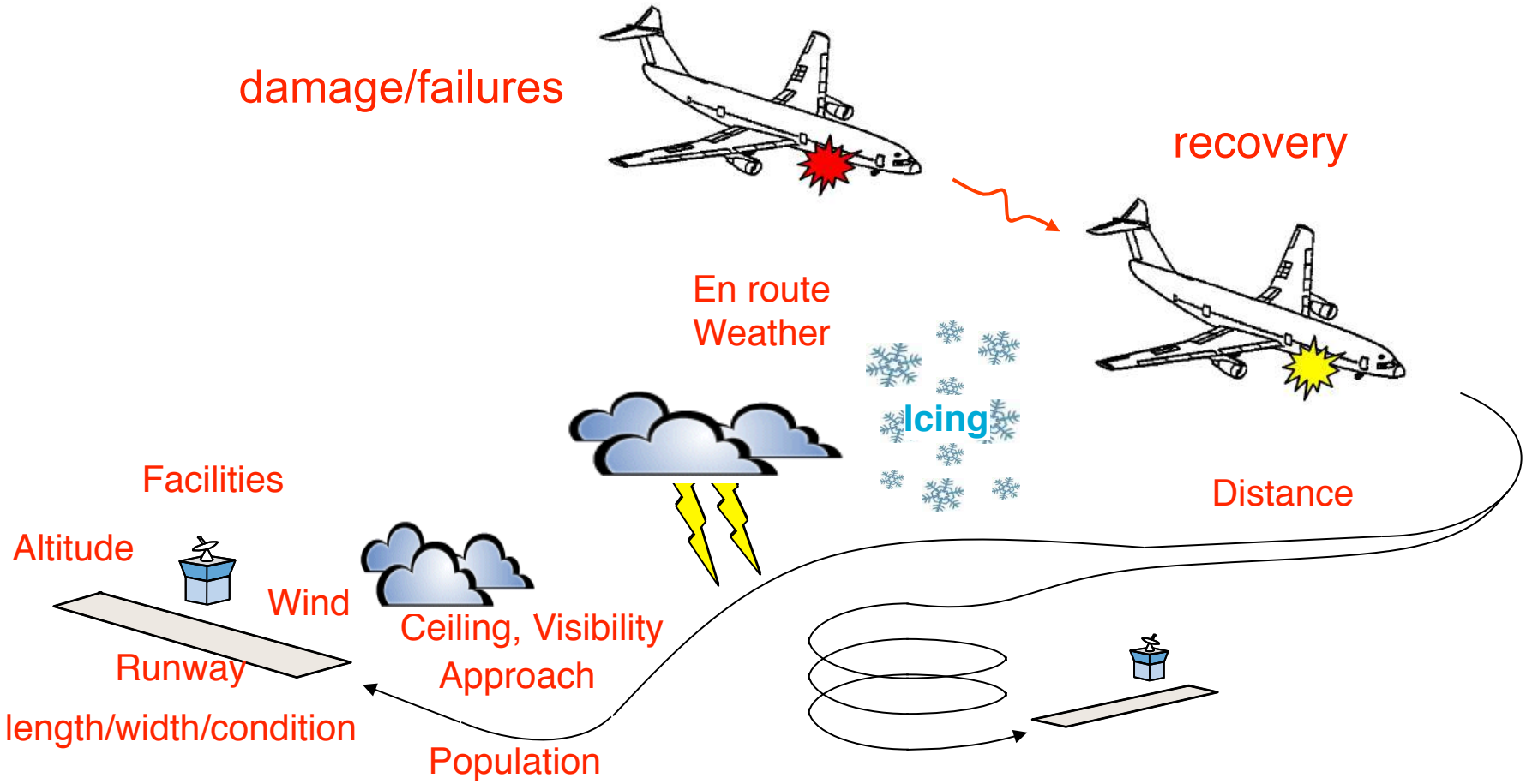
ELP – Emergency Landing Planner (2007-2012)

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

ACFP – Autonomous Constrained Flight Planer (2013-2017)

- Ground station decision aid
- Diversion selection, route planning, route evaluation
  - weather diversion
  - medical emergencies
  - less critical system failures

ELP Objective



Find the best landing sites and routes for the aircraft

ELP Approach

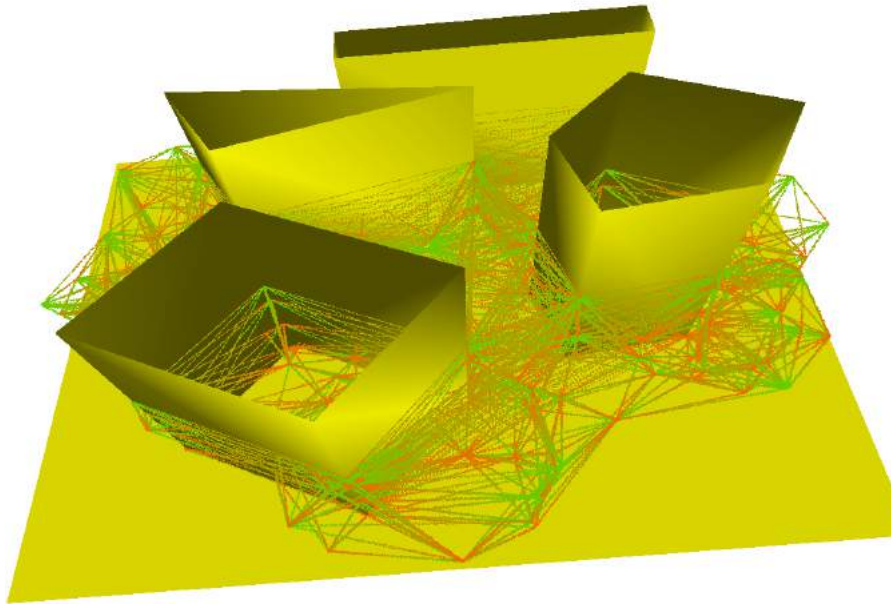
Consider all runways within range (150 miles)

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

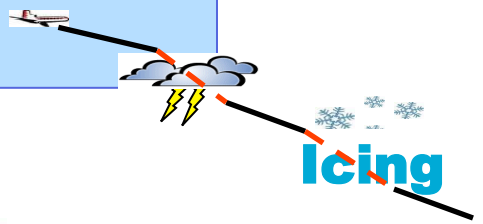
- Enroute path
  - Distance/time
  - Weather
- Approach path
  - Ceiling & Visibility
  - Approach minimums
  - Population density
- Runway
  - Length
  - Width
  - Surface condition
  - Relative wind
- Airport
  - Density altitude
  - Tower
  - Weather reporting
  - Emergency facilities

P_{stable} ≡ probability of success / nm in stable flight

P_{wx} ≡ probability of success / nm in light weather

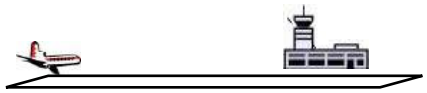
$P_{leg} \equiv (P_{stable} * (P_{wx})^S)^D$

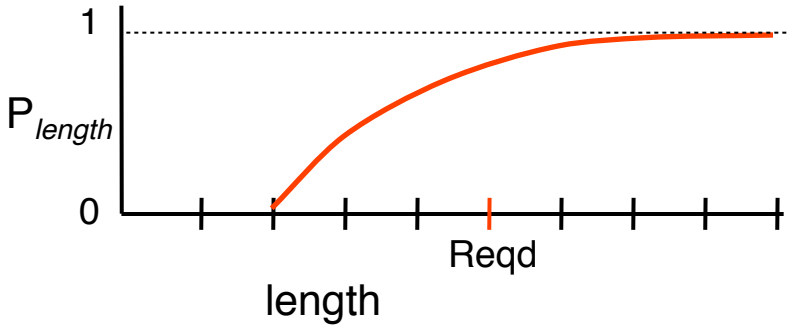
$P_{route} \equiv \prod P_{leg}$



$P_{appr} \equiv P_{leg} * P_{ceil} * P_{vis}$

$P_{rnwy} \equiv P_{length} * P_{width} * P_{surf} * P_{speed} * P_{xwind}$





Emergency Page on the CDU

Runway length

Runway

Airport

Select

Principal Risks

Page #

Distance to airport

Bearing to airport

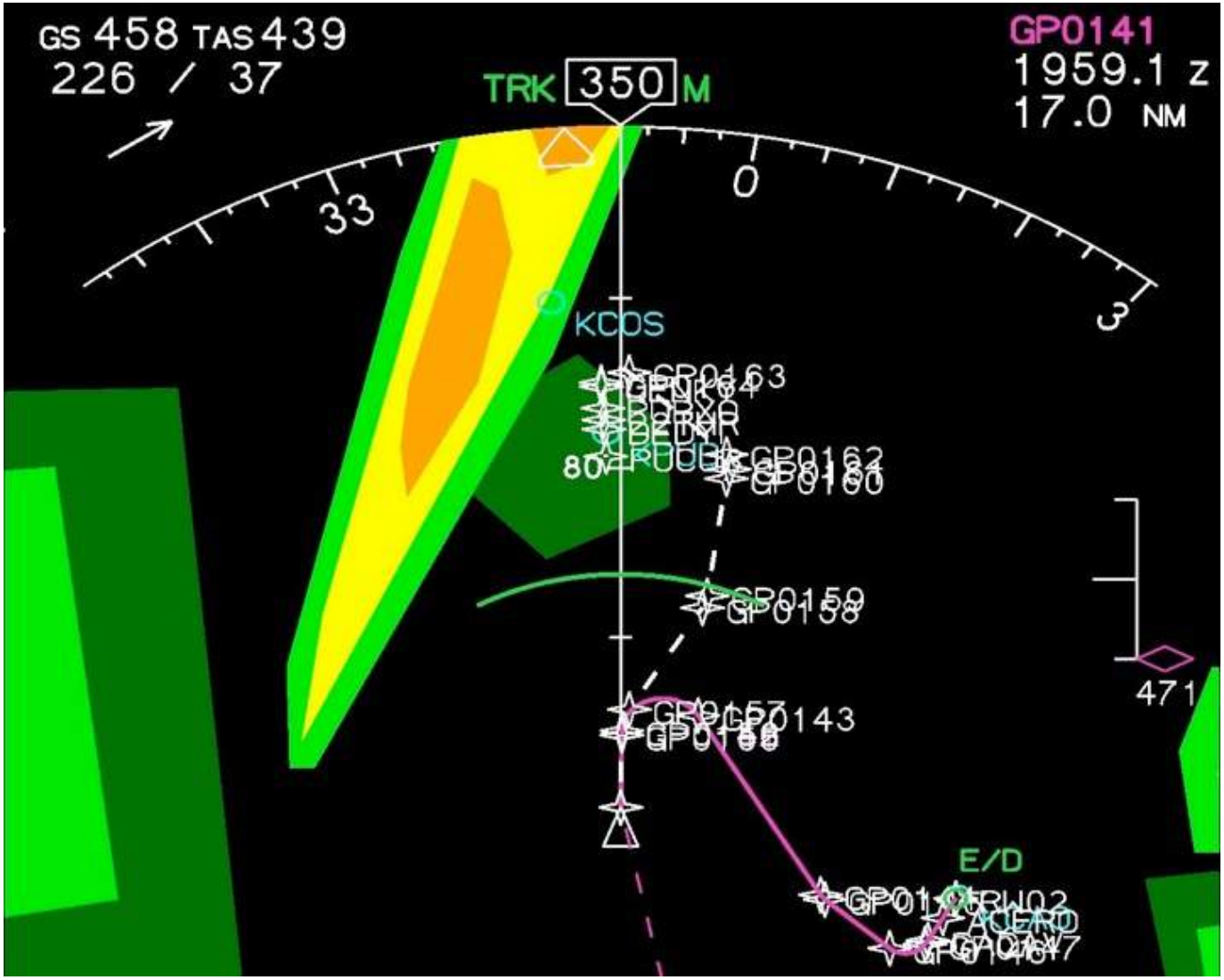
Show Airport Info Page

Update

Execute the selection

Go to Previous/Next Page

ELP Routes on the Navigation Display



ELP Experiment (2010)

Evaluation of ELP in ACFS

- 3 physical damage scenarios
- 5 pilot teams
- 16 scenarios each

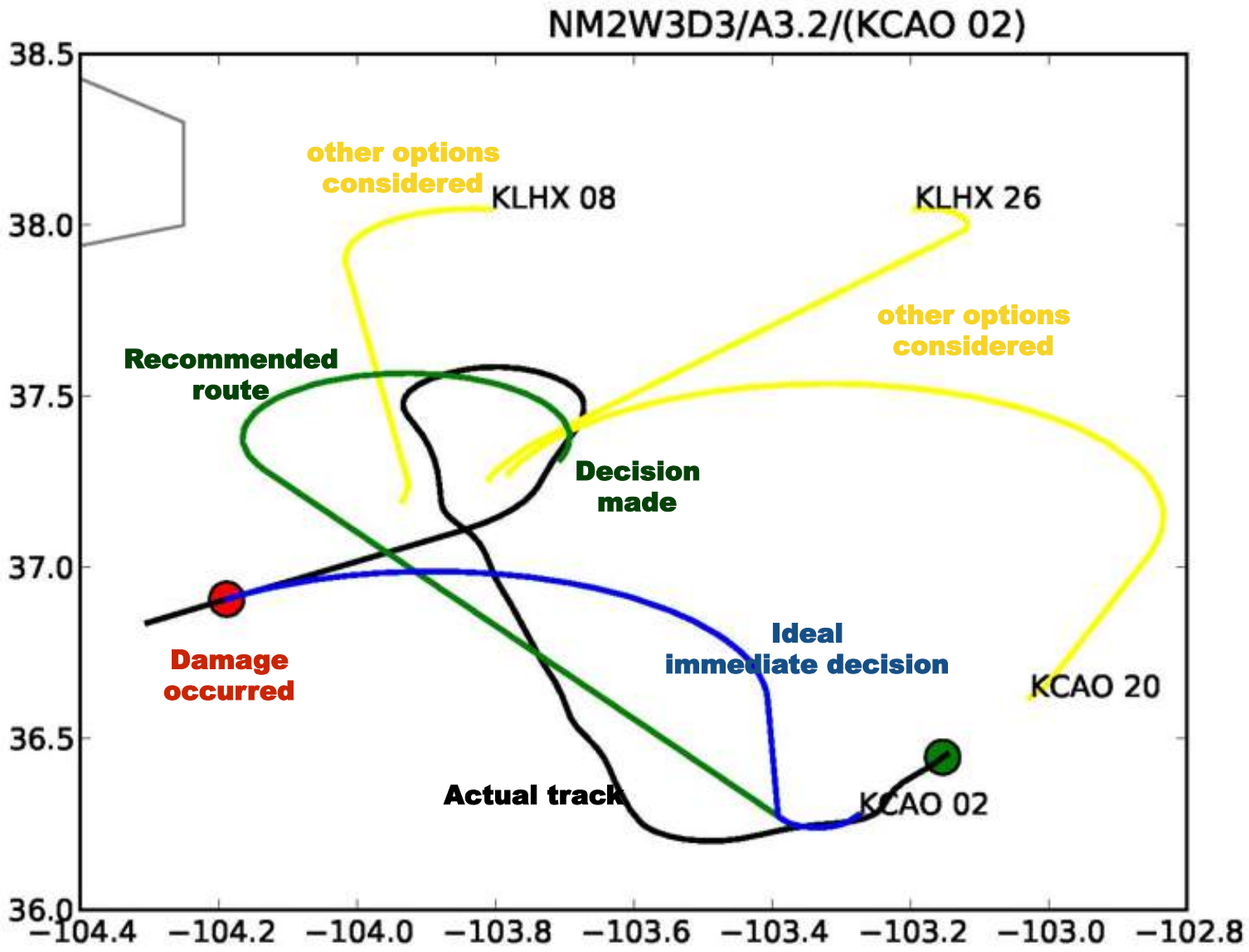
Results

- 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


NM2W3D3/A3.2/(KCAO 02)
38.5
38.0
37.5
37.0
36.5
36.0
−104.4
−104.2
−104.0
−103.8
−103.6
−103.4
−103.2
−103.0
−102.8
other options considered
KLHX 08
KLHX 26
other options considered
Recommended route
Decision made
Damage occurred
Ideal immediate decision
KCAO 20
Actual track
KCAO 02

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

RCO Ground station

Optimization

Situations:

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

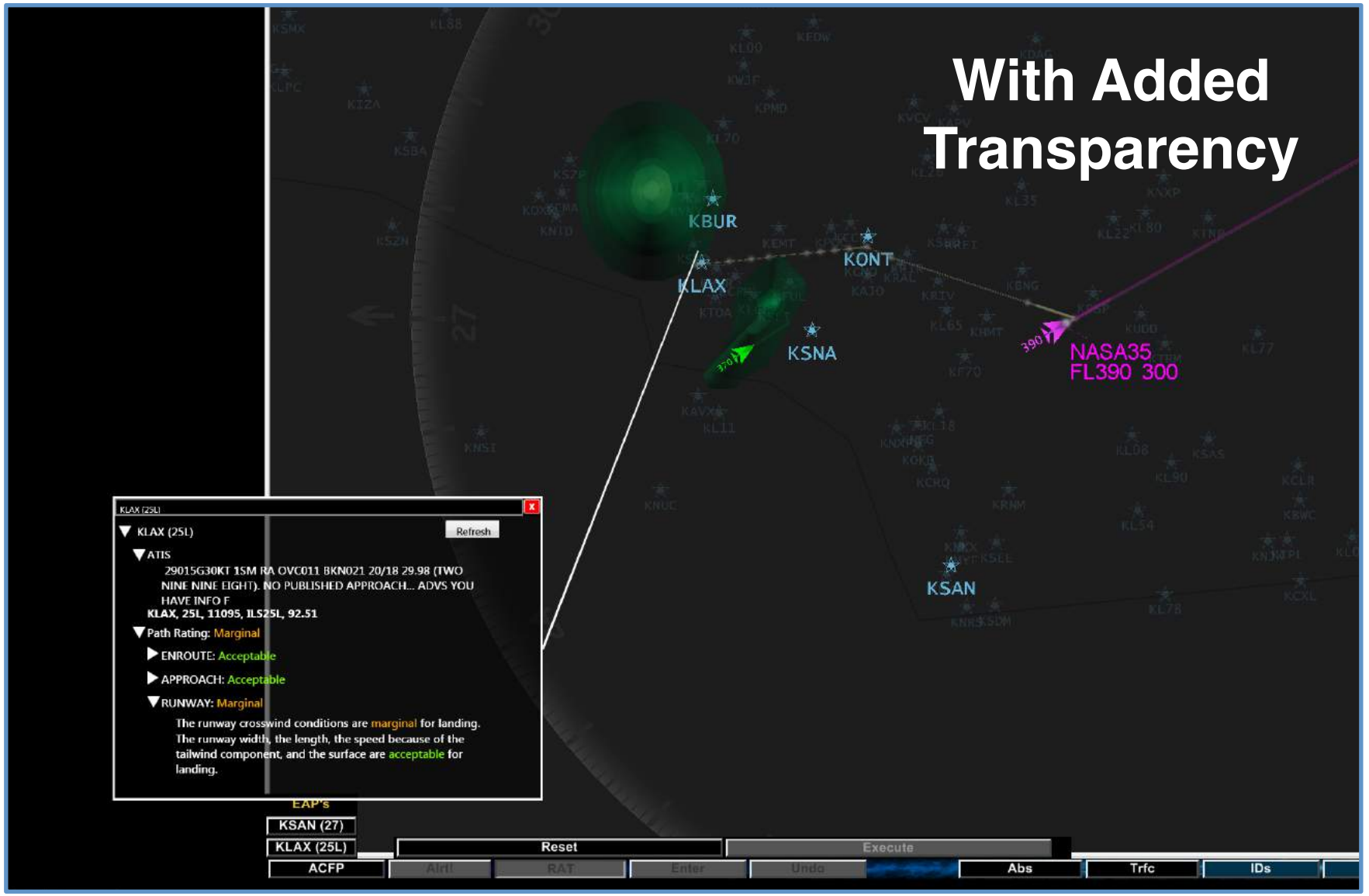
Safety	Time	Medical	Conven.	Maint.
★	★		★	
★			★	
★			★	★
★			★	★
★		★	★	
★		★	★	
★	★		★	★
★	★			★
★	★			
★	★			

Simulated Ground Station

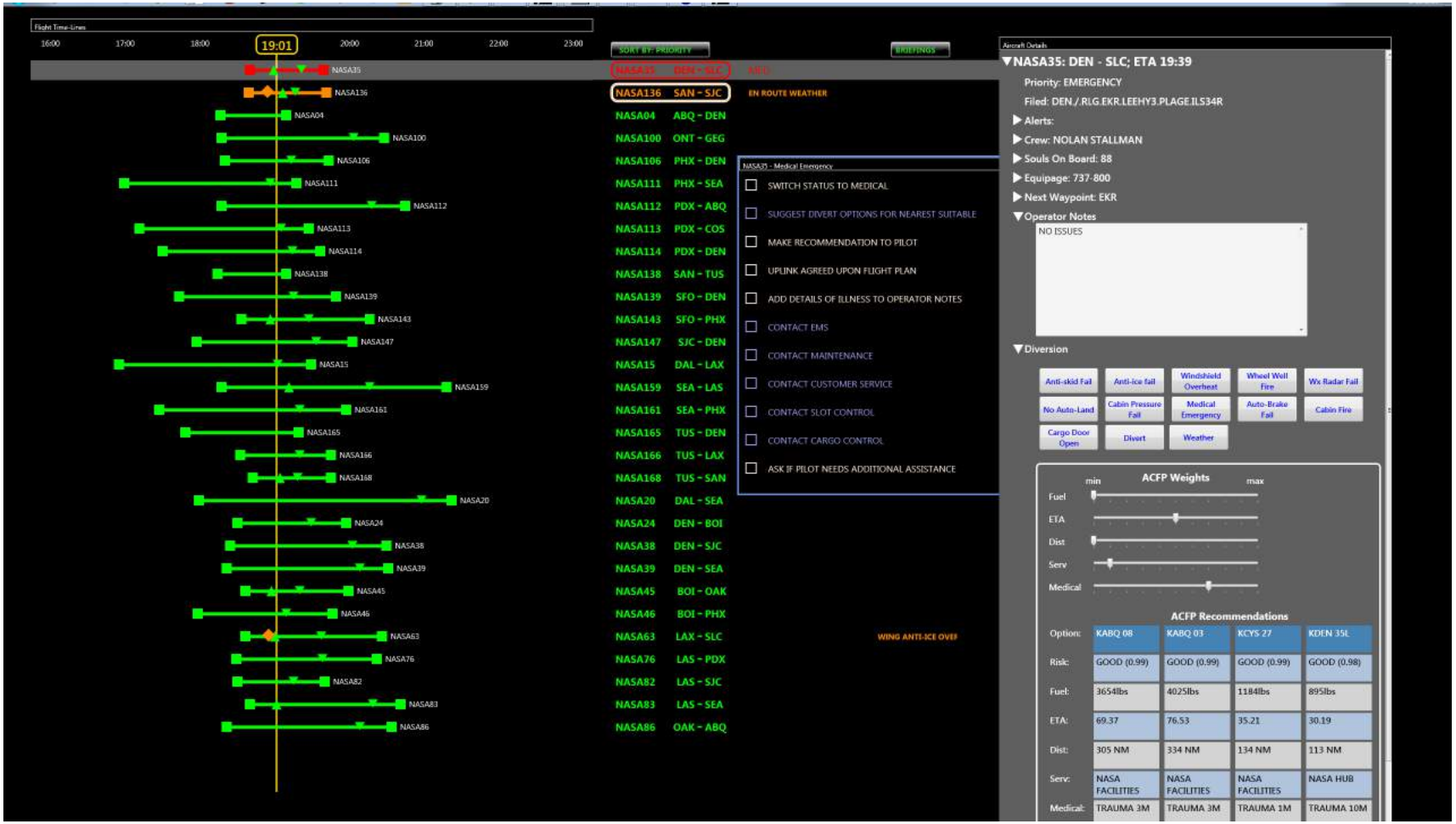
ACFP Before HAT

Recommended airports - rank ordered.

Adding HAT Principles to the Ground Station

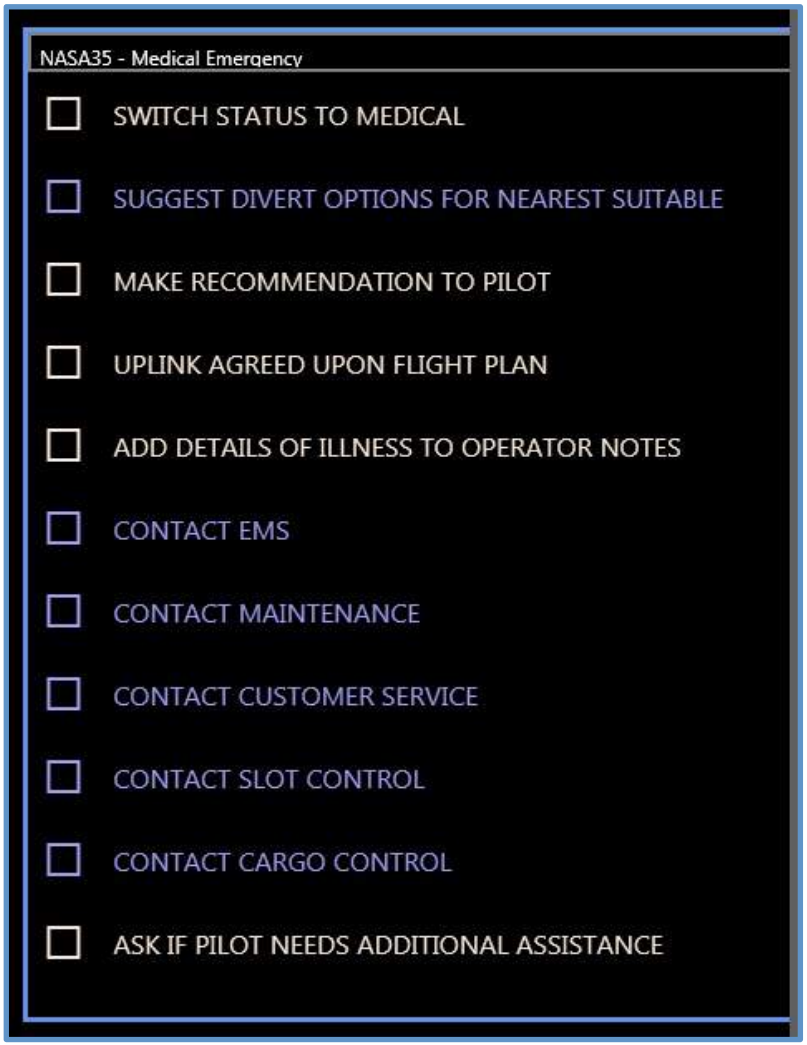


Adding HAT Principles to the Ground Station



Adding HAT Principles to the Ground Station

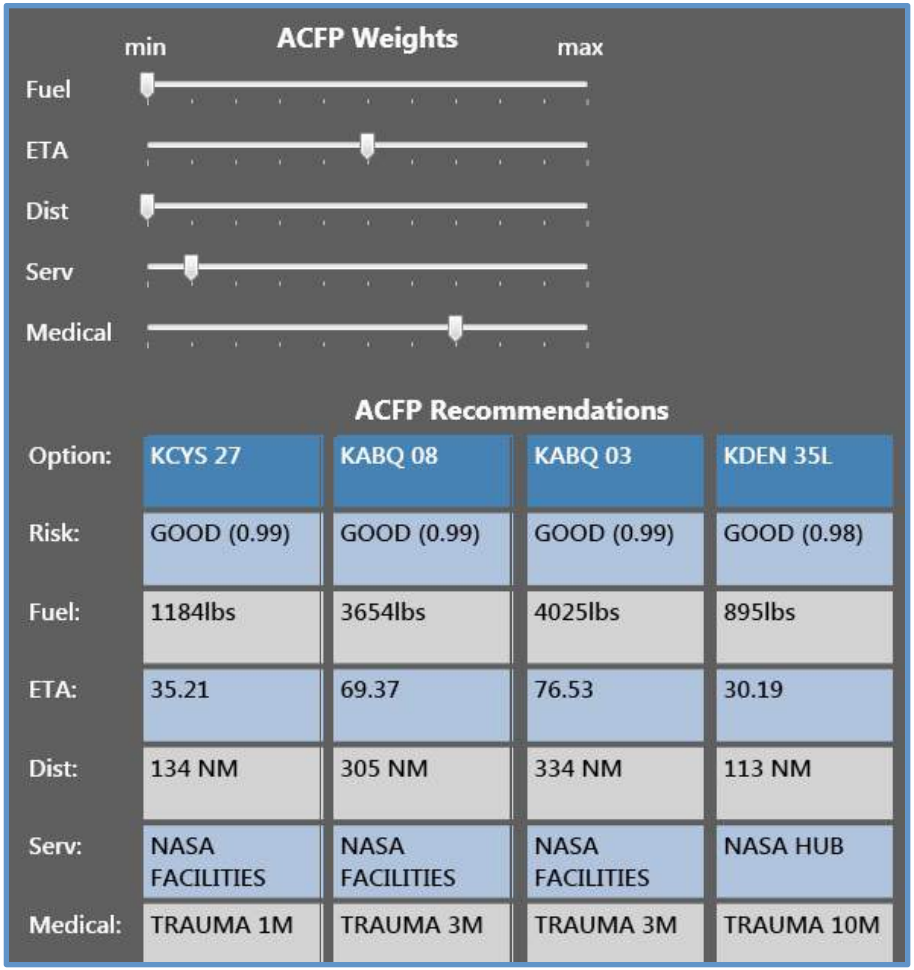
- Human-Directed: Operator calls “Plays” to determine who does what



A play encapsulates a plan for achieving a goal.
It includes roles and responsibilities
what is the automation going to do
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.



ACFP Recommendations

Option:	KCYS 27	KABQ 08	KABQ 03	KDEN 35L
Risk:	GOOD (0.99)	GOOD (0.99)	GOOD (0.99)	GOOD (0.98)
Fuel:	1184lbs	3654lbs	4025lbs	895lbs
ETA:	35.21	69.37	76.53	30.19
Dist:	134 NM	305 NM	334 NM	113 NM
Serv:	NASA FACILITIES	NASA FACILITIES	NASA FACILITIES	NASA HUB
Medical:	TRAUMA 1M	TRAUMA 3M	TRAUMA 3M	TRAUMA 10M

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

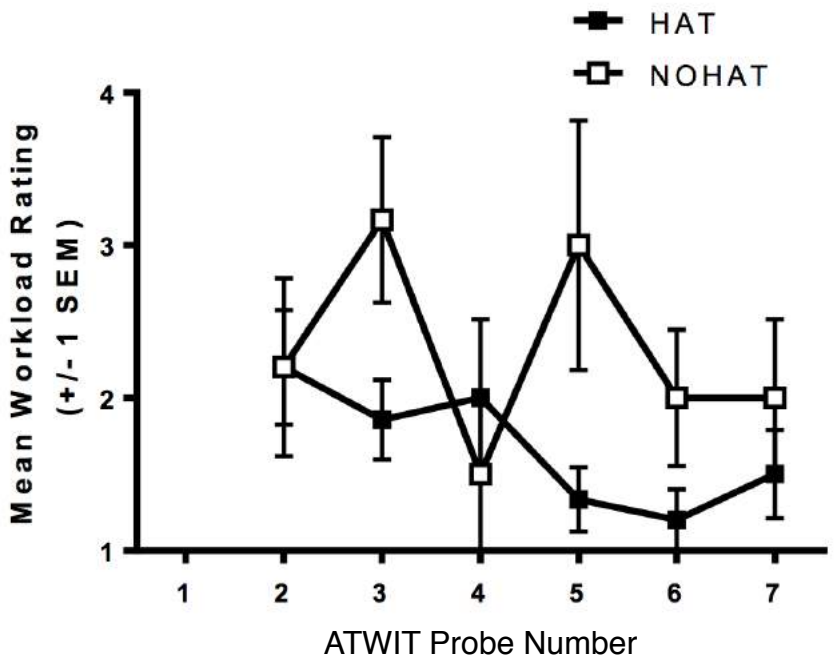
- Ran with HAT tools and without HAT tools

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 to 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 diverts. 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)

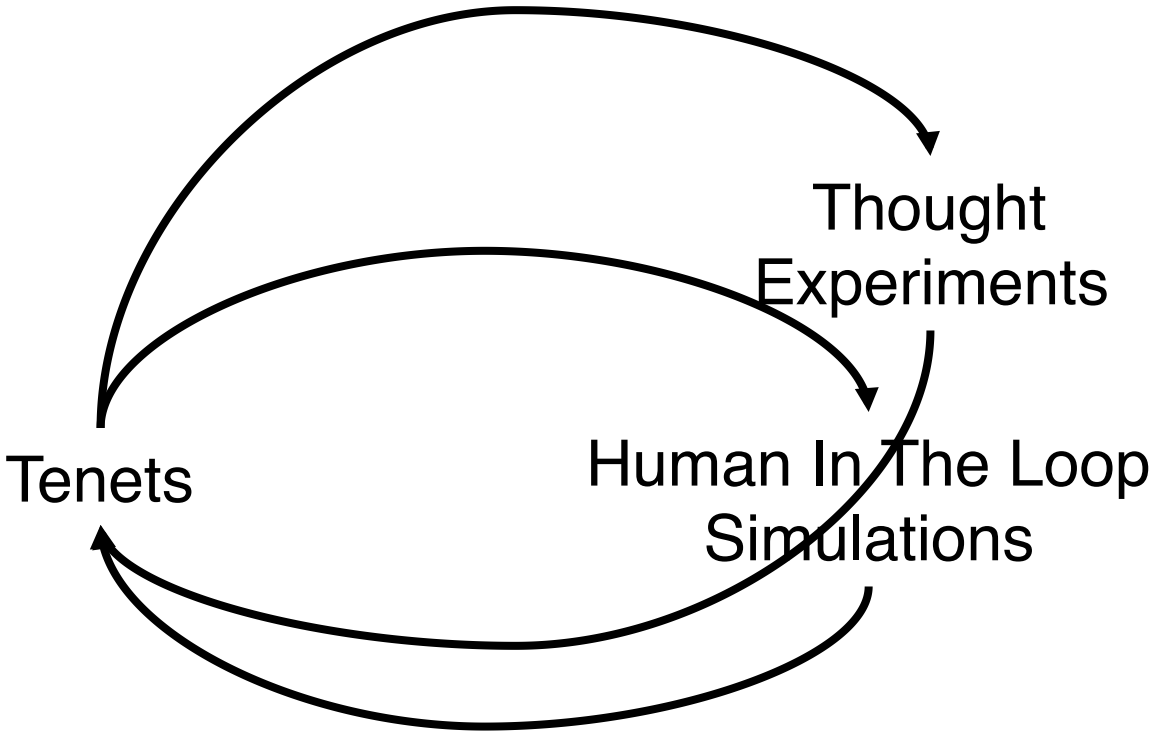
- Implementing HAT features on the flight deck

Spring ’17 (Flight Deck)

- Developing a software framework for creating HAT Agents
- Updating ground station re-routing tool
- UX testing

Summer ’17 (Ground Station Agent)

Generalization



HAT in Photography

HAT in Photography

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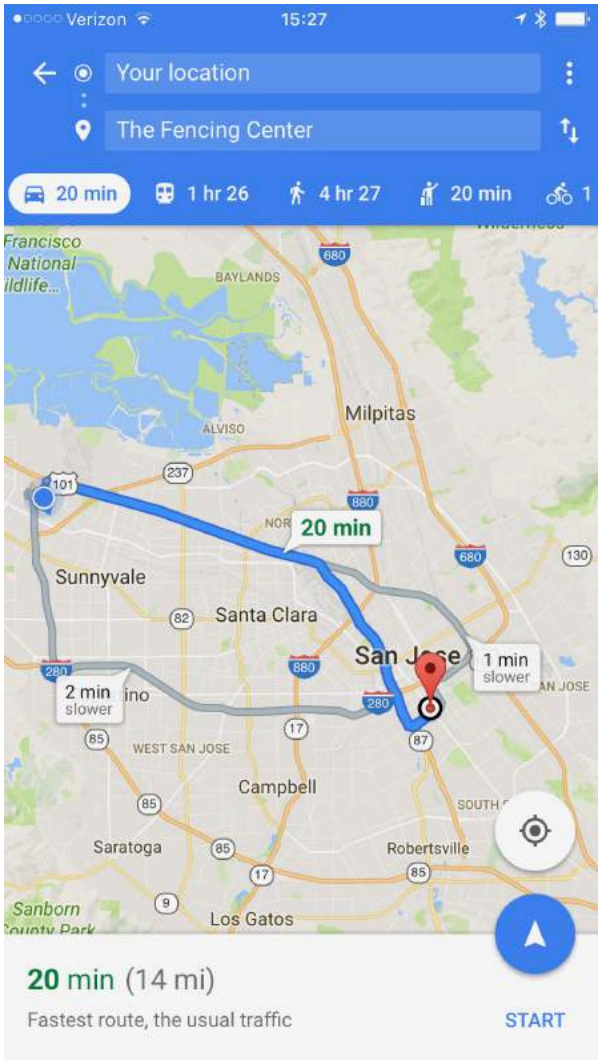
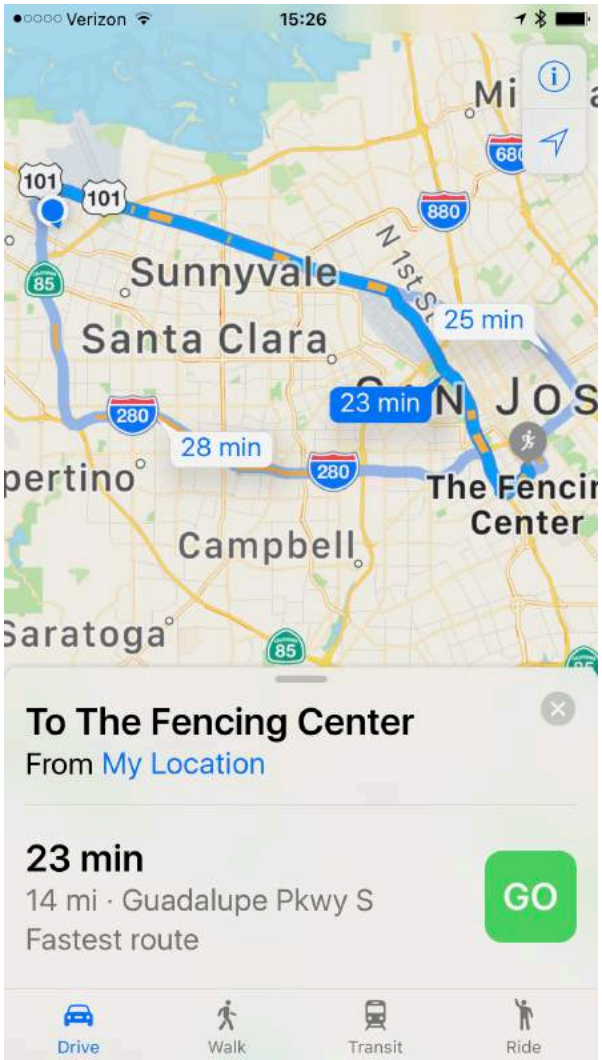
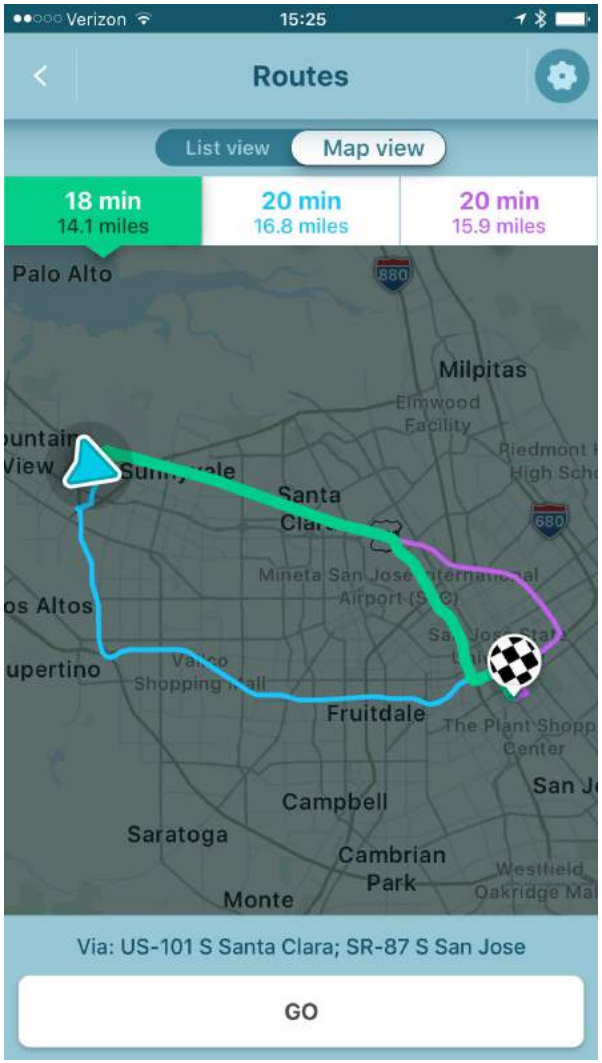
HAT in Photography

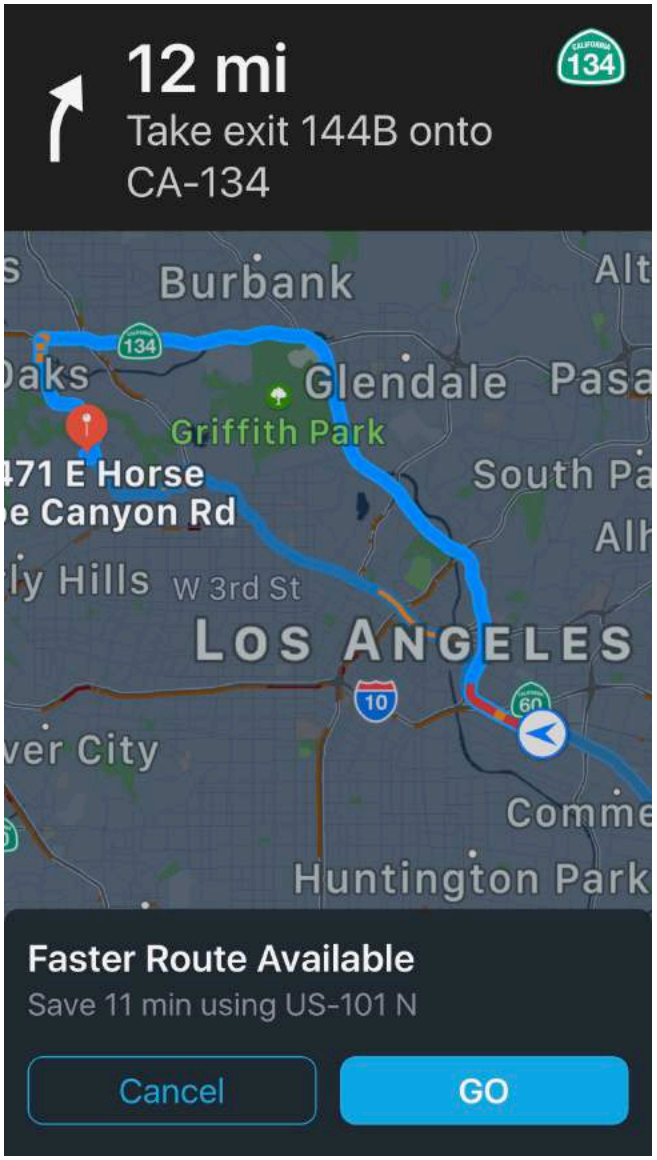
HAT in Navigation







HAT in Navigation



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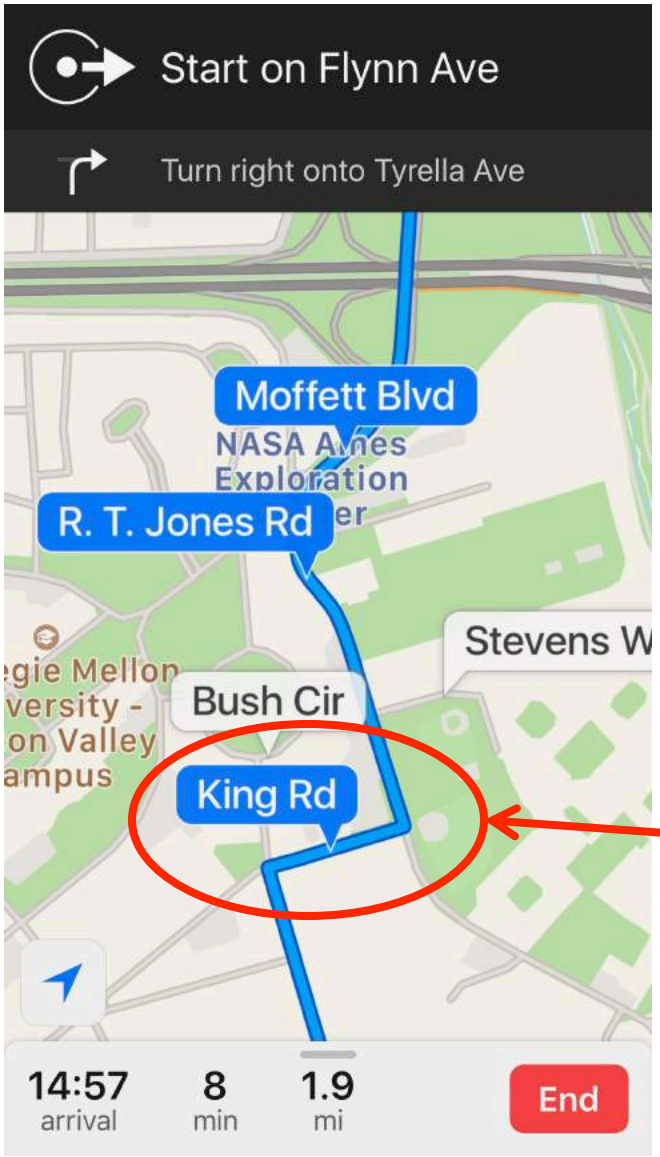


Centerwide Announcement

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, 201

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

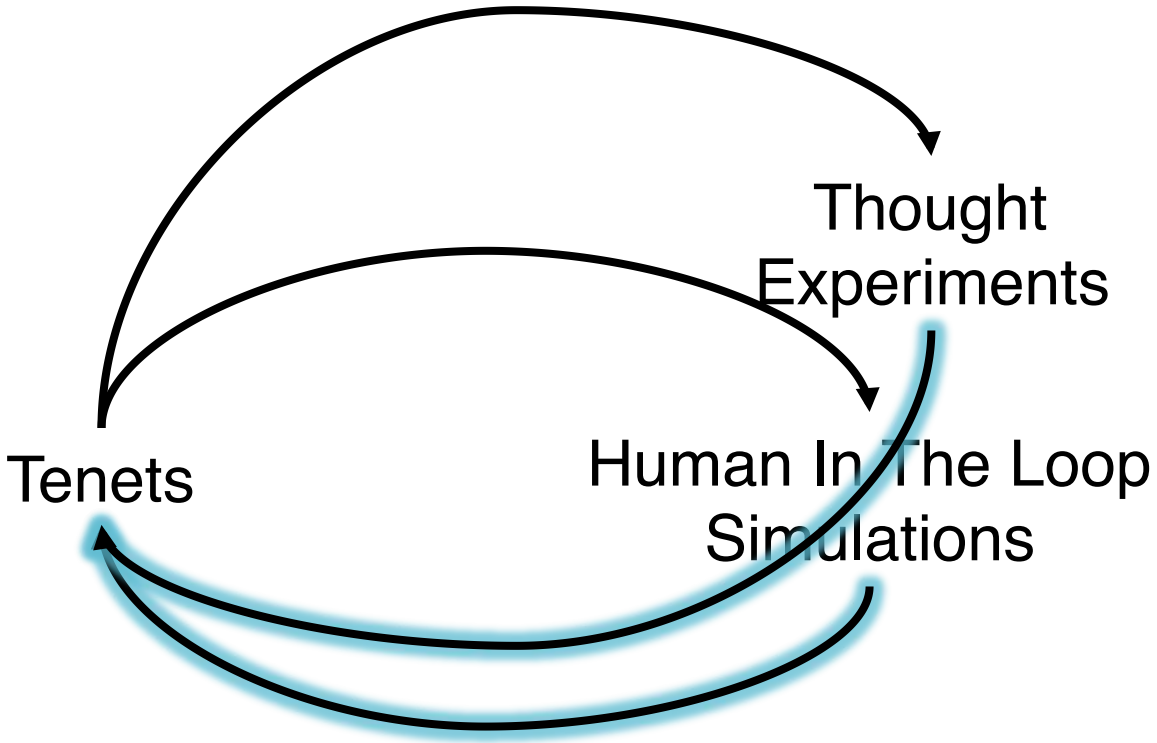
You will notice that the Main Gate intersection has changed. The g need to present identification at the Arnold Avenue gate. Because badges at the visitor badging office before approaching the Arnold

All gates will return to the same operating hours as before the clos
- 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

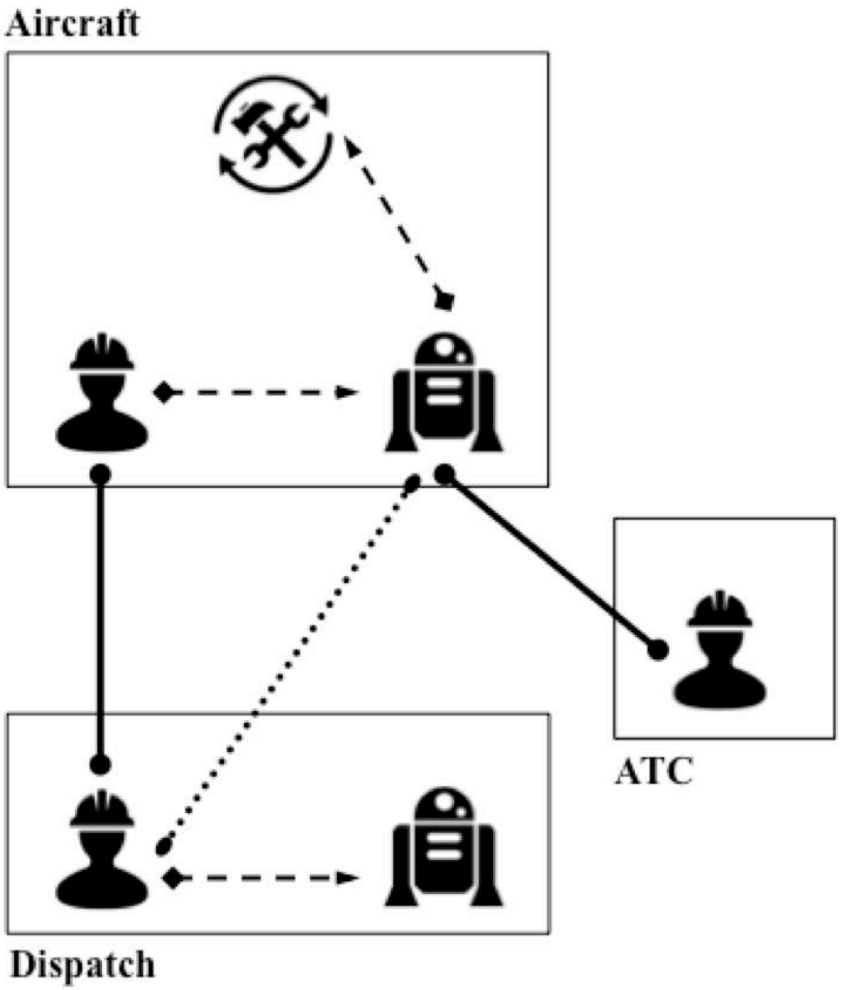


Design Patterns

- 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

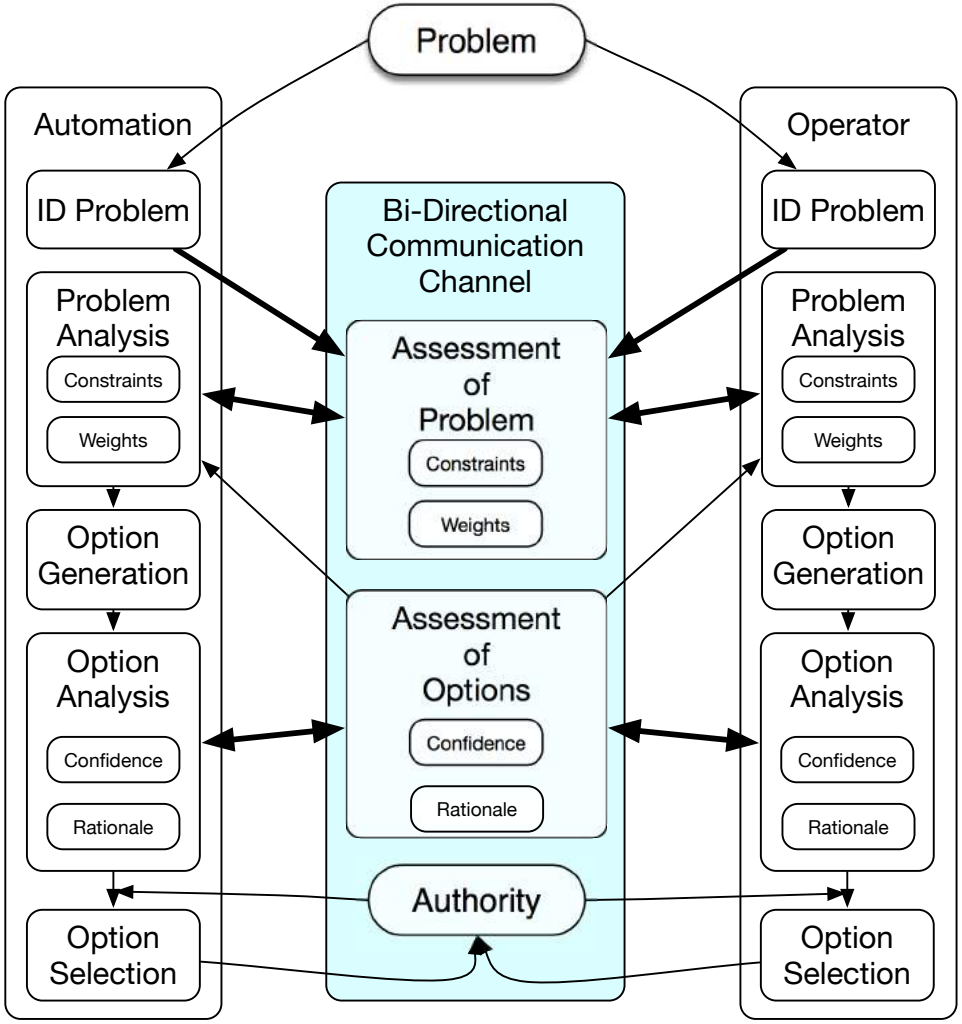
Design Patterns for HAT

- 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)

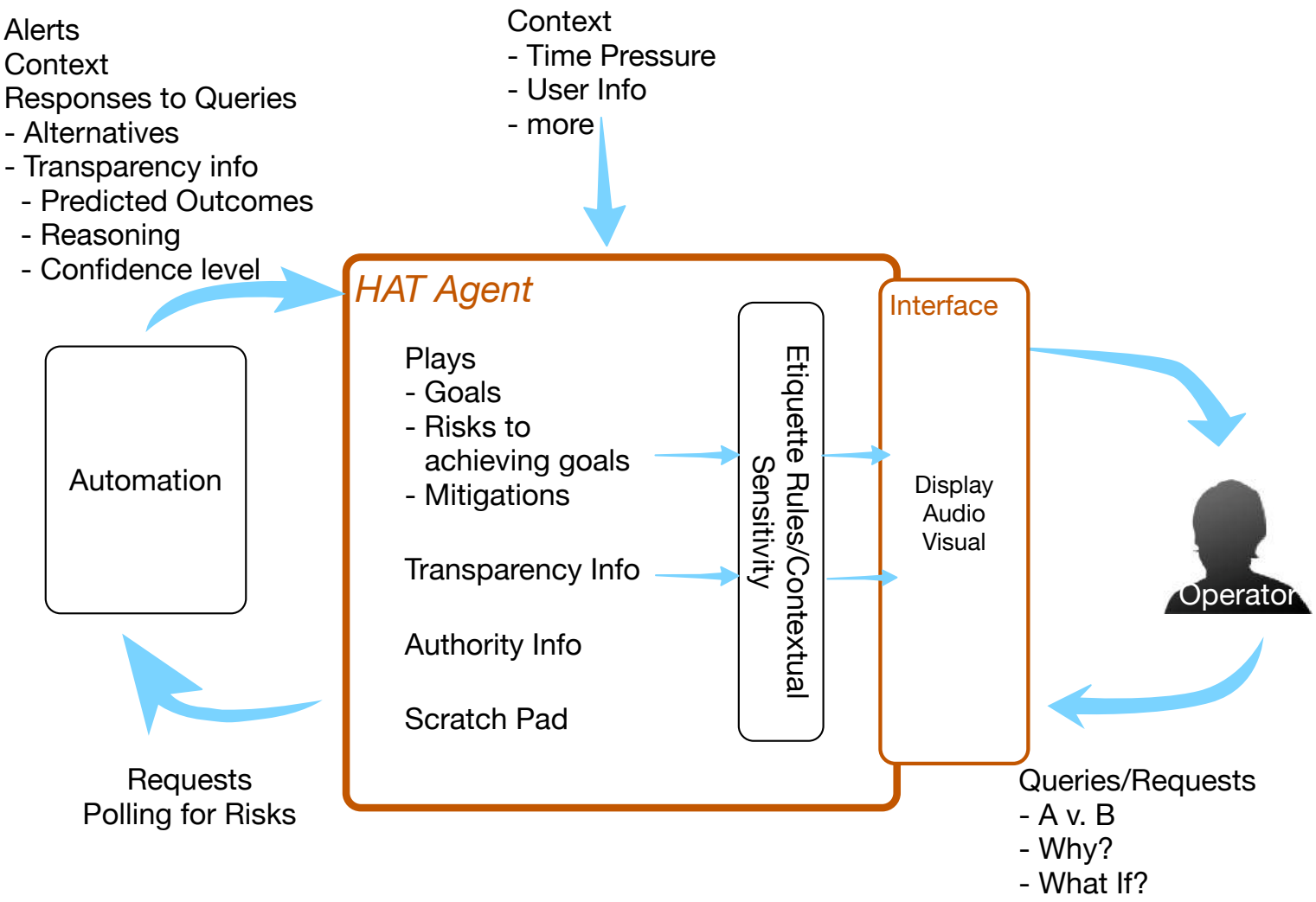


Design Patterns for HAT

- 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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- Why?
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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?
- Brandt, S.L., Lachter, J., Russell, R., & Shively, R. J., A Human-Autonomy Teaming Approach for a Flight-Following Task.
- Lachter, J., Brandt, S. L., Sadler, G., & Shively, R. J., Beyond Point Design: General Pattern to Specific Implementations.