Symbiotic Planning: Cognitive-Level Collaboration Between Users and Automated Planners

14th ICCRTS

Ronald Scott
BBN Technologies

Collaborators

Emilie Roth
Roth Cognitive Engineering

Jeffrey Wampler
AFRL Human Effectiveness Directorate

Liz Kean
AFRL Information Directorate

88 ABW PA Cleared 4/20/2009; 88 ABW-2009-1621

Work-Centered and Symbiotic Design

- **The Human Effectiveness Directorate of the Air Force Research Lab (AFRL/RH -Wright-Patterson) has been successfully demonstrating Work-Centered Support Systems (WCSS) since 2001.**
- **Work-Centered Design is based on principles of Cognitive Engineering, coming out of the realm of cognitive psychology and human factors.**
- **Symbiotic Design focuses on building systems in which human operators collaborate with semi-automated support tools to produce solutions better than either one could do alone.**
- **I'll explain with a concrete example.**

Air Mobility Command (AMC)

- **Headquartered at Scott AFB in Illinois.**
- **618th Tanker Airlift Control Center (TACC) at AMC is responsible for planning and execution of hundreds of air missions a day.**
- **TACC C2 personnel deal with 37,000 phone calls a month (per Lt. Col Chris Rosenthal, 1/2009).**

You Be the TACC Duty Officer (DO)

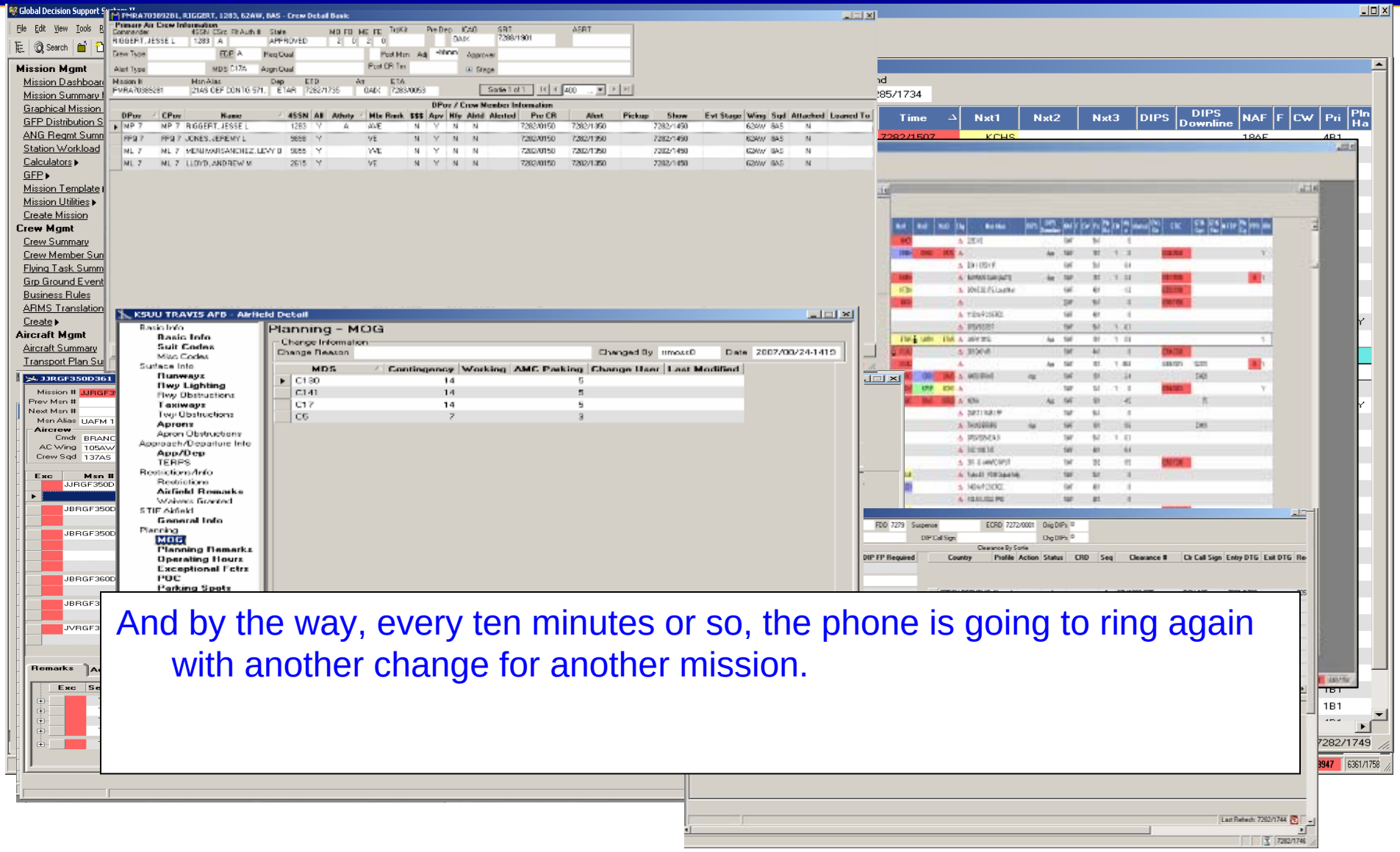
The phone rings – it's the pilot of a mission due to take off an hour from now, flying from Ramstein to Al Udeid.

"The plane is still being loaded – we'll be ready to take off in 3 hours. Is this OK?"

Your job: Evaluate the effects on this and other missions.

- Airfield operating hours, quiet hours, day/night restrictions.
- Crew duty day limits, crew scheduled return time, restrictions on where crew can remain overnight (if needed)
- Diplomatic Clearances.
- Air refueling reservations.
- Required ground times at intermediate airfields.
- Required delivery times/available load times for cargo/passengers.
- MOG (maximum on-ground – parking space limitations).

Your Tools – the GDSS System



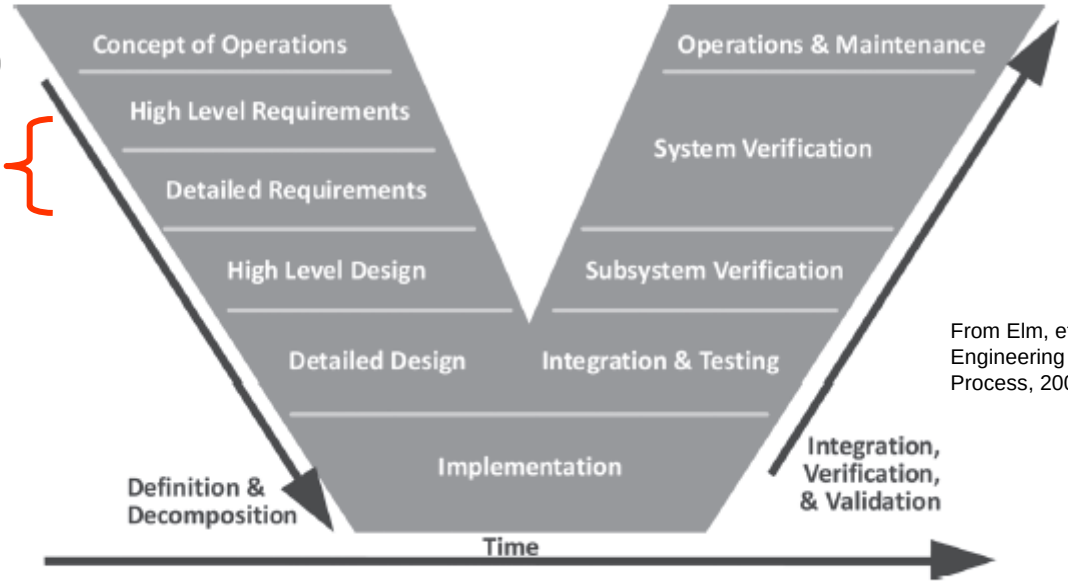
And by the way, every ten minutes or so, the phone is going to ring again with another change for another mission.

What's The Effect?

- DO's in the TACC generally get issues with the current sortie right (i.e., this takeoff to this landing).
- But, as a rule, they don't do so well with issues with future sorties or other affected missions.
- Senior leadership complains "We fix the current problems and don't worry about the next shift's problems".
- $$$!

How Did We Get Here?

We went wrong right in here.



From Elm, et al. Integrating Cognitive Systems Engineering Throughout the Systems Engineering Process, 2008

Typical Requirements Analysis Process:

- *The system shall be able to display the takeoff and landing times of each sortie of each mission.*
- *The system shall be able to display the operating hours of each airfield.*
- *The system shall be able to display the diplomatic clearances in effect for each sortie.*

How Do We Fix This?

Change the way we think about our systems!

- *Joint Cognitive System*:
  - The combination of human problem solver and automation/technologies which must act as co-agents to achieve goals and objectives in a complex work domain.
- *Joint Cognitive Systems Engineering*:
  - The process of integrating the insights gleaned from cognitive systems engineering into the systems engineering process.

How Do We Fix This?

Go from this:

Typical Requirements Analysis Process:

- *The system shall be able to display the takeoff and landing times of each sortie of each mission.*
- *The system shall be able to display the operating hours of each airfield.*
- *The system shall be able to display the diplomatic clearances in effect for each sortie.*

To this:

Work-Centered Requirements:

- *The user must be able to use the system to simultaneously view all basic planning factors and constraints for all sorties of a mission, and be alerted to any constraint violations.*
- *The user must be able to use the system to quickly do a what-if – i.e., reschedule a mission and immediately see the effects on planning factors and constraints.*

A Key Observation on Design of Decision Support Systems

Data in the database *is NOT the same as* **Data on the screen**

(Nobody would argue this point.)

Data on the screen *is NOT the same as* **Data, in context, in a decision-maker's head.**

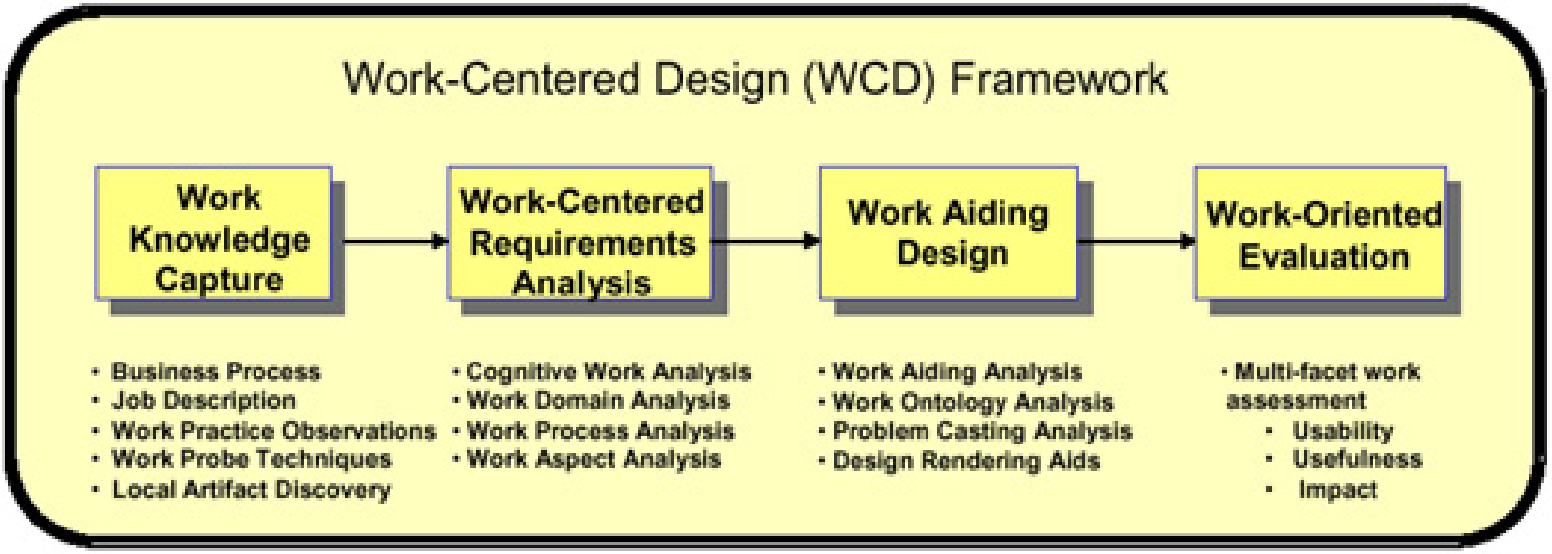
Many decision support systems stop here.

This imposes a cost on the system, payable in:

- ***Time to make decisions.***
- ***Wrong decisions.***
- ***Ultimately, $$$!***

When they need to be here.

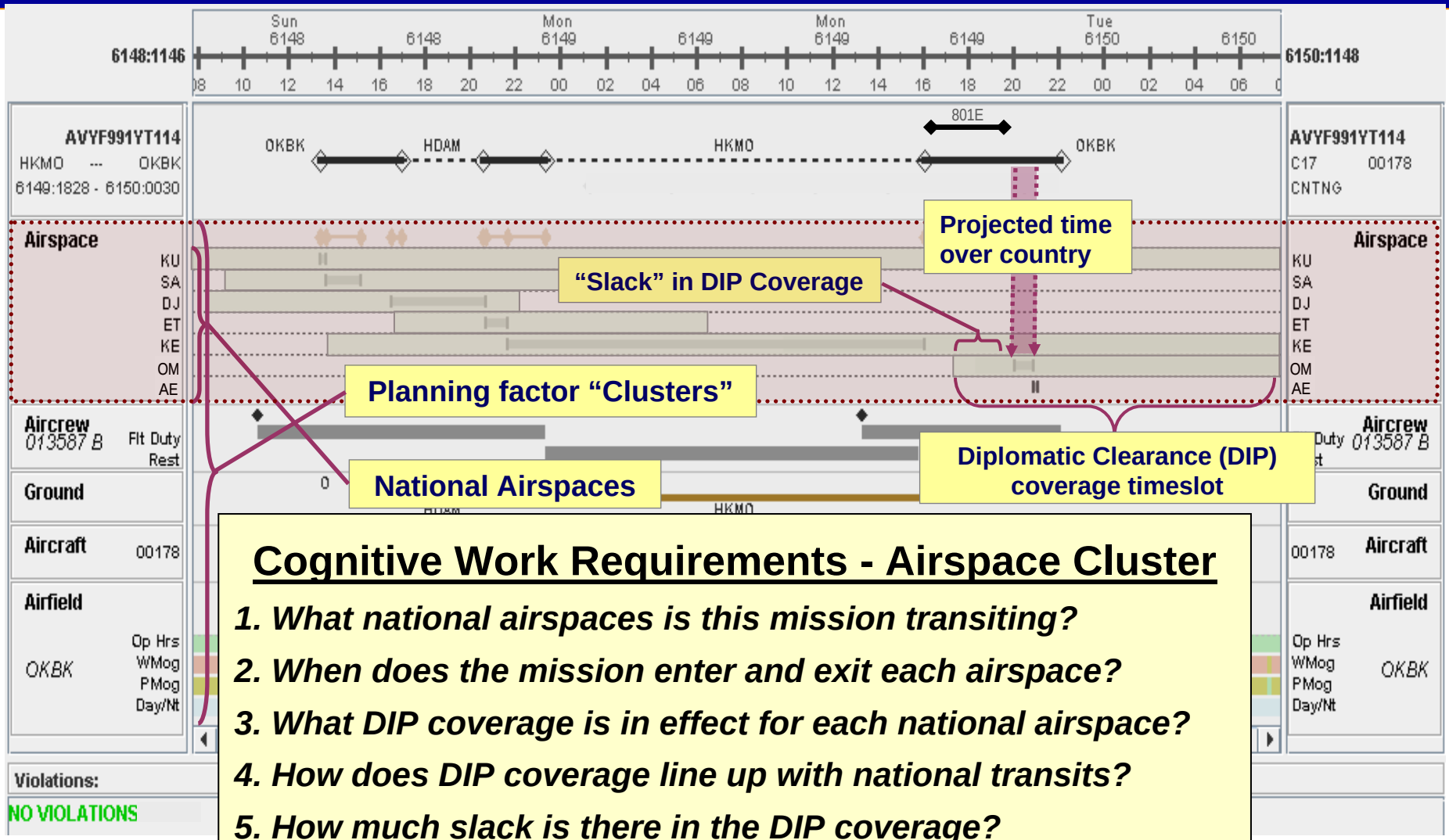
Work Centered Design (WCD)



SOURCE: Eggleston, R. G. (2003). Work-centered design: A cognitive engineering approach to system design. *In Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting* Denver, CO: Human Factors and Ergonomics Society.

- Differs from User-Centered Design (UCD) (e.g. RAD/JAD, Traditional Human Factors and Usability based design, etc.)
- Focus of the analysis is on the work domain or environment, rather than on the end user or a specific task/process.
- An important goal of WCD is to make inherent constraints and complex relationships in the work environment perceptually evident (e.g. visible) to the user in an easily accessible and coherent fashion.

WIDE Mission Timeline Capability
Temporal Synchronization



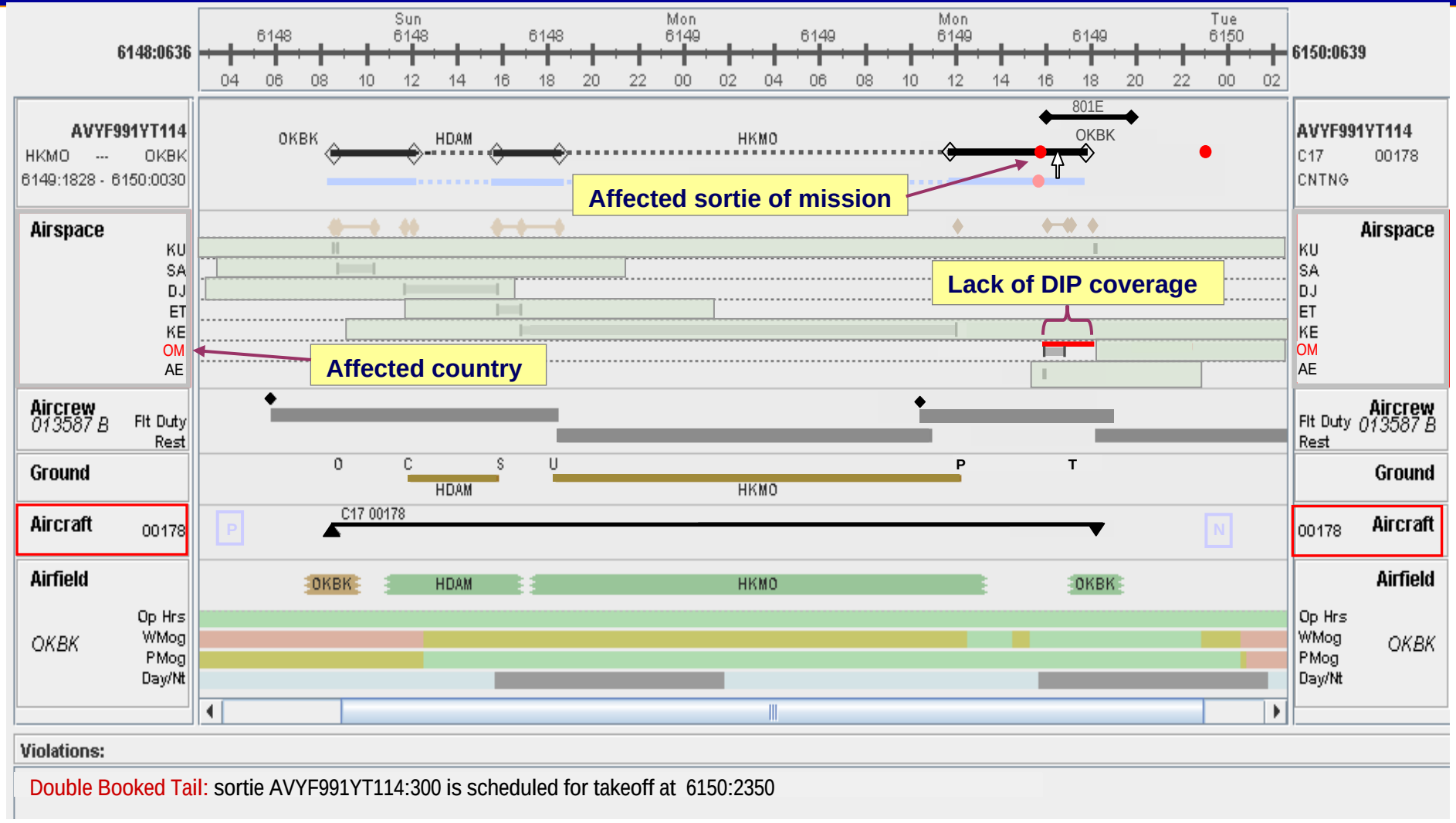
Cognitive Work Requirements - Airspace Cluster

1. *What national airspaces is this mission transiting?*
2. *When does the mission enter and exit each airspace?*
3. *What DIP coverage is in effect for each national airspace?*
4. *How does DIP coverage line up with national transits?*
5. *How much slack is there in the DIP coverage?*

Temporal constraints are visually apparent in WIDE

WIDE Mission Timeline Capability

Airspace Cluster Alerting Design

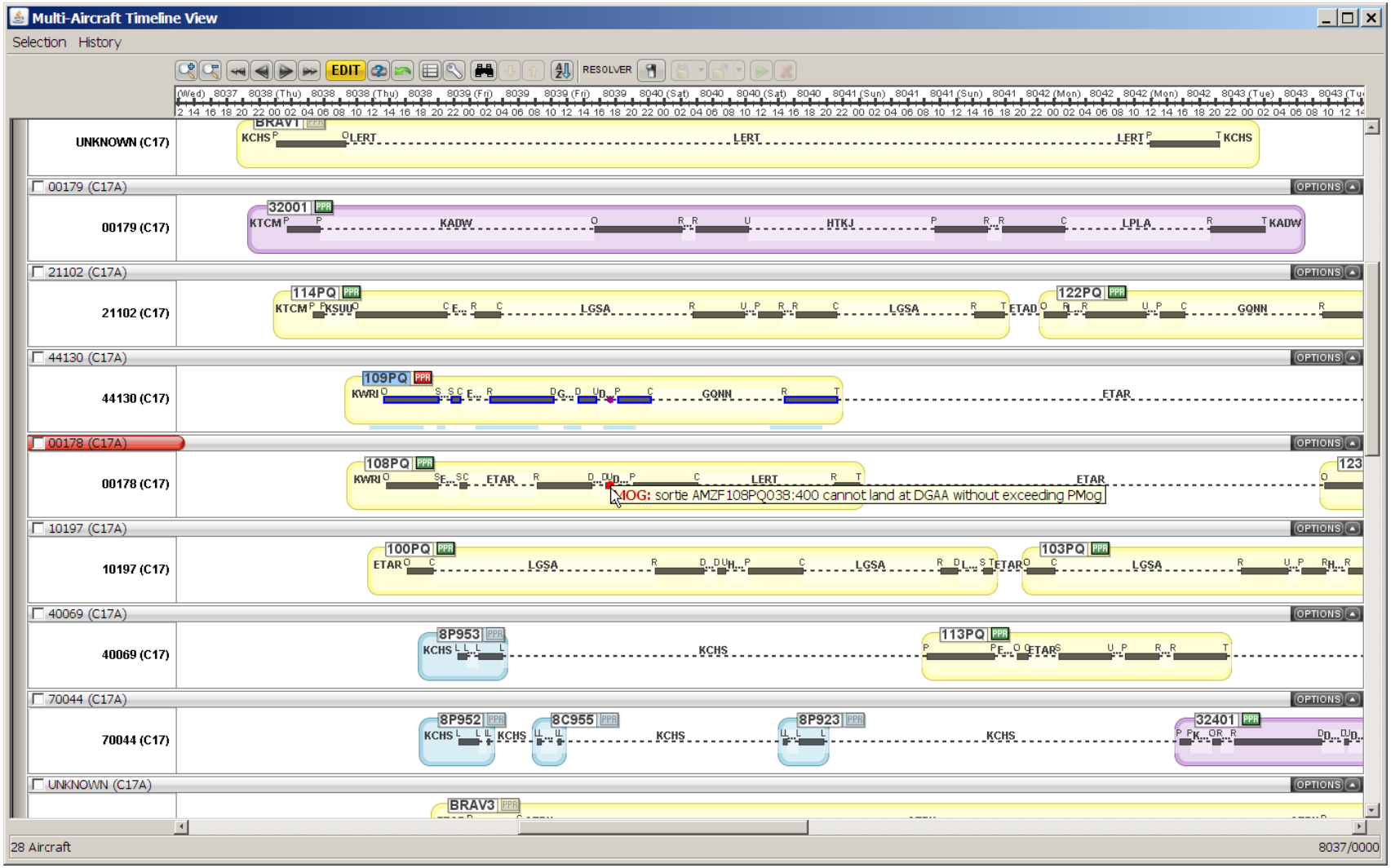


What-if allows visual and direct manipulation within plan constraints

Extending the Problem

- This is all good, but -
- What if the dominant problem is resource allocation (airfield parking space) among multiple missions?
- In that case, drilling into problems a single mission at a time is not effective.
- We need to extend our visualization and what-if capability to deal with multiple aircraft simultaneously.

Multi-Aircraft Timeline



Trying to Resolve a Problem Manually

The GRS Concept

Problem:

Replanning missions on the fly is hard.

The WIDE visualization and alerting tool helps, but the DO still may need to move a lot of missions to find a good schedule.

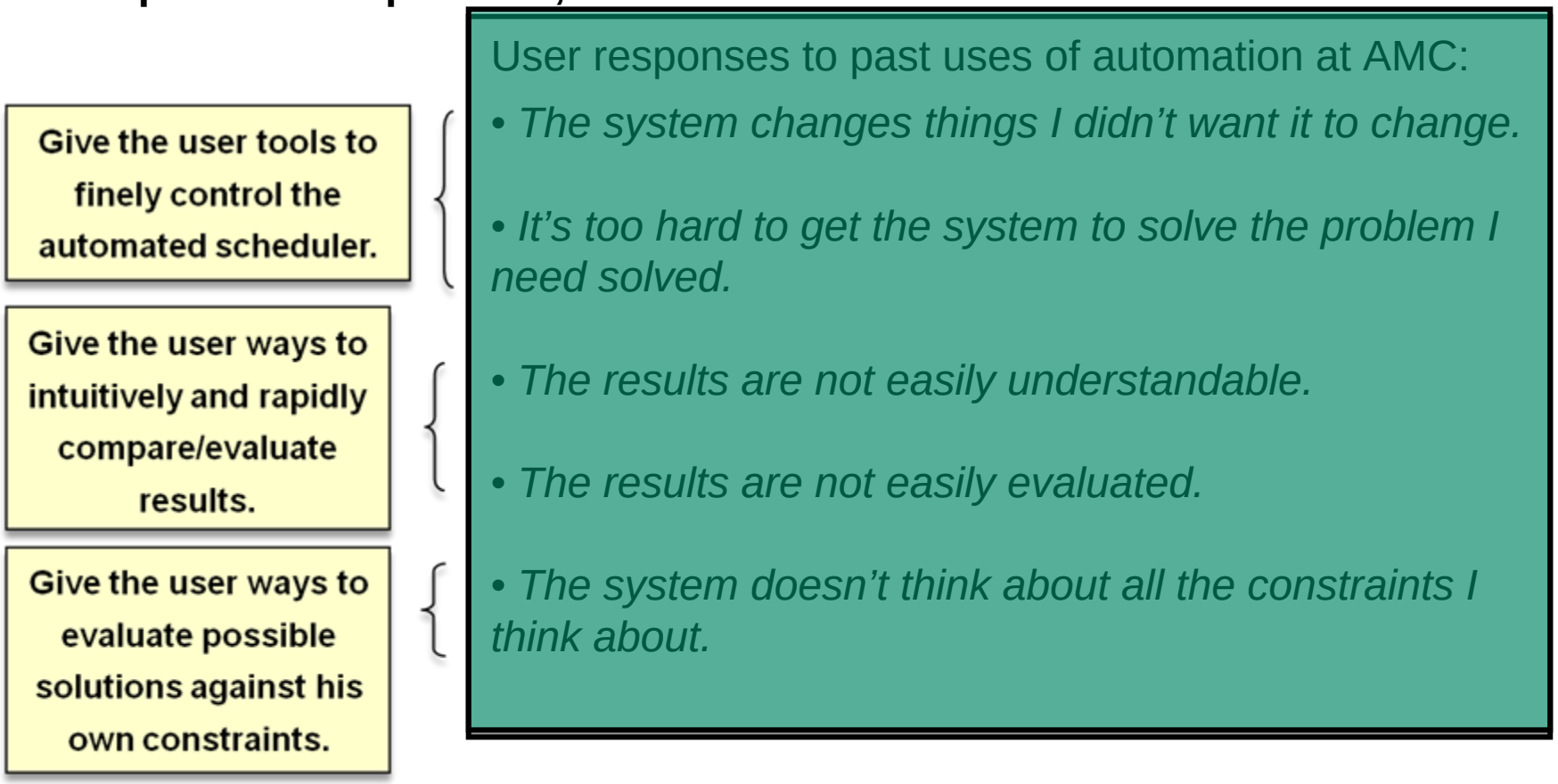
Solution:

Provide a collaborative assistant for a TACC user:

- a “resolver” that produces options for fixing problems, reasoning about many of the constraints a TACC user would think about,
- a visualization system to allow the user to compare and evaluate options,
- an iterative process for the user to go back to the resolver, having overridden some of the changes the resolver suggested.

Automation to the Rescue?
The Need for Symbiotic Design

Hooking up the WIDE timeline to an automated scheduler might help solve this problem, but:

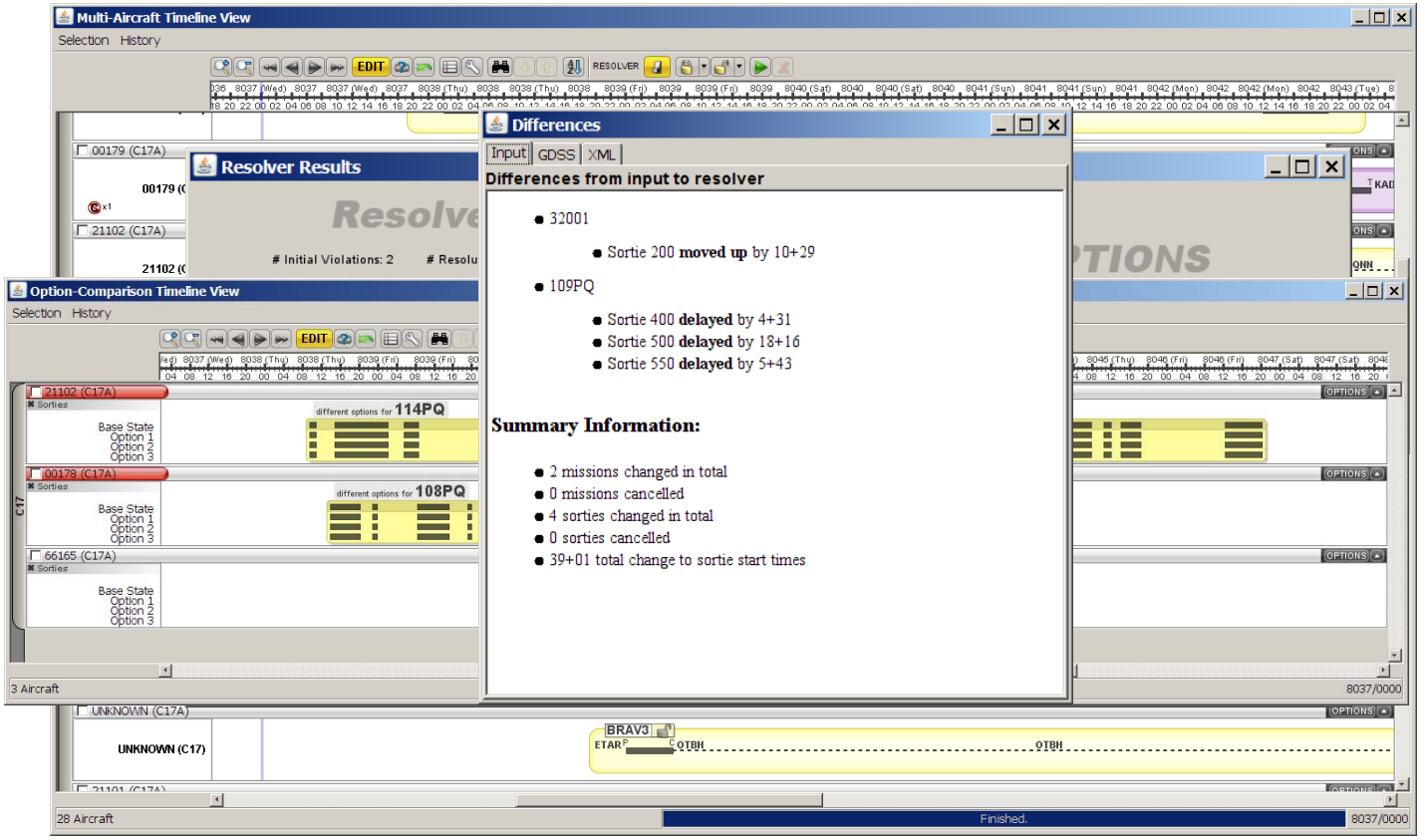


Many of these criticisms have been justifiably made – we need to do better.

Features of our Symbiotic Design Solution

- We use DWARP (Distributed World-Wide Aeronautical Planner, by our collaborators On-Time Systems) as a schedule "optimizer"
- Allow the user to scope and constrain the problem given to the Optimizer
- Allow the user to visualize, evaluate, and compare options (relative to each other, and relative to the original state)
- The Optimizer returns to us multiple, operationally distinct options (solution sets of mission schedules)
- Allow the user to pick an option, tailor an option further, or iterate with the Optimizer after updating constraints

Problem-Solving Procedure



1. Define th
   - Which m
   - What ad
   constraints?

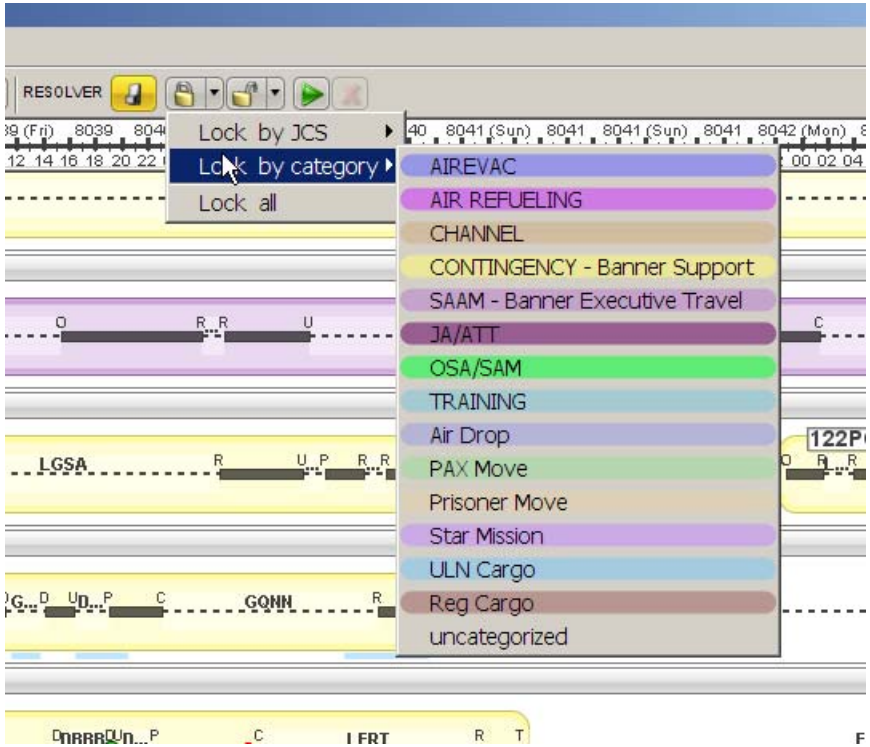
2. View pos
   elimina
   be unw

3. Drill into and com
   remaining optior

4. Choose one to go with, or to iterate on.

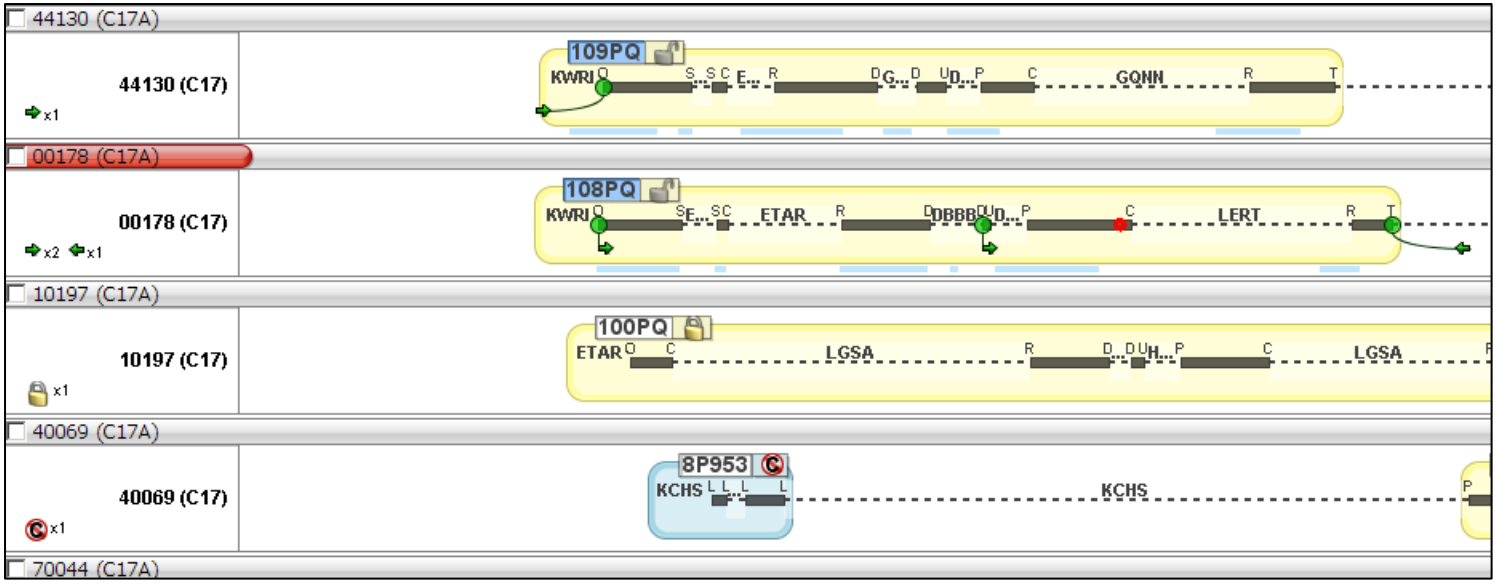
Scoping the Problem

Missions can be locked (put "out of play" for rescheduling) by mission type, or by priority.



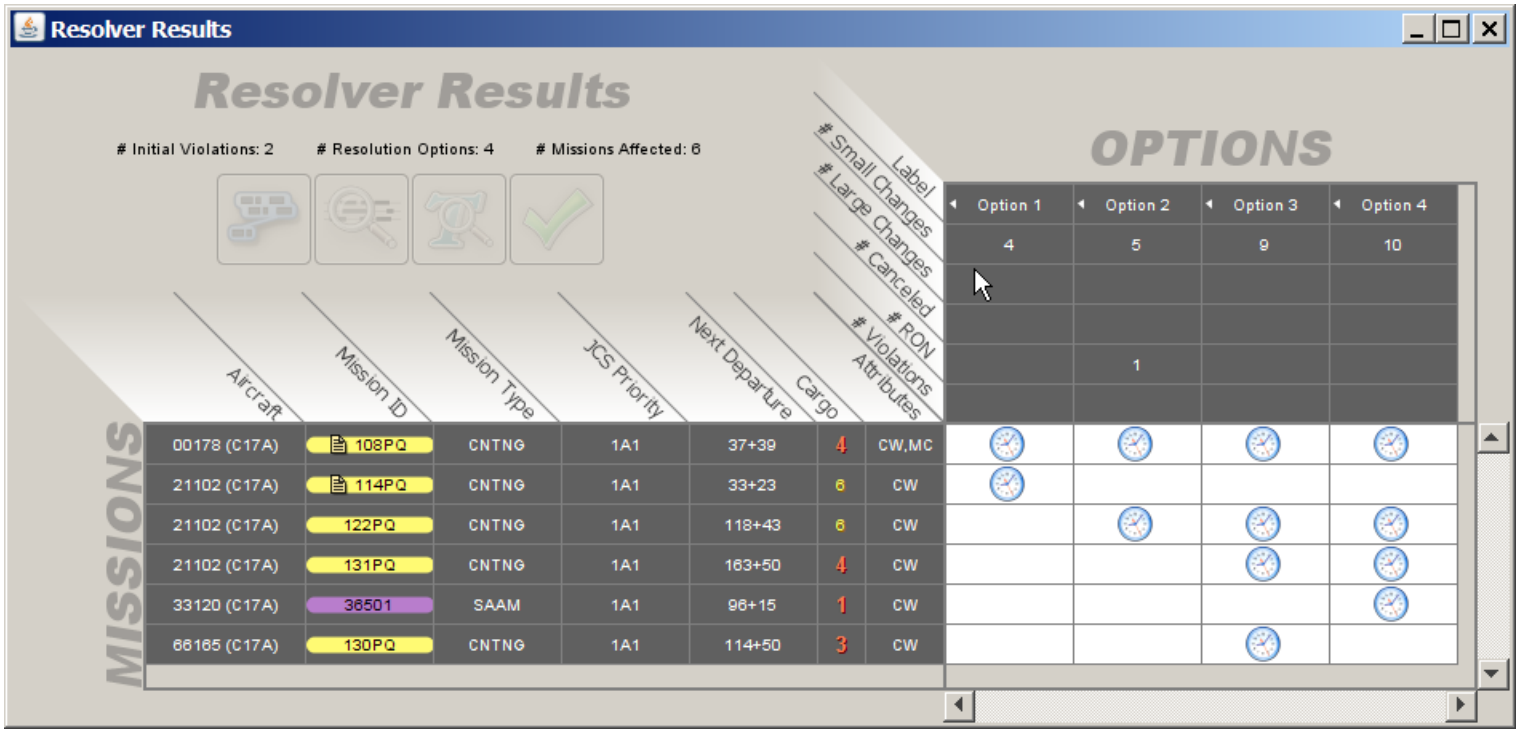
Constraining the Problem

Individual take-offs or landings can be given lower or upper bounds in time.



Individual missions can be locked, or noted as not cancellable.

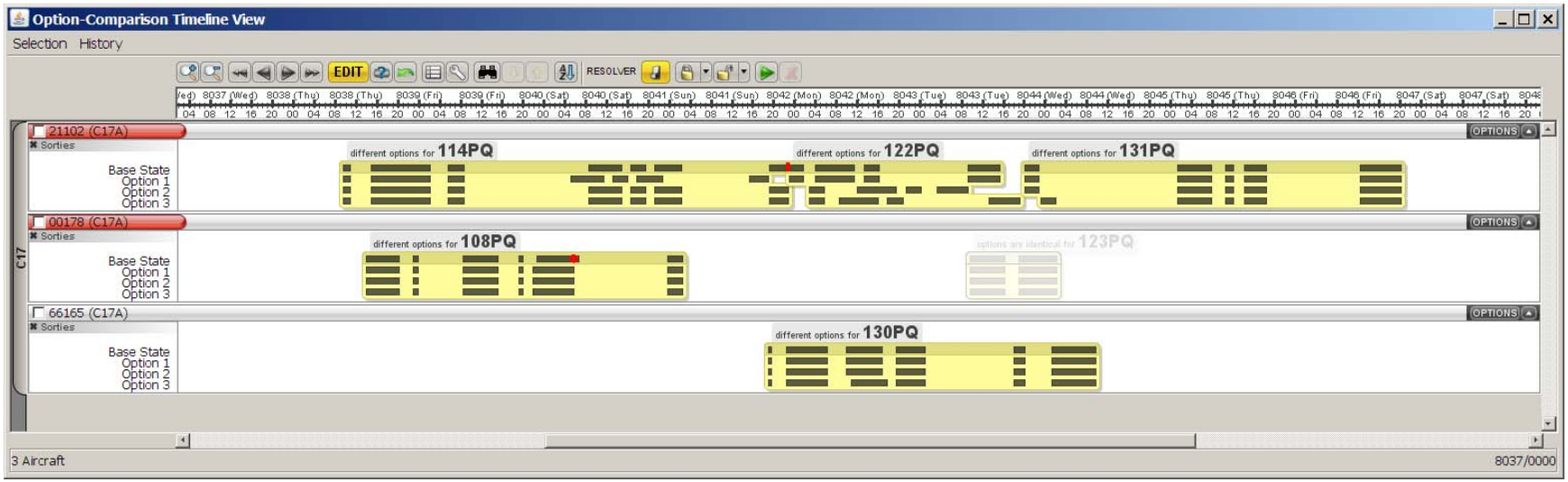
Tabular Display of Options



Each row is a mission moved by one of the options, with priority, cargo, attribute, and annotations available.

Each column is an option, with clock faces noting missions this option reschedules.

Comparison View



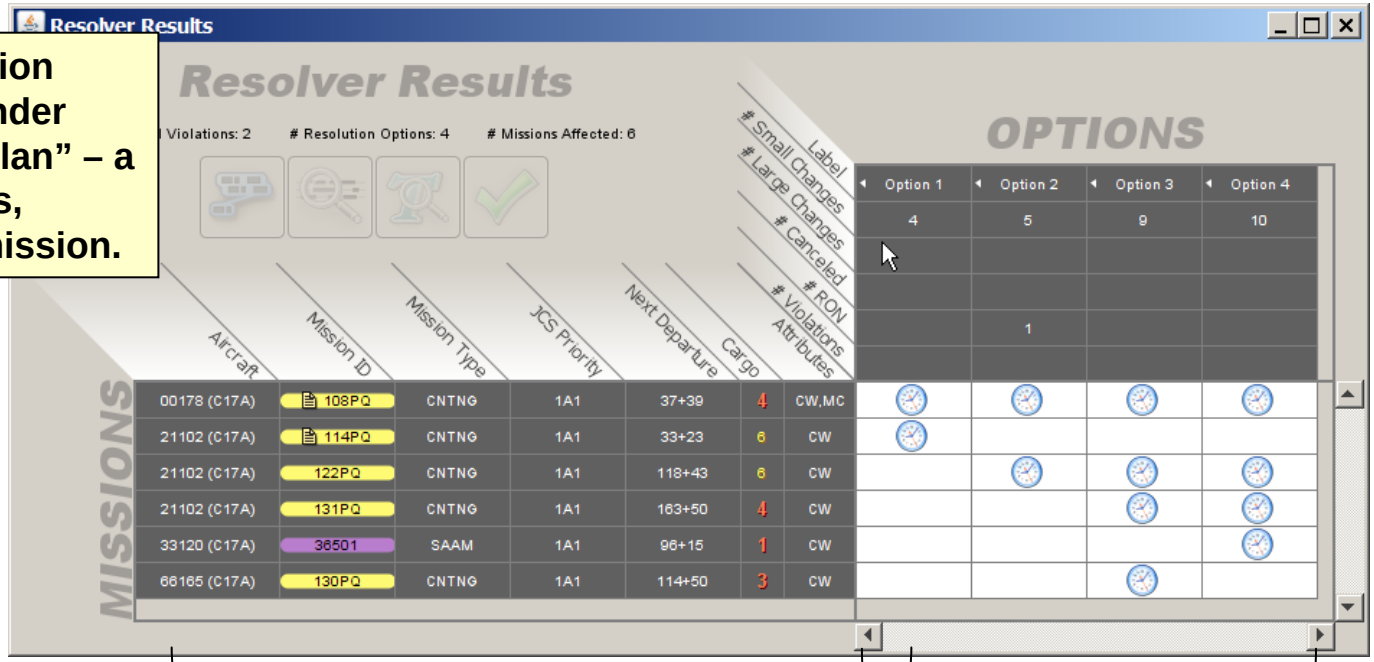
A graphic view allowing the user to visually inspect the effect of multiple options on individual missions

Characteristics of our Problem Space

- We operate in an environment of missing and imperfect information.
- The user is the authority, potentially knowing more about each mission than the system does.
- While a user may not be able to find a solution by hand, he can effectively evaluate a potential solution if he's given one.
- Thrashing (constantly changing solutions) is very bad. Replanning missions takes re-coordination between real people, and is expensive.
- Our replanning problems generally allow multiple solutions.
- There is no user consensus on a way to measure goodness of a plan:
    - complete missions as quickly as possible
    - get aircrews home on time
    - get high-priority cargo delivered on time
    - minimize time spent re-coordinating
    - The only thing users agree on all the time: "It depends."

Displaying Options in the Cognitive Frame of the Operator

We've upped the abstraction level – the basic object under consideration now is a "plan" – a set of scheduled missions, instead of an individual mission.



The row header section of the table answers:

1. **Does my plan negatively affect any mission I really care about?**
2. **For any mission I really care about, is there any plan that doesn't move it?**

lement

GRS User Evaluation – 11/08

- **GRS enabled users to identify *better solutions* that resulted in *fewer perturbations* to the mission schedule overall.**

- **The dramatic GRS improvement strongly suggests that a *six fold reduction in solution time and more than a three fold improvement in quality of solution* would be achieved on the floor once transitioned.**

- **Bottom line:**
  - **Increased efficiency in terms of time required to come up with a revised mission plan**
  - **Increased mission replan quality, in terms of reduced mission delays, fewer mission cancellations**
  - **Improved asset utilization to meet AMC objectives**