Content and Representation of Information Needed to Support Time-Constrained Problem Solving

IWS 2025 - SESS-437

2025 Human Research Program
Investigators' Workshop

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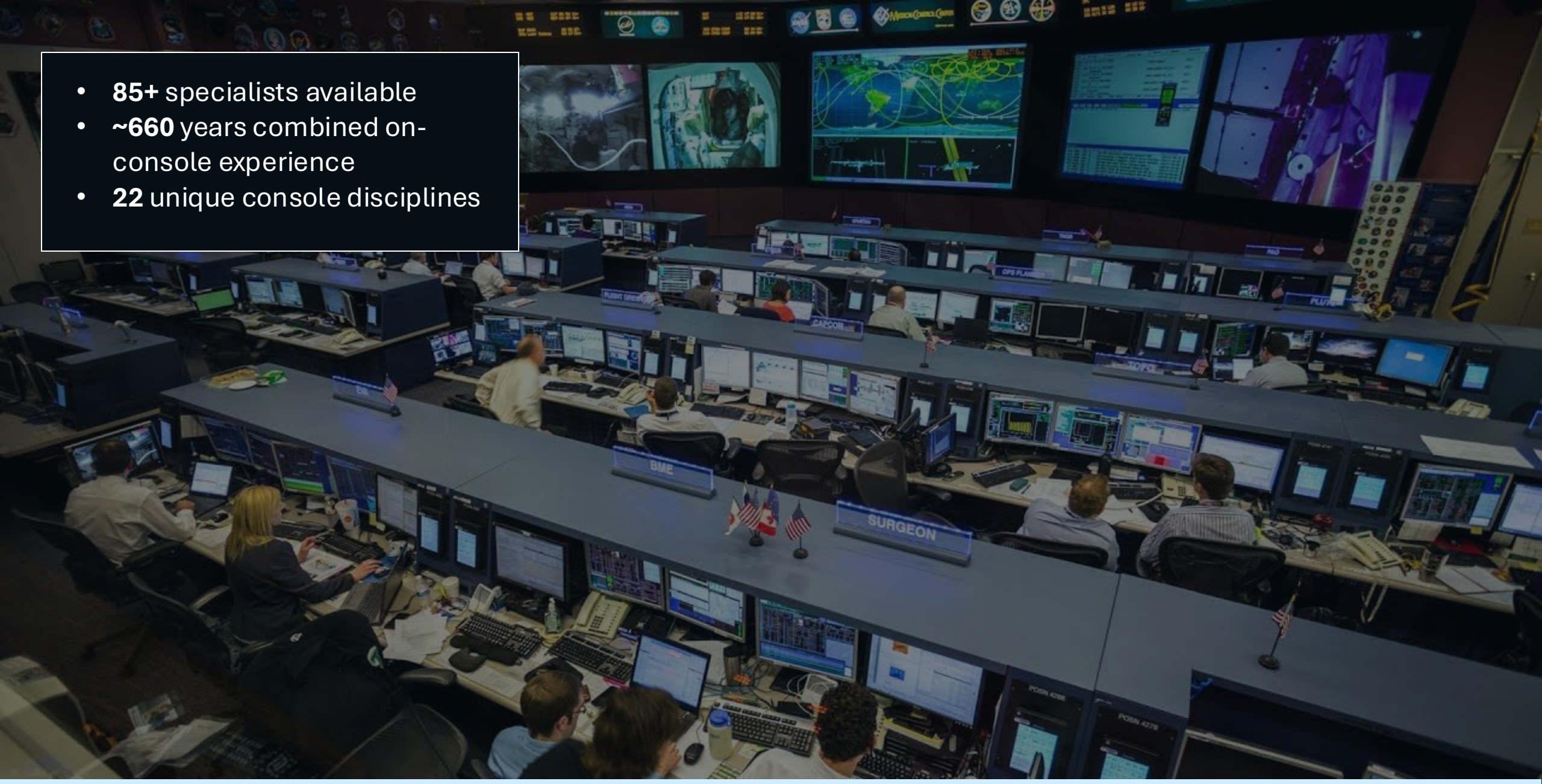
Earth-Dependent
Operational Paradigm

Near-complete, **real-time dependence on a ground team** to manage the combined state of the mission, vehicle, and crew.

Apollo, 1961 - 1973

ISS, 2000 - present


BME
SURGEON



- **85+** specialists available
- **~660** years combined on-console experience
- **22** unique console disciplines

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Amount of data monitored by a single Flight Controller (SPARTAN)

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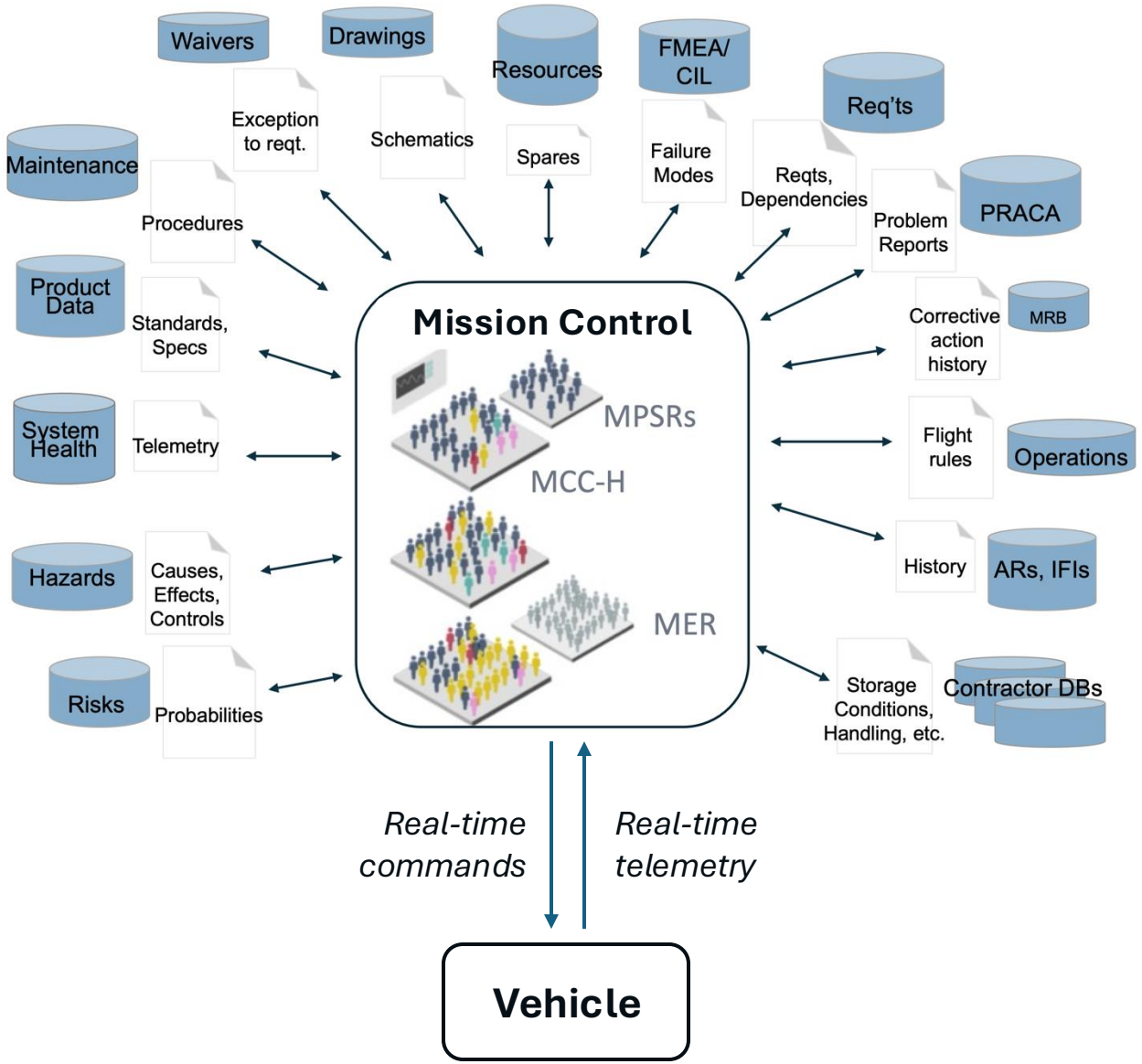
ISS, 2000 - present

Information utilized:



Earth-Independent Missions Beyond LEO

A **new operational paradigm** is needed as distances and communication latencies increase.

Apollo, 1961 - 1973

ISS, 2000 - present

?

Moon to Mars

Crew will need to independently respond to anomalies historically handled by a team 20x their size

With limited attention and expertise

ISS Anomaly Rates (2000 – 2019)

Reported Anomalies

~10k

Anomaly Reports
(in MCC Gateway, ISS Increments 4 – 60 + shuttle ISS missions)

Average of 161/ ISS increment

Average of 58 / shuttle mission to ISS

Items for Investigation

~4500

Items for Investigation
(Created by MER)

Critical / significant

64

High priority IFIs
(Marked high priority)

10

Significant Incidents and Close Calls, Z-Card

Require urgent diagnosis

33

Vehicle incidents requiring urgent diagnosis
(Determined by SME)

Average of 1.7 / year (but higher during the burn-in phase!)

Earth-Independent Missions Beyond LEO

A **new operational paradigm** is needed as distances and communication latencies increase.

Apollo, 1961 - 1973

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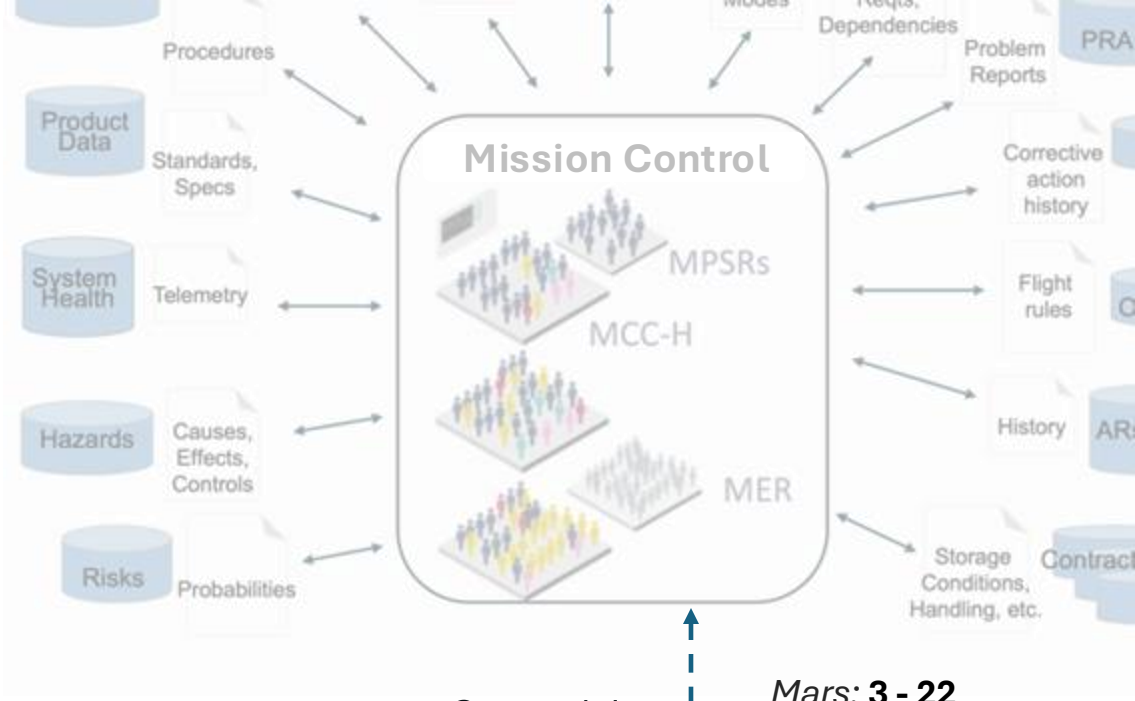
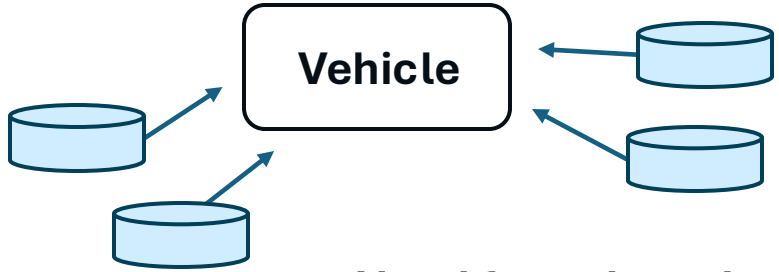
?

Moon to Mars



Comm delay

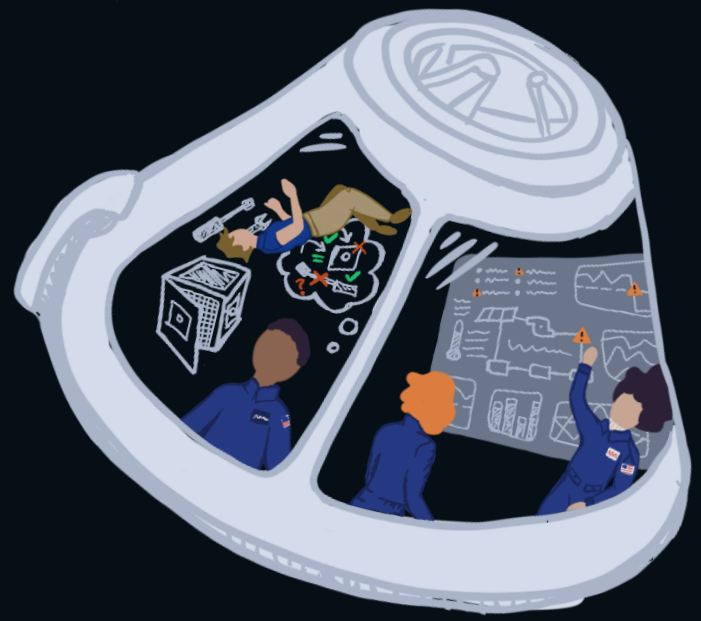
Mars: **3 - 22** minutes *one-way*



Need for onboard access to data!

Crew will not only need *access* to information, but to information that has been compiled, refined, and *represented* appropriately

How can a crew of four monitor (and understand) the same amount of data as 20+ experts?



They can't (on their own)

Task: Content and Representation of Information Needed to Support Time-Constrained Problem Solving

Purpose: Assess the content and representation of information needed to support time-constrained problem solving and decision-making during procedure execution and anomaly resolution by the crew under conditions of reduced and/or intermittent communication with the ground team.

Goals:

- Determine specific information accessed and assembled for problem solving, including declarative (e.g., facts), procedural (e.g., rules), schematic (e.g., principles) and strategic (e.g., heuristics) types
- Understand how to organize and integrate this information into appropriate mental models that can then be exercised to produce solutions

The users:

- Small crew (~4)
- Limited attention
- Limited expertise
- Generalists

Approach

- Literature review
- Problem-solving modeling
- Information classification/mapping
- Interviews (spaceflight SMEs, analogous domain experts, operators, etc.)
- UI reviews and requirements
- Exploratory designs

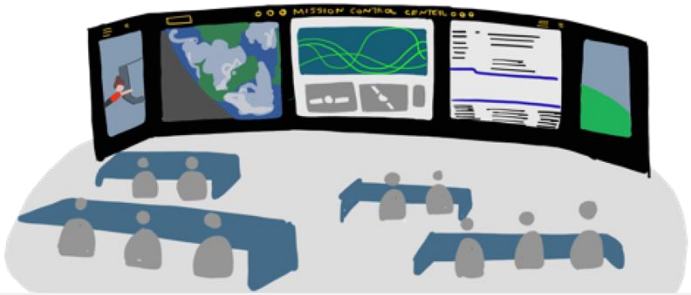
Analogous Domains

We interviewed expert problem solvers and surveyed information systems in safety-critical industries:

- Hospital command centers
- Air traffic control
- Nuclear industry ops

To understand how experts solve critical problems under time pressure

> "…by and large, you know, you're just kind of doing a more high-level general monitoring of things and relying on, you know, either catching the trends deviating or, you know, an enunciator to call out your attention."
>
> - *Nuclear SME*



"…being able to look at things in that way where it becomes visually obvious …would be a very helpful way to help the crew understand what's wrong…there are many different ways to group things: by power, by cooling, by data path, or by physical location, and any one of those could provide you the clue…as to what the common factor is."

- *Crew Member*

ISS Lessons Learned

- Interviewed flight operations personnel
- Investigated real ISS anomaly scenarios
- Reviewed training resources and processes for flight controllers

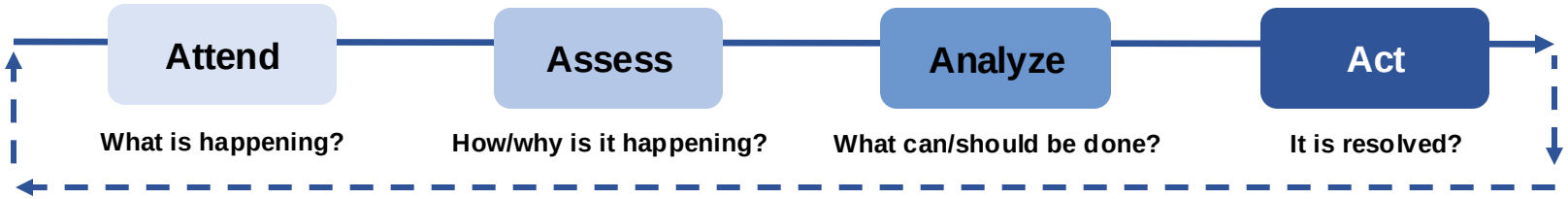
To understand:

- How MCC solves problems
- Key challenges for anomaly response beyond LEO
- Skills/tools needed by crew

What information do crew need on board to support problem solving?

Types of Problem-Solving Information

Problem Solving Model Synthesis



Types of Information

Declarative Knowledge: *Knowing "that" e.g., definitions, descriptions, etc.*

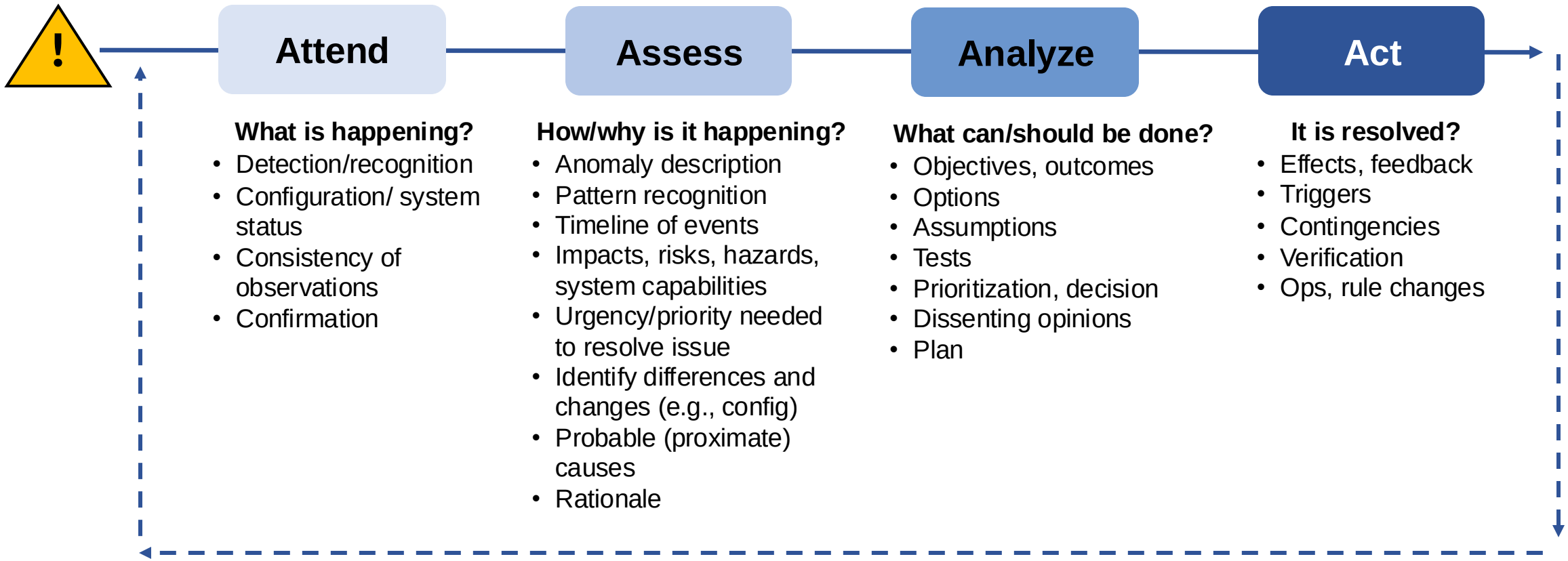
Procedural Knowledge: *Knowing "how" e.g., sequences, rules, etc.*

Strategic Knowledge: *Knowing "applicability" e.g., heuristics, judgement, etc.*

Schematic Knowledge: *Knowing "why" e.g., principles, schemes, etc.*

Shavelson et al. (2005)

Problem Solving Model: Information Needs



Enabling crew to think like experts: system design

GROUND TEAM-SYSTEM

understanding, resolution ...

"I see it, crew action is not required, I'll get back to you in 15 minutes with more."

meaning, patterns ...

KNOWLEDGE
e.g., flight controller

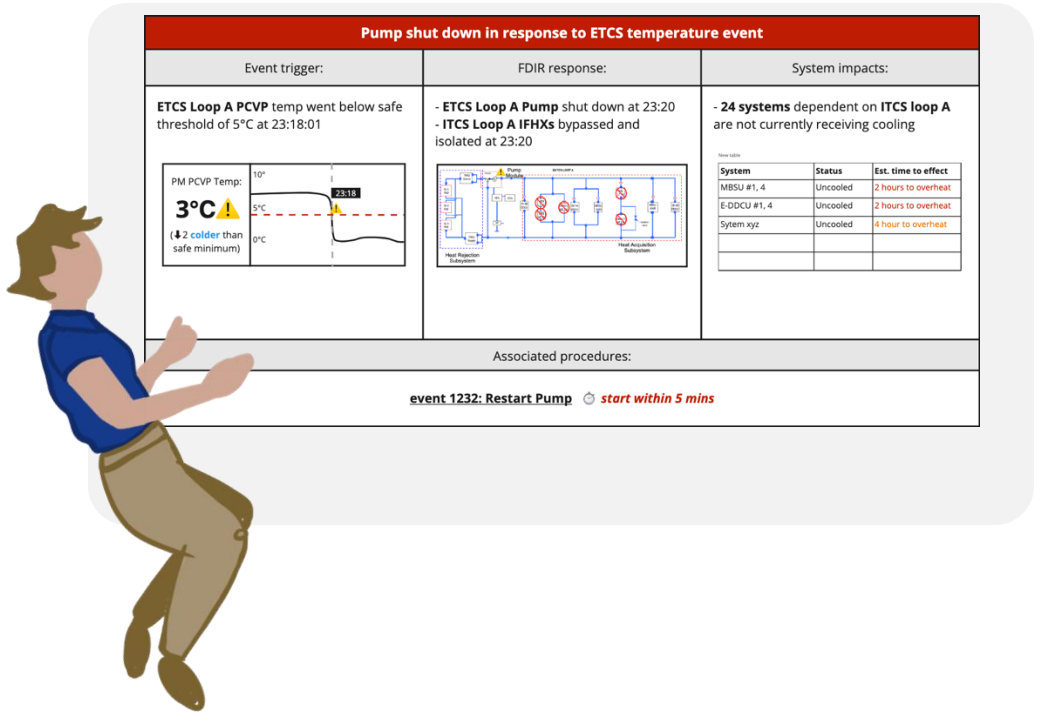
contexts, relationships ...

INFORMATION
e.g., flight control station

measurements, observations ...

DATA
e.g., 3000 data points/sec

ONBOARD CREW-SYSTEM



How should this information be integrated and organized?

Prioritized Needs

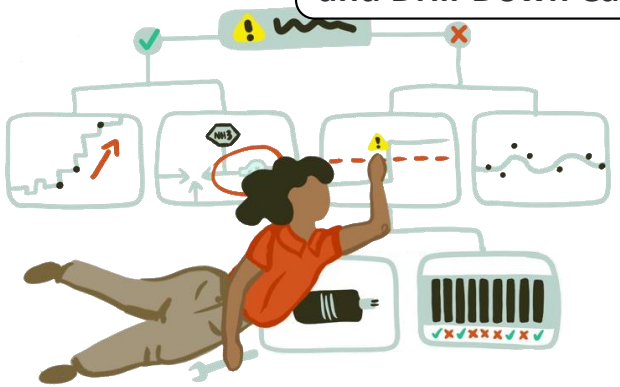
	Problem solving model	Prioritized needs	Maps
ATTEND	• Detection/recognition • Configuration/ system status	**System Status and Health Overview:** • Information on system status and availability • information on current configuration and constraints imposed • detect/display unusual trending **Caution and Warning Data Management:** • alerts for anomalous events • FDIR limits and their implications • parent-child relationships noted; triaged	• Physical • Functional
ASSESS	• Urgency/Time to effect • History/timeline of events • Impacts, risks, hazards, system capabilities • Probable (proximate) causes	**Detailed Event Analysis and Drill-Down Capabilities:** • Information on downstream impacts and time frame • Information on norms and ranges • System manuals, logs • Troubleshooting “cheat sheet” • Information on possibly relevant past anomalies	• Temporal • Contextual • Evidential • Causal

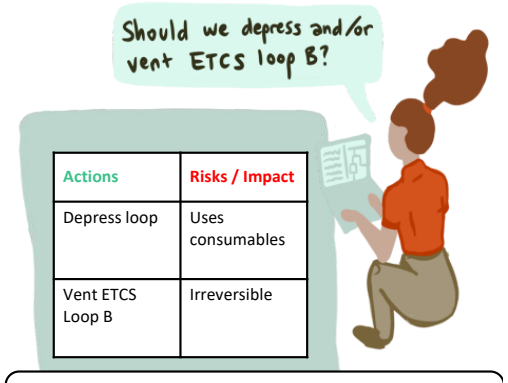
	Problem solving model	Prioritized needs	Maps
ANALYZE	• Objectives, outcomes • Options	**Trial Action Options/Plans**: • Information on available resources • Information on constraint-based timeline options • Information on possible consequences of actions • Information on sequence of actions determined to be executed (based on then information)	• Tactical • Resource • Capability • Procedural
ACT	• Effects, feedback • Triggers	**Automated Procedure Execution Oversight and Feedback:** • Real-time feedback on procedure effects • Automated alerts for rule violations or threshold breaches • Status tracking to ensure successful execution and monitoring of procedures	

Countermeasure Areas

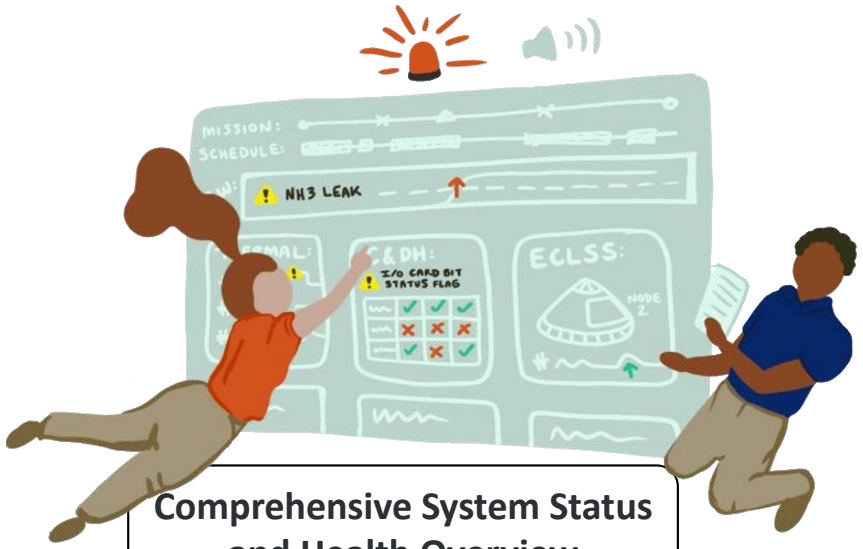
Caution and Warning Data Management

Detailed Event Analysis and Drill-Down Capabilities



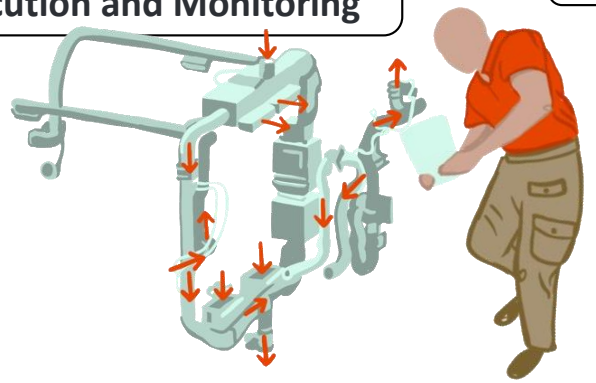


Trial Action Plans/Options



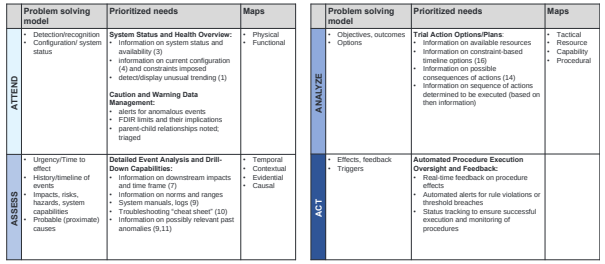
Comprehensive System Status and Health Overview

Real-Time Procedure Execution and Monitoring



How should this information be represented?

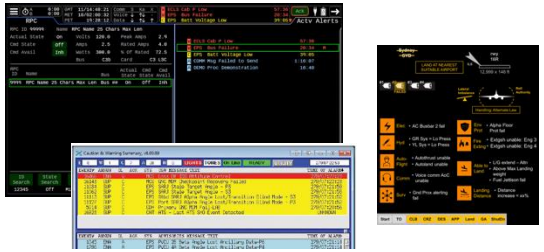
Design Process



	Problem solving model	Prioritized needs	Maps
ATTEND	• Detection/recognition • Configuration/ system status	**System Status and Health Overview:** • Information on system status and availability (3) • Information on current configuration (4) and constraints imposed • detect/display unusual trending (1) **Caution and Warning Data Management:** • alerts for anomalous events • FDIR limits and their implications • parent-child relationships noted; triaged	• Physical • Functional
ASSESS	• Urgency/Time to effect • History/timeline of events • Impacts, risks, hazards, system capabilities • Probable (proximate) causes	**Detailed Event Analysis and Drill-Down Capabilities:** • Information on downstream impacts and time frame (7) • Information on norms and ranges • System manuals, logs (9) • Troubleshooting "cheat sheet" (10) • Information on possibly relevant past anomalies (9,11)	• Temporal • Contextual • Evidential • Causal

	Problem solving model	Prioritized needs	Maps
ANALYZE	• Objectives, outcomes • Options	**Trial Action Options/Plans:** • Information on available resources • Information on constraint-based timeline options (16) • Information on possible consequences of actions (14) • Information on sequence of actions determined to be executed (based on then information)	• Tactical • Resource • Capability • Procedural
ACT	• Effects, feedback • Triggers	**Automated Procedure Execution Oversight and Feedback:** • Real-time feedback on procedure effects • Automated alerts for rule violations or threshold breaches • Status tracking to ensure successful execution and monitoring of procedures	

Prioritized Needs



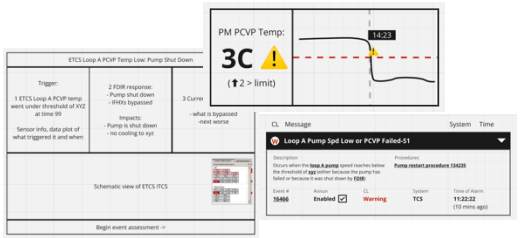
Literature Review

- Interfaces in analogous domains
- Existing ISS interfaces
- Data viz best practices
- Requirements

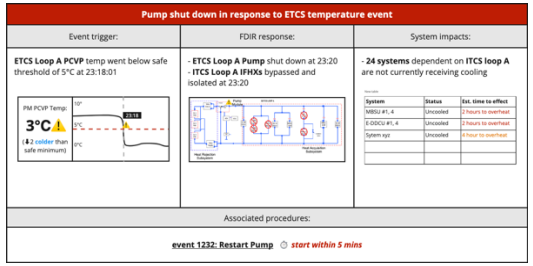
Data needs, features, tools

Iterative design

Storyboards



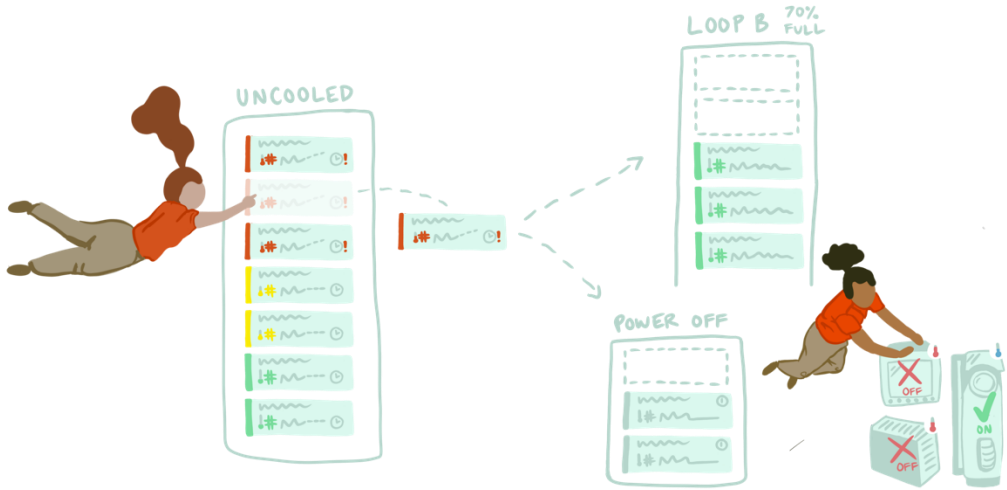
Sketches / Wireframes

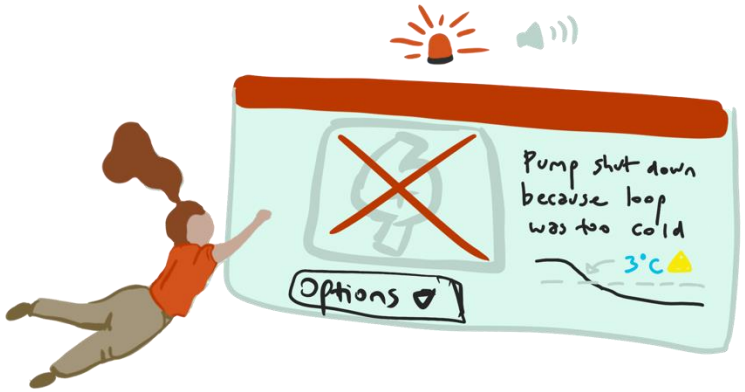


Exploratory Design Concepts

UI patterns, best practices

ISS Cooling Loop A Anomaly Case Study





Design Approach

50+ alarms in the first two hours…

ISS Current State

- Some alarms are impacts (“children”) of other alarms
- Some alarms are repeated at intervals, or duplicated across systems
- Some alarms are just notifications of (anticipated) FDIR actions
  - **ETCS Loop A Pump Spd Low or PCVP Failed-S1**
- Some alarms are just (anticipated) effects of FDIR actions
  - **ETCS Loop A PCVP Loss of Comm-S1**

ETCS Loop A PCVP Temp Low: Pump Shut Down	C	ETCS Loop A PCVP Temp Low-S1	54	TCS	ETCS	14:23:18
	W	ETCS Loop A Pump Spd Low or PCVP Failed-S1	55	TCS	ETCS	14:23:30
FCV not at required position	C	ETCS Loop A FCV Not At Required Posn Following Pump Shutdown-S1	56	TCS	ETCS	14:23:39
Pump shutdown cmds feedback	A	S1 1 MDM Detect RT Loss of Comm - ETCS Pump Ctrl Vlv Pack A-S1	57	CDX	MDM	14:23:40
	C	ETCS Loop A PCVP Loss of Comm-S1	59	TCS	ETCS	14:23:42
	C	ETCS Loop A PCVP Temp Low-S1	58	TCS	ETCS	14:23:42
	C	ETCS Loop A Pump Shutdown Command Sequence Failed-S1	60	TCS	ETCS	14:24:05
ITCS warming up because pump is shut down	C	TCA L LTL Temp Out Of Limits-JPM	61	TCS	ITCS	14:26:06
	A	Node 3 MTL TWMV Overtemp-NODE3	62	TCS	ITCS	14:26:13
	C	LTL IFHX Out Temp High-JPM	63	TCS	IFHX	14:26:18
	A	Node 3 MTL REGEN TWMV Overtemp-NODE3	64	TCS	ITCS	14:26:32
	C	TCA L LTL Temp Abnormal-JPM	65	TCS	ITCS	14:28:47
	C	Node 3 MTL REGEN TWMV Overtemp-NODE3	66	TCS	ITCS	14:29:03
SARJ cmd feedback	A	SARJ DLAs Engaged and Locked-P3	67	EPS	SARJ	14:31:09
ITCS impacts	C	Node 3 MTL REGEN TWMV Overtemp-NODE3	68	TCS	ITCS	14:32:06
	A	Node 3 MTL REGEN TWMV Overtemp-NODE3	69	TCS	ITCS	14:32:08
	A	Node 3 MTL REGEN TWMV Undertemp-NODE3	70	TCS	ITCS	14:32:13
	C	Node 3 MTL REGEN TWMV Undertemp-NODE3	71	TCS	ITCS	14:32:15
	C	Node 3 MTL REGEN TWMV Undertemp-NODE3	72	TCS	ITCS	14:33:07
	A	Node 3 MTL REGEN TWMV Undertemp-NODE3	73	TCS	ITCS	14:33:22
	A	Node 3 MTL TWMV Overtemp-NODE3	74	TCS	ITCS	14:33:37

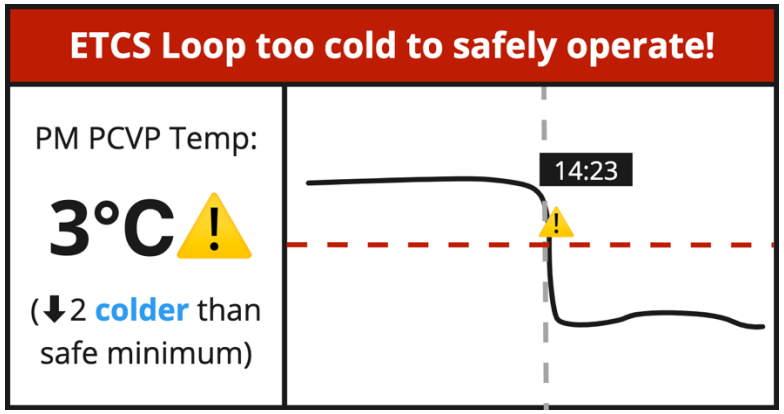
Contextualizing alarms with telemetry

- Some alarms could benefit from additional context of telemetry

ISS Current State

ETCS Loop A PCVP Temp Low-S1

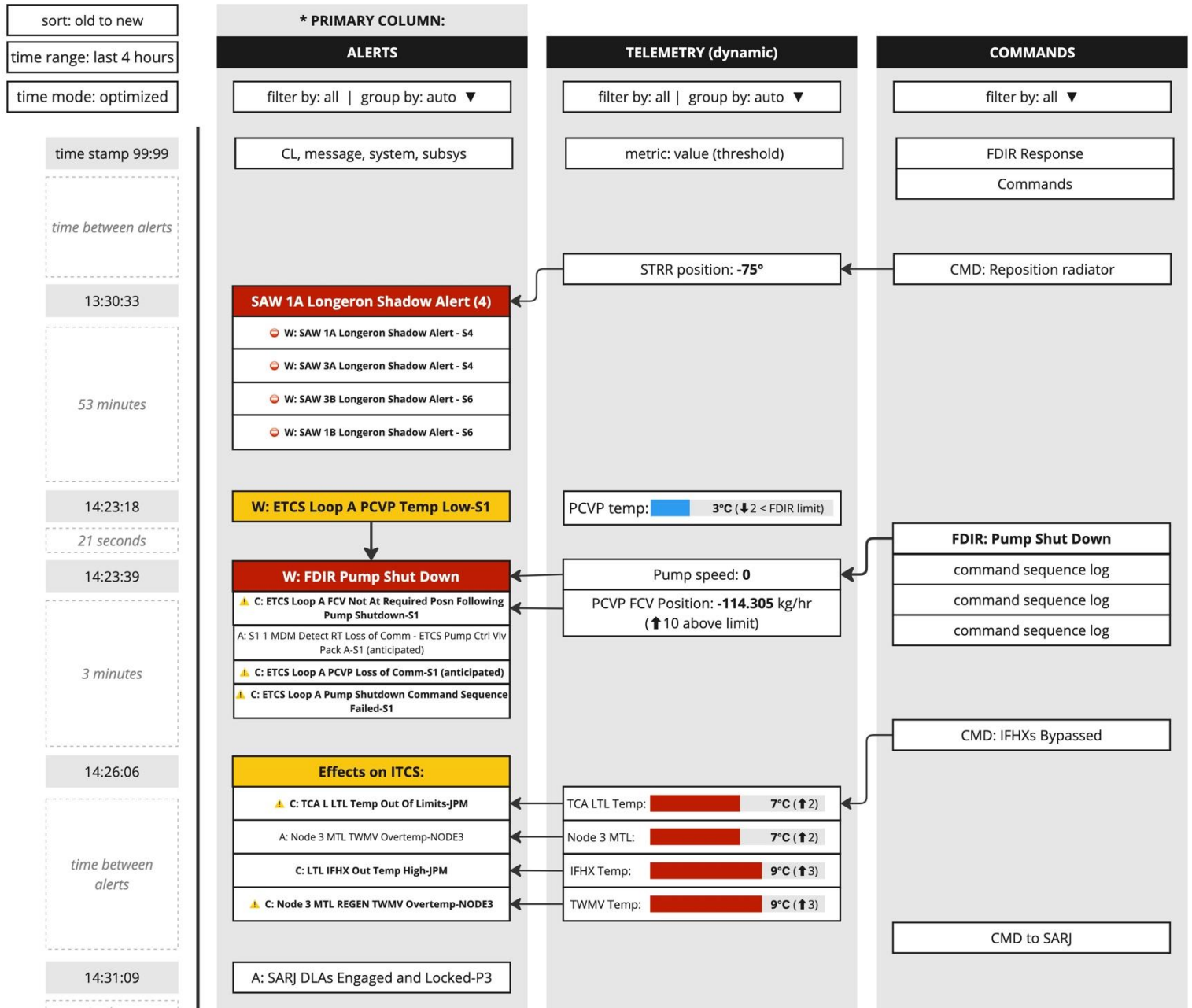
Proposed for BLEO



Caution and Warning Data Management

- Alerts for anomalous events
- FDIR limits and their implications
- Parent-child relationships noted; triaged

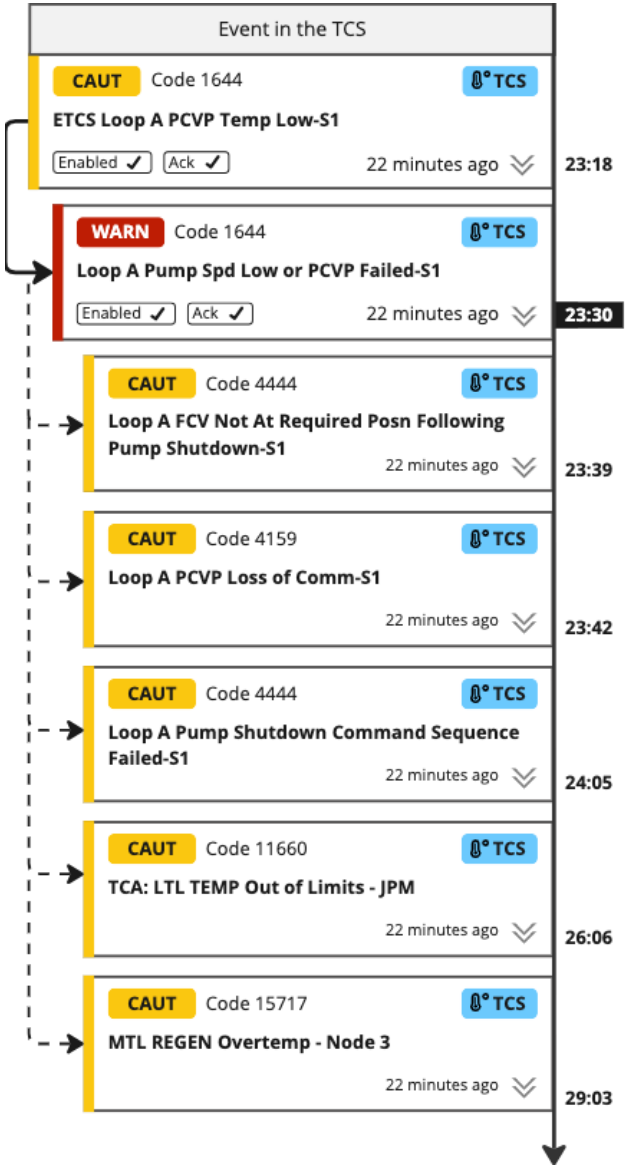
Mapping: ***temporal***

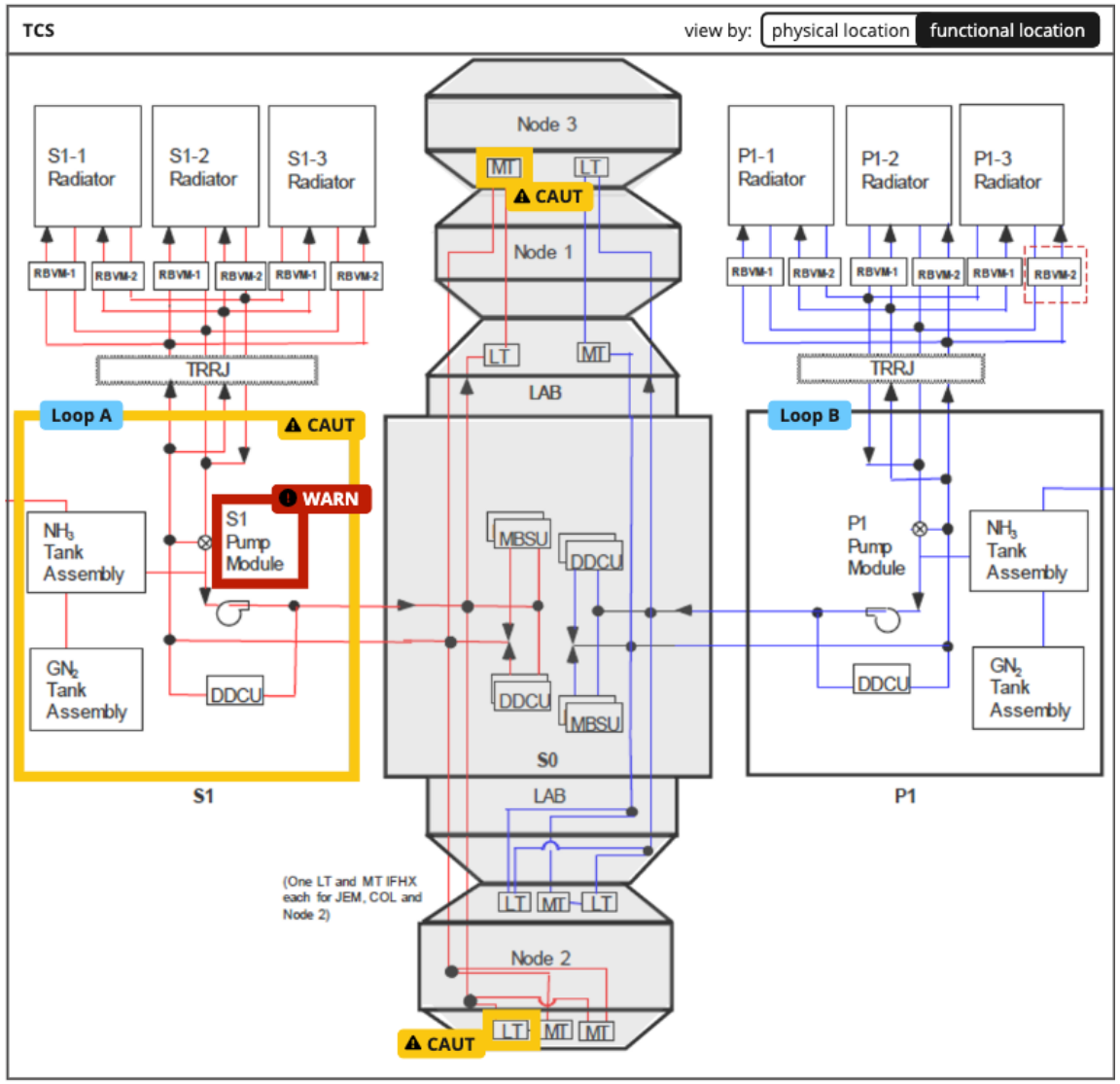


Caution and Warning Data Management

- Alerts for anomalous events
- FDIR limits and their implications
- Parent-child relationships noted; triaged

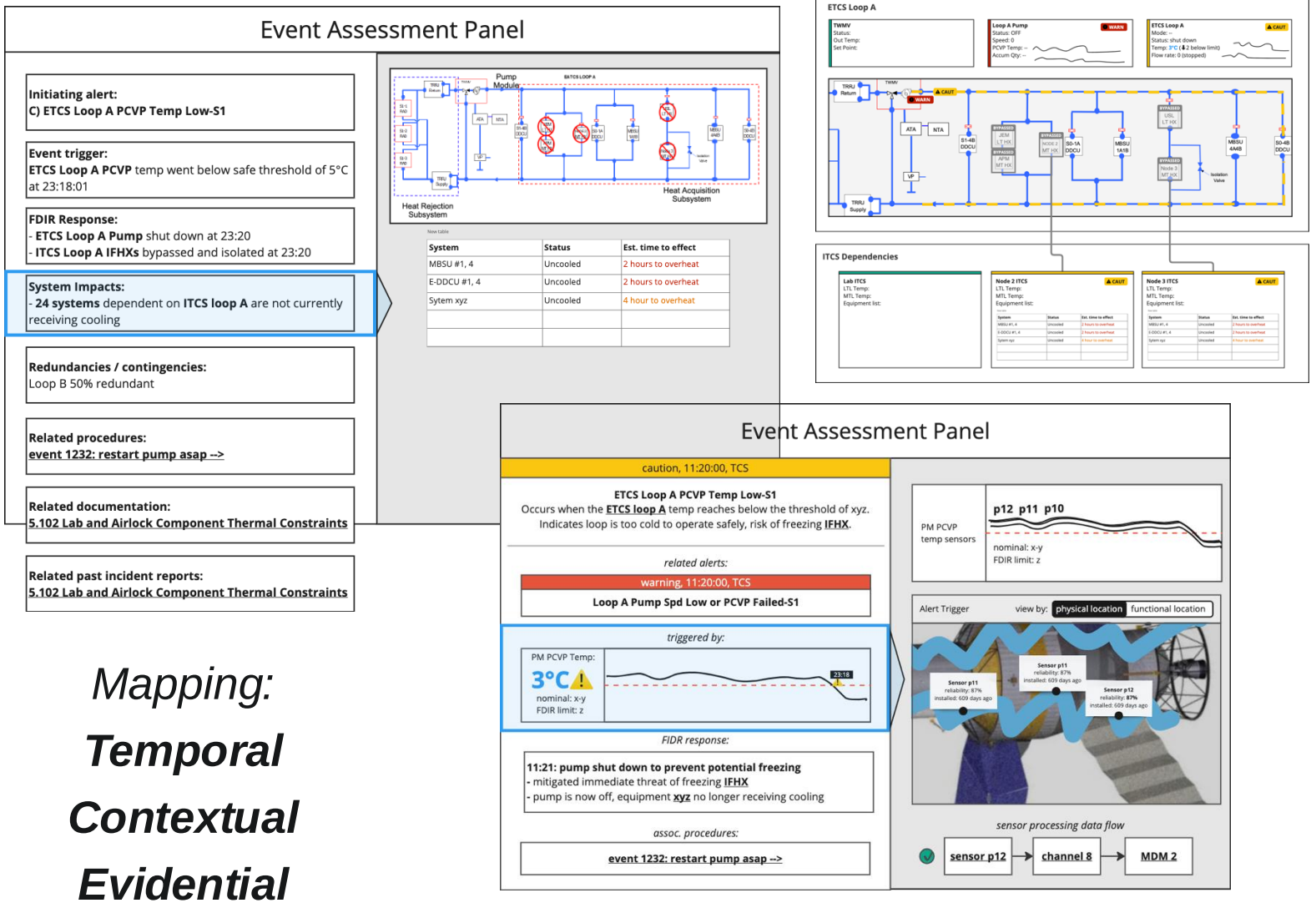
Mapping: ***functional***





Detailed Event Analysis and Drill-Down Capabilities

- Information on downstream impacts and time frame
- Information on norms and ranges
- System manuals, logs
- Troubleshooting “cheat sheet”
- Information on possibly relevant past anomalies



Mapping:

Temporal

Contextual

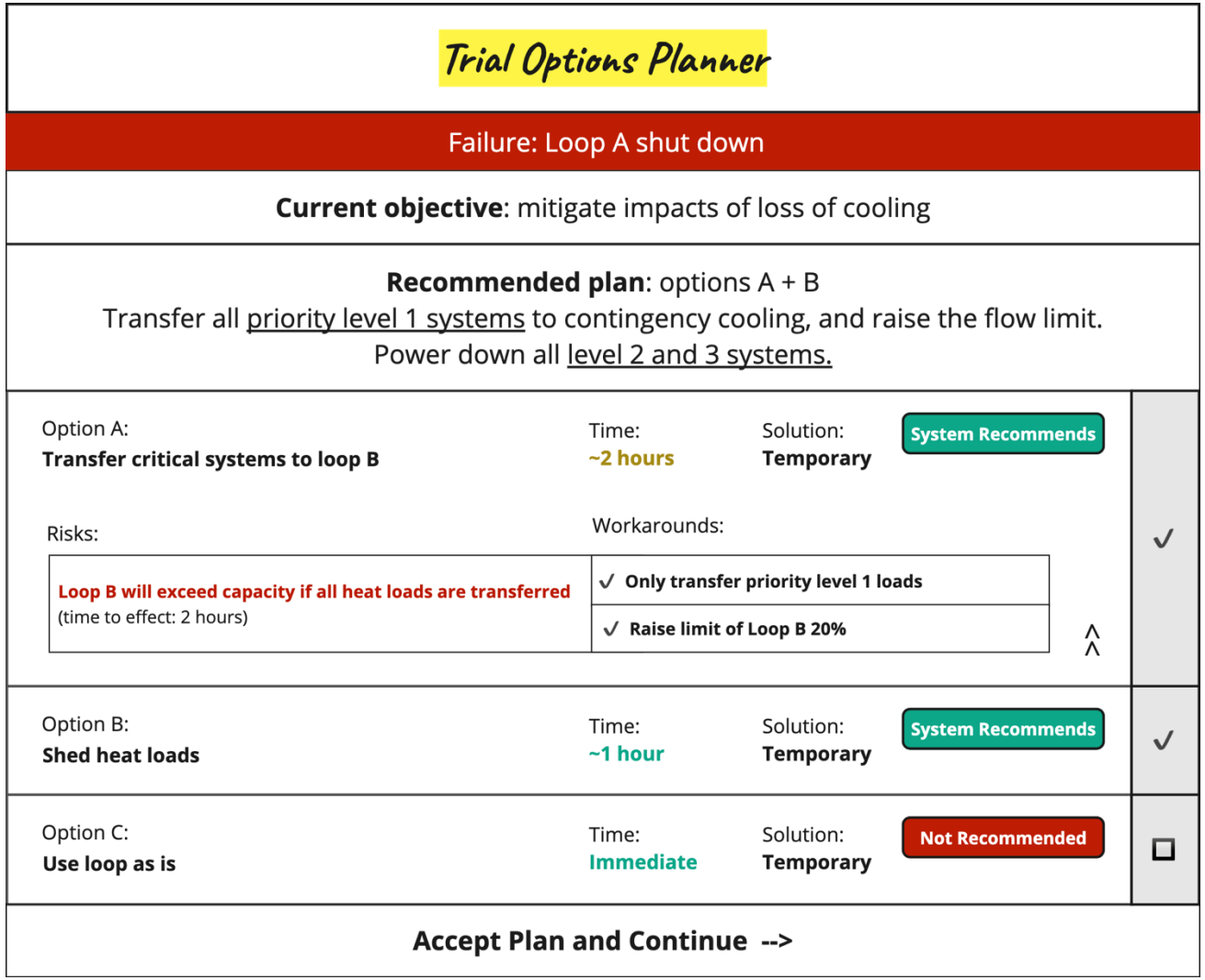
Evidential

Causal

Event assessment: information architecture concepts

Trial Action Options/Plans

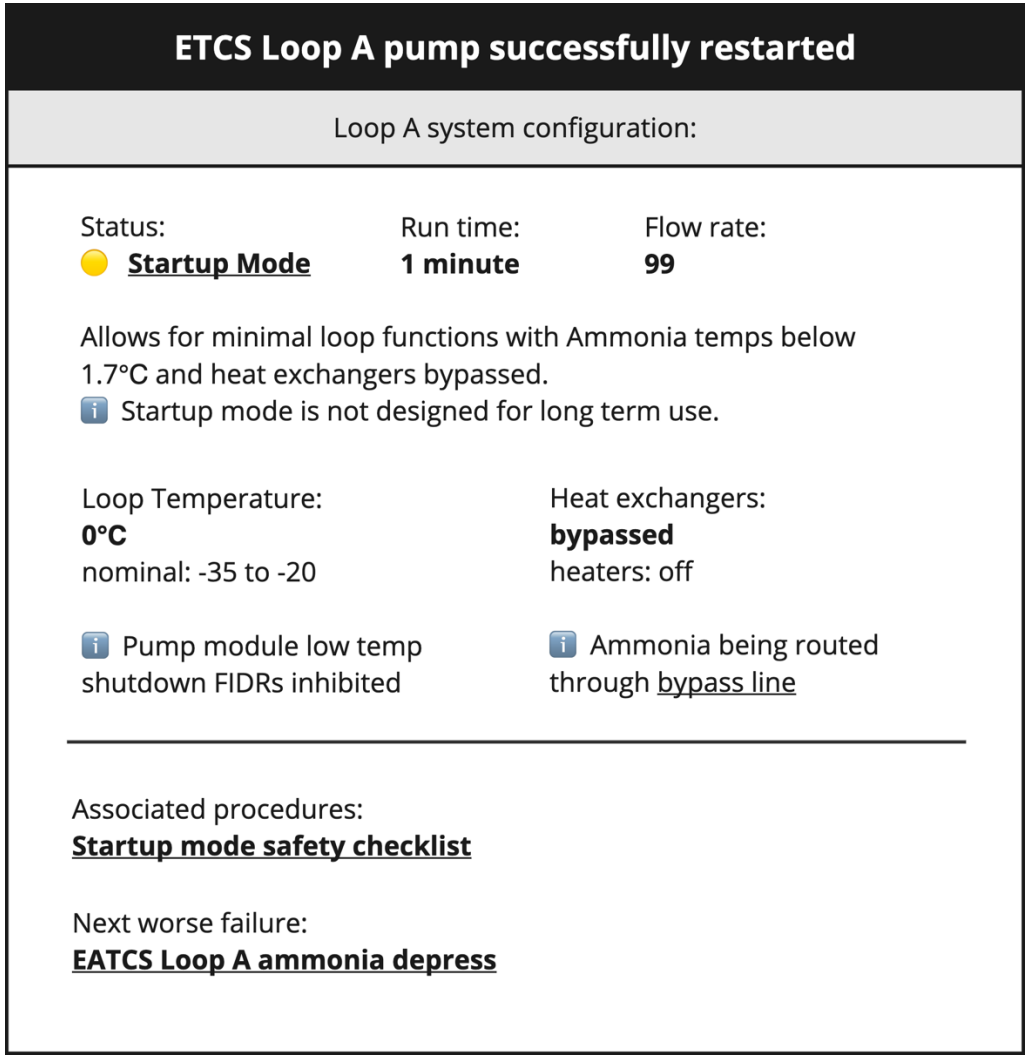
- Information on available resources
- Information on constraint-based timeline options
- Information on possible consequences of actions
- Information on sequence of actions determined to be executed (based on then information)



Decision support planning tool concept

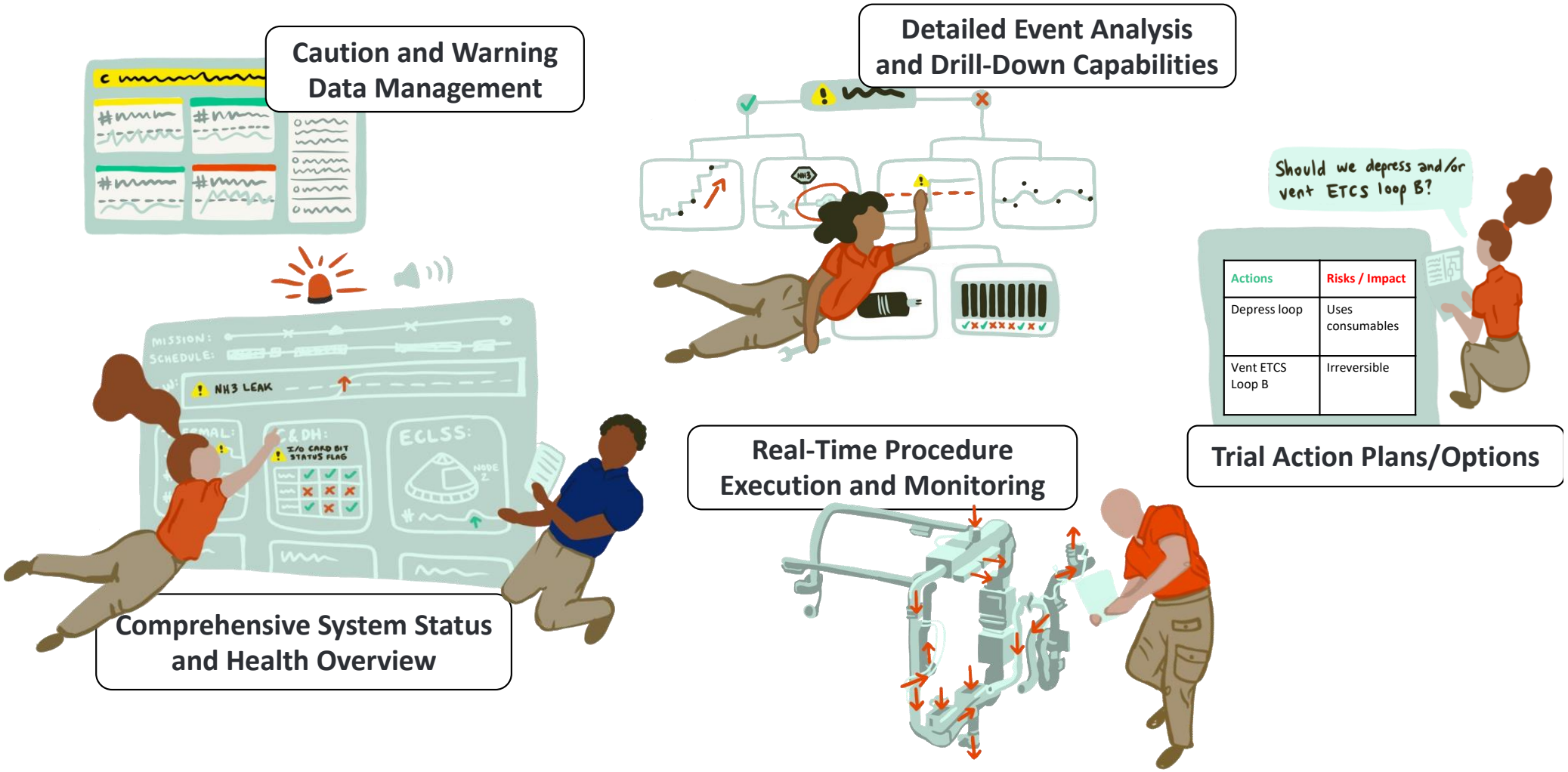
Automated Procedure Execution Oversight and Feedback

- Real-time feedback on procedure effects
- Automated alerts for rule violations or threshold breaches
- Status tracking to ensure successful execution and monitoring of procedures



Procedure effects dialogue

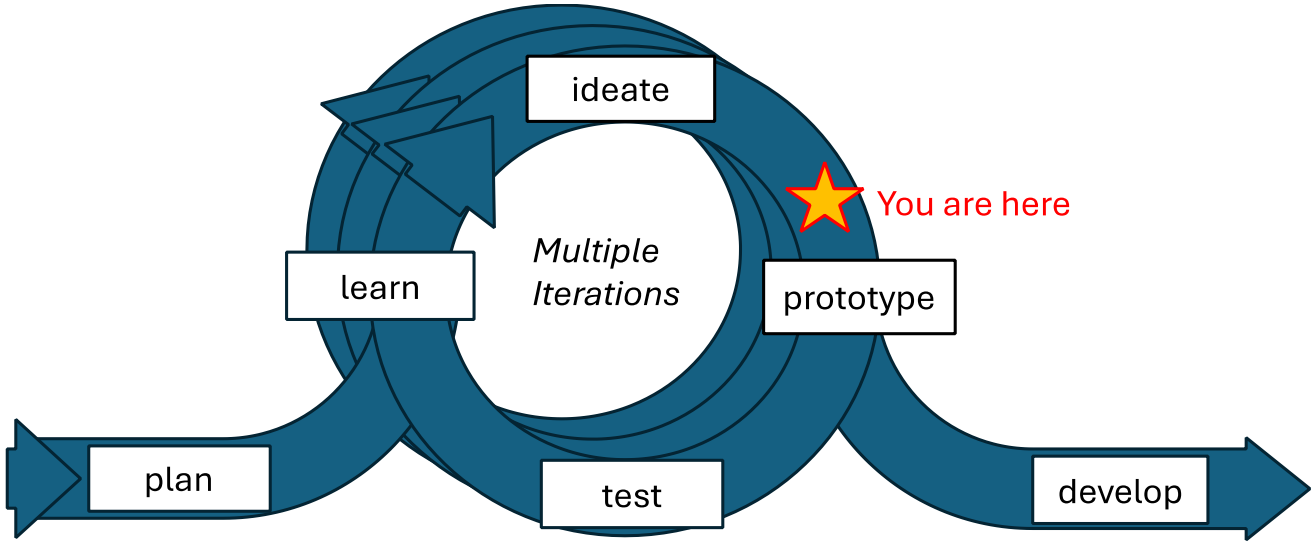
Content and Representation of Information Needed to Support Time-Constrained Problem Solving



Summary: Deliverables

- ✓ **1.** Annotated literature search on information needed/used for problem solving
- ✓ **2.** Common themes and features of problem-solving models used in time-constrained contexts
- ✓ **3.** Conceptualization of information content and representation incorporating these problem-solving themes/features and informed by ISS data model
- ✓ **4.** Countermeasure concepts and requirements to support time-constrained, crew-reliant problem solving and decision-making during procedure execution and anomaly resolution
- ✓ **5.** Findings integrated with deliverables from Mapping BLEO Task (i.e., beyond LEO HSIA anomaly response specifying crew roles and responsibilities, teaming, and interactions with onboard systems and delayed ground support)

Summary



- Concepts firmly grounded by substantial research (problem solving and solvers, mental modes, etc.) and needs analyses

- Some questions still remain (e.g., How much info is too much? How much context is too much?)
- Testing and maturation now needed to progress designs

Thank you!