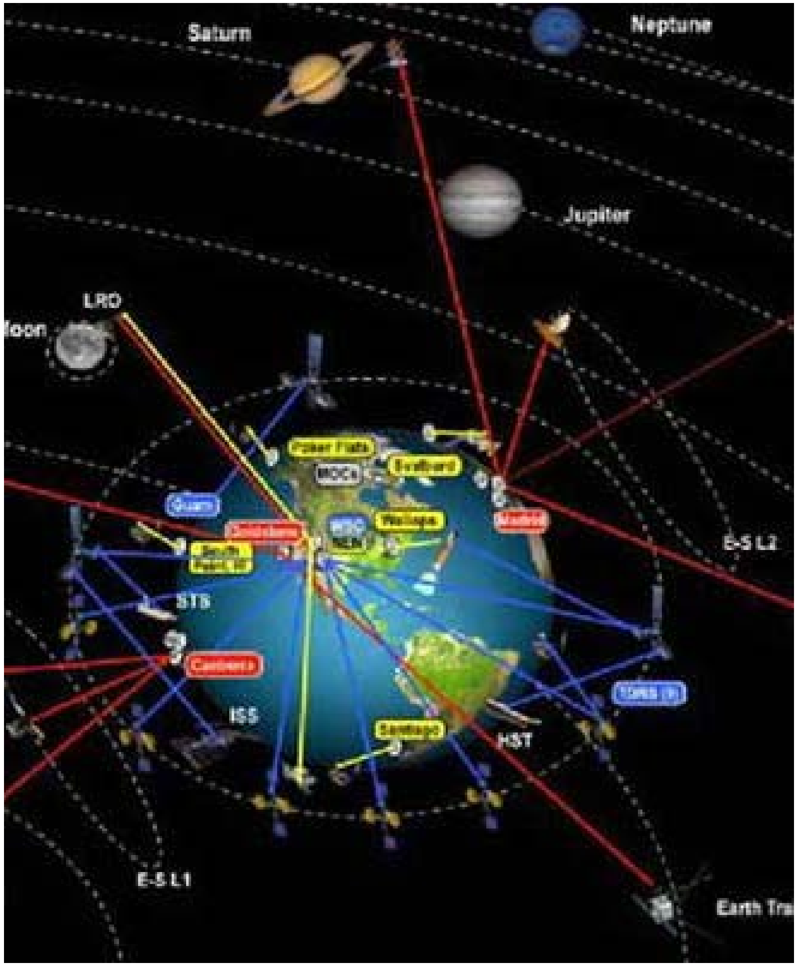
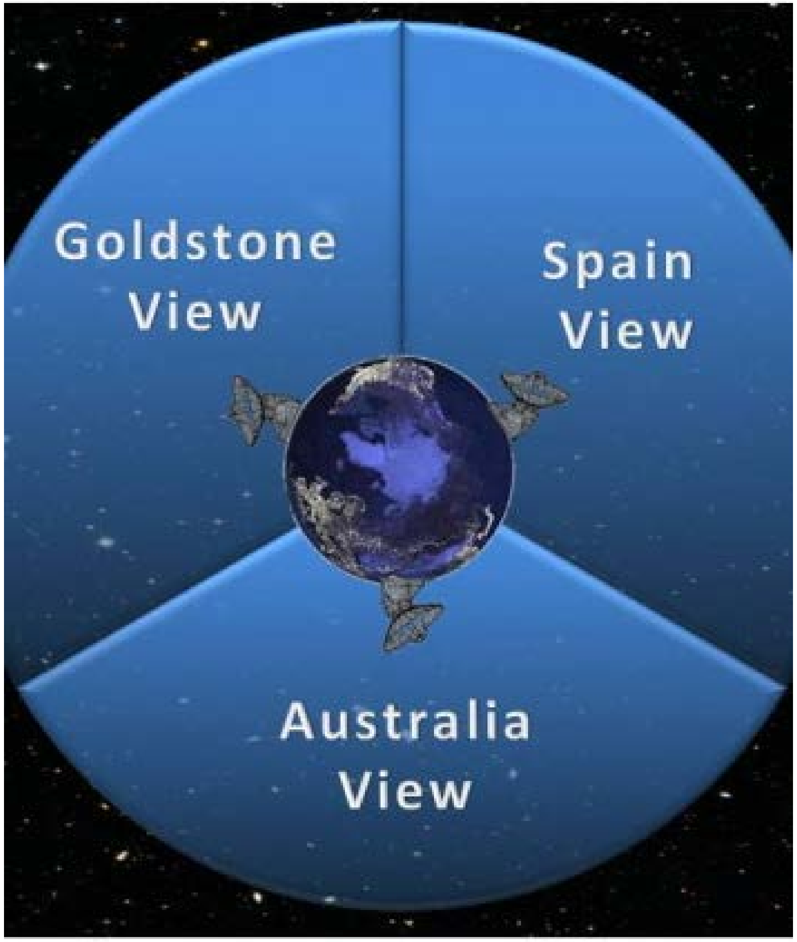
Designing for situation awareness and operator control with large data volumes in NASA's Deep Space Network

Alexandra Holloway

“From the Desert to the Stars”

DSN provides support to most of the world's spacecraft





Deep Space Network

13
Antennas

3
Sites

50
Years old

37 hour
Round-trip light time

Staffing

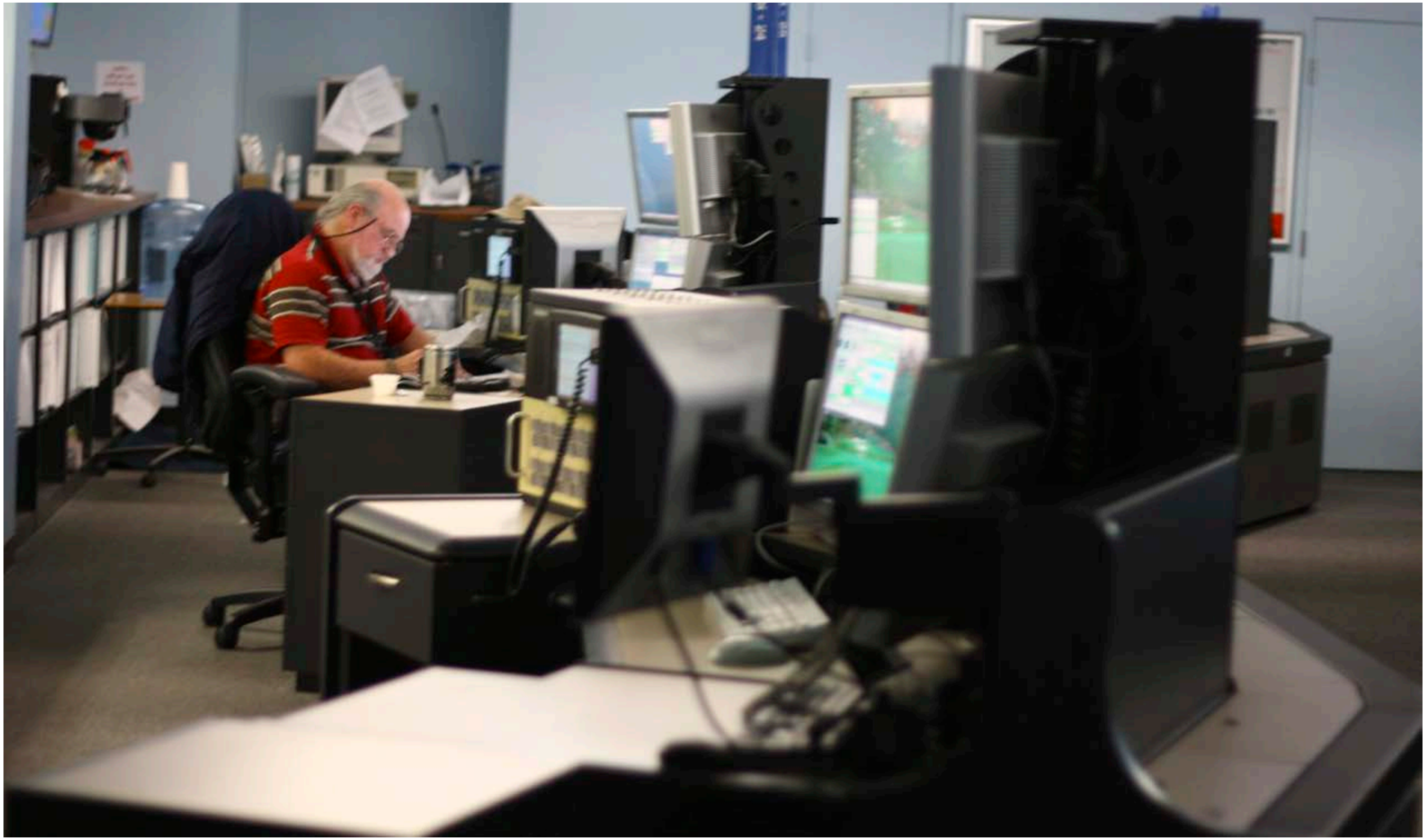
3–6
Operators per shift

2
Links per operator

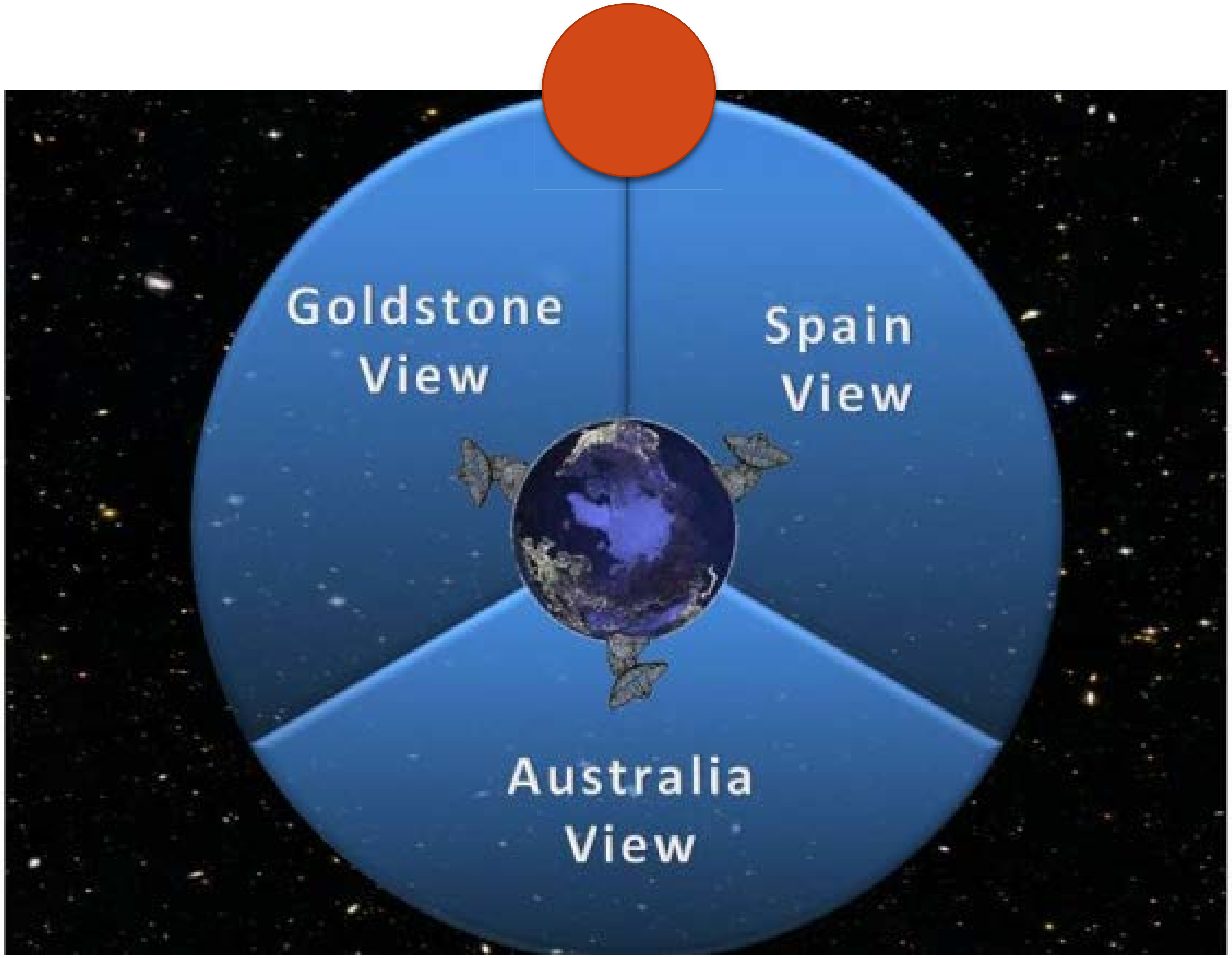
3
8-hour shifts per station

24
Hours per day

Two links per operator

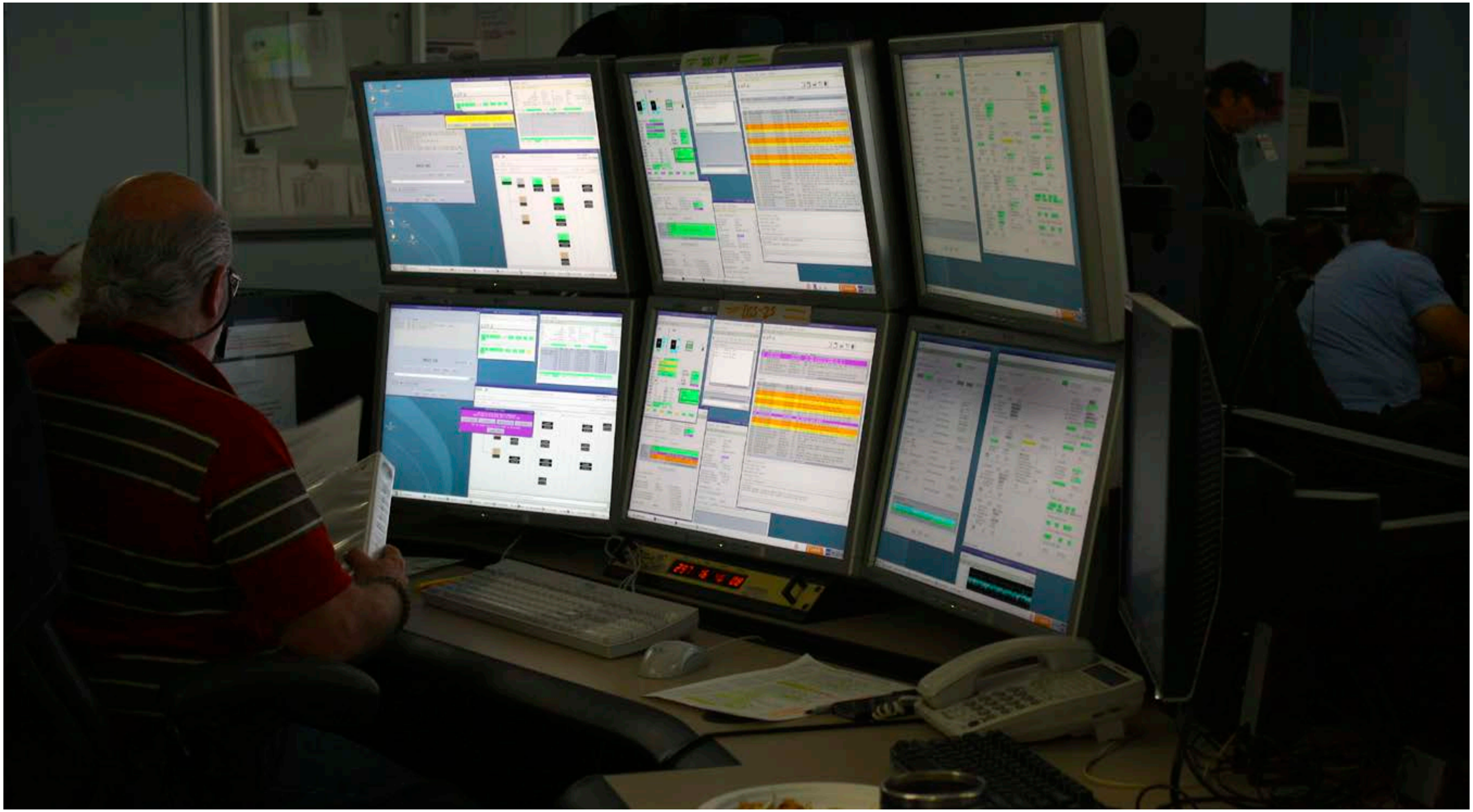


Following the sun



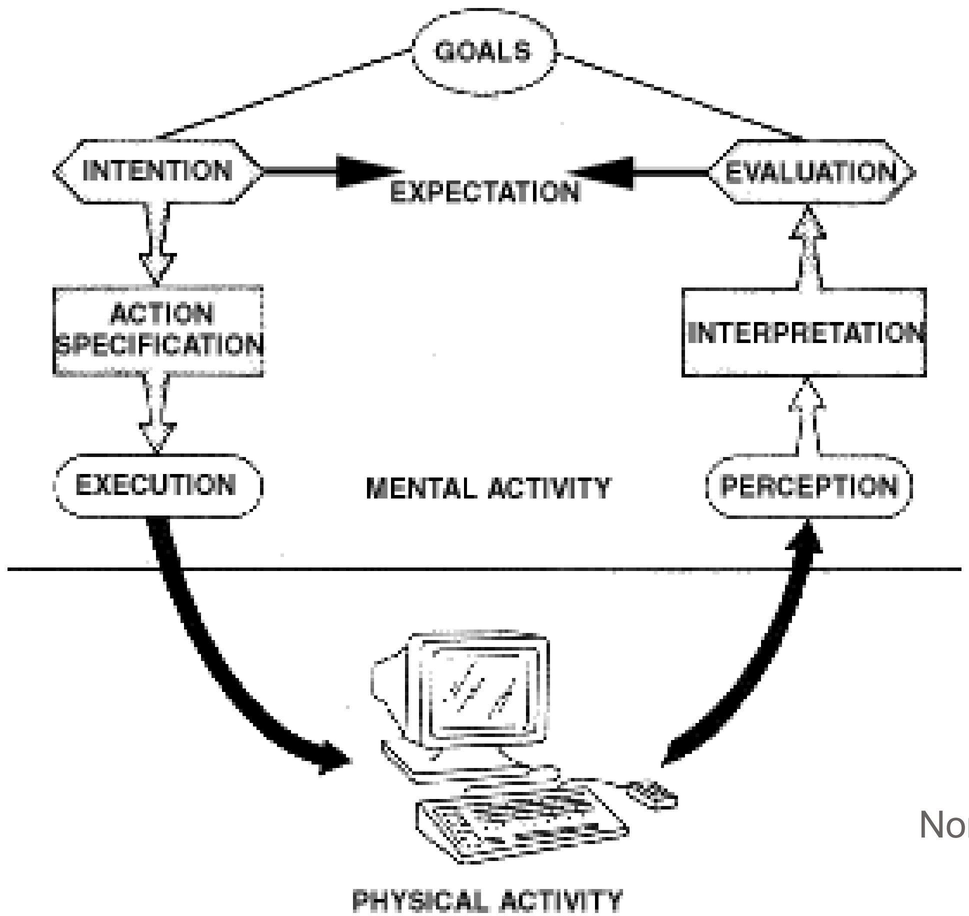
Human problems in “big” data

Q: What should I pay attention to?



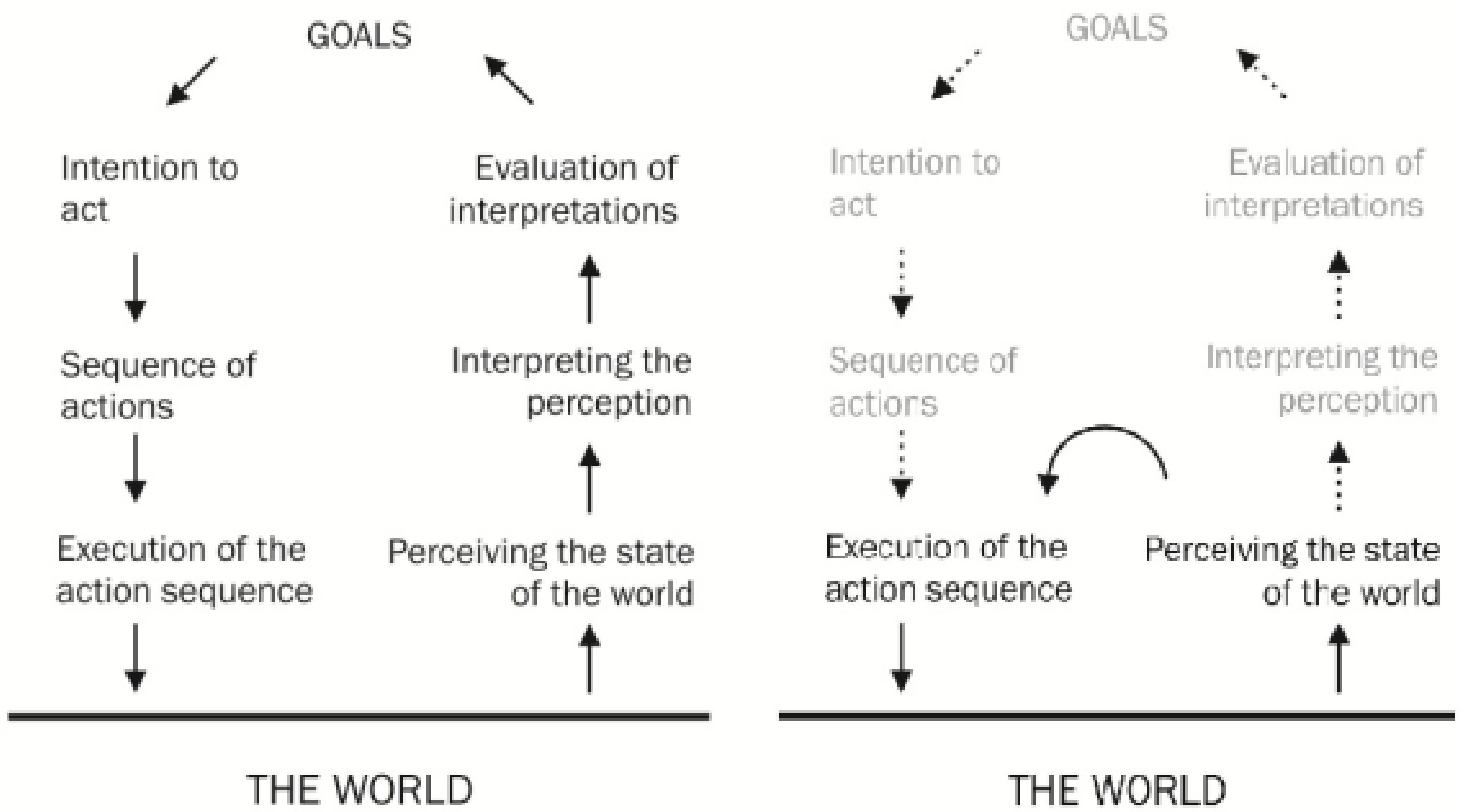
A: Only the things that need it.

Task Action Sequence, Basic



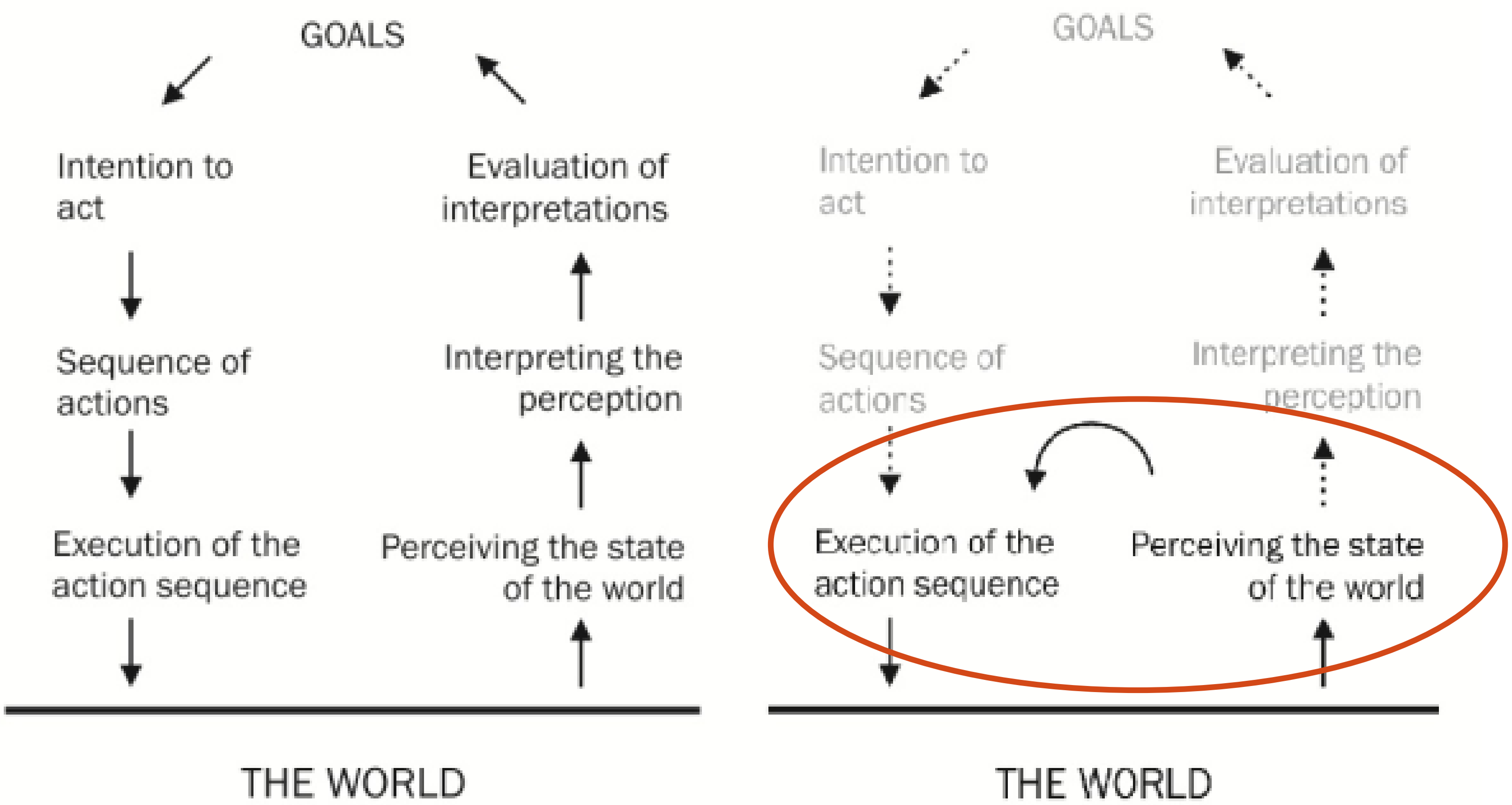
Norman (1986)

Task Action Sequence, Expert



Berkman (2009)

Task Action Sequence, Expert



Berkman (2009)

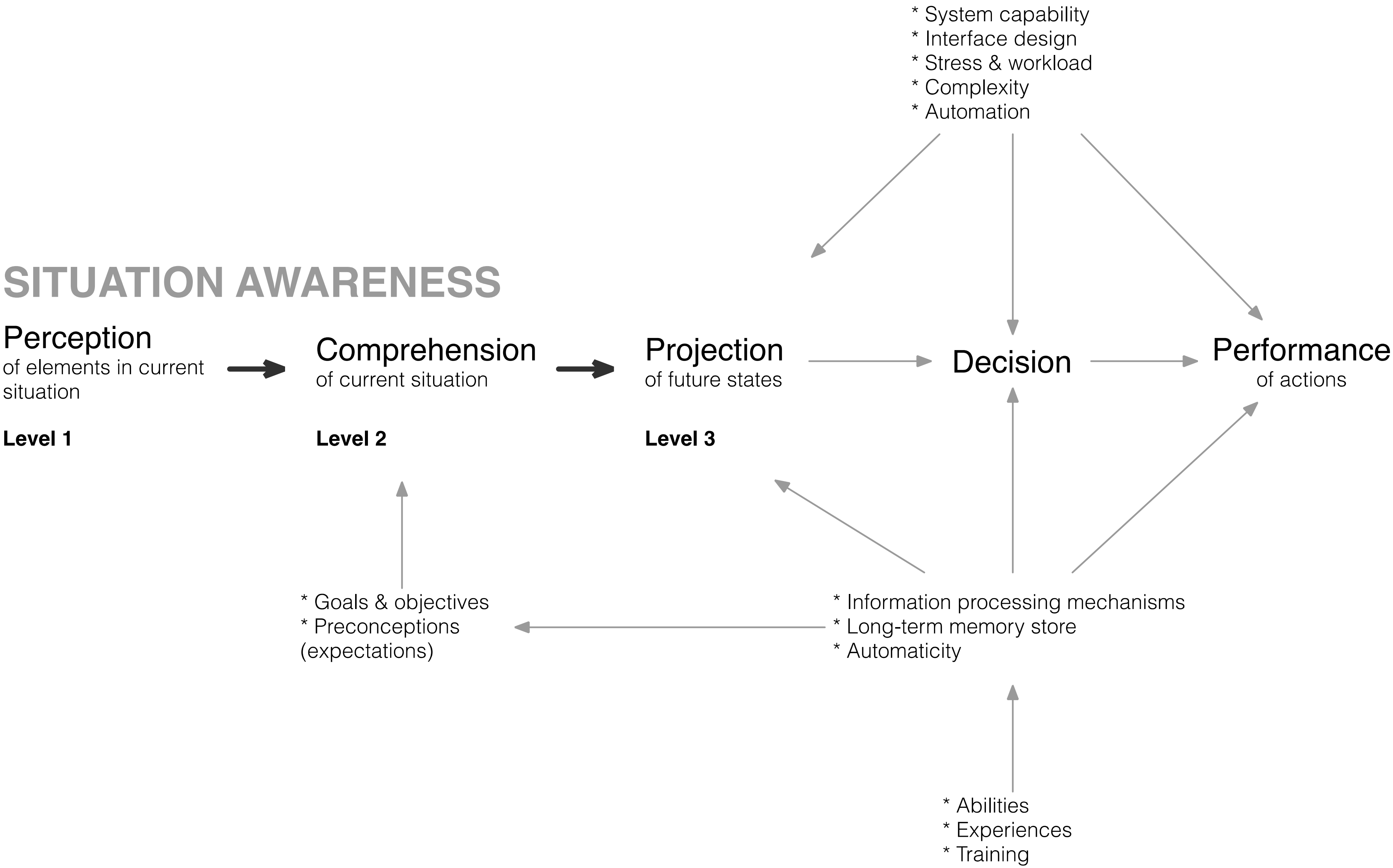
Situation Awareness

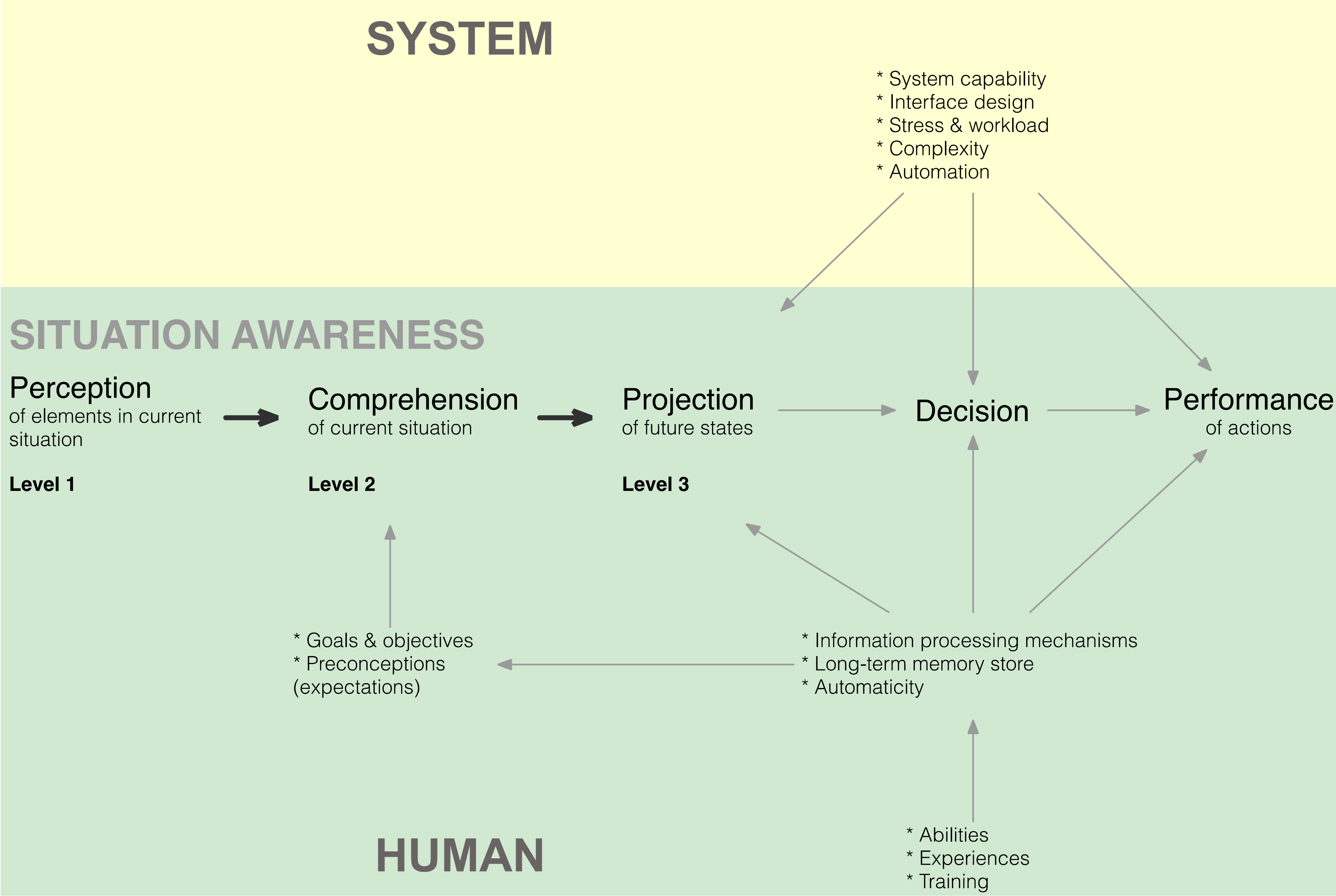
Perception of elements in current situation → **Comprehension** of current situation → **Projection** of future states

Level 1 | **Level 2** | **Level 3**

Endsley (1995)

SITUATION AWARENESS




SYSTEM
* System capability
* Interface design
* Stress & workload
* Complexity
* Automation
SITUATION AWARENESS
Perception
of elements in current situation
Level 1
Comprehension
of current situation
Level 2
Projection
of future states
Level 3
Decision
Performance
of actions
* Goals & objectives
* Preconceptions (expectations)
* Information processing mechanisms
* Long-term memory store
* Automaticity
HUMAN
* Abilities
* Experiences
* Training

8 Things That Help Situation Awareness

Decreasing workload, fatigue, anxiety

Verify necessary support documents and equipment

Step 1

Not relying on short-term memory alone

Verify necessary support documents and equipment

Step 1

Misplaced salience

Verify necessary support documents and equipment

Step 1

Out of the loop

Verify necessary support documents and equipment

Step 1

Complexity

Verify necessary support documents and equipment

Step 1

Support correct mental models

Verify necessary support documents and equipment

Step 1

Watch for data overload

Verify necessary support documents and equipment

Step 1

Where do we add autonomy?

Where?

Raising SA in an autonomous world

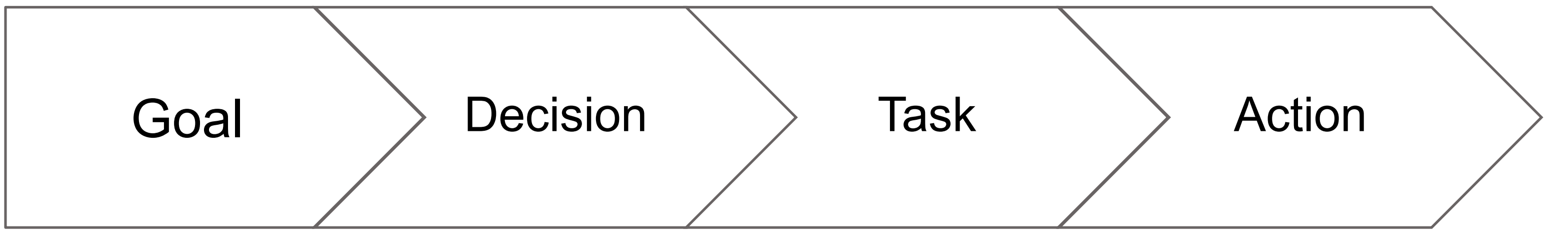
Levels of automation

Adaptive automation

Design principles

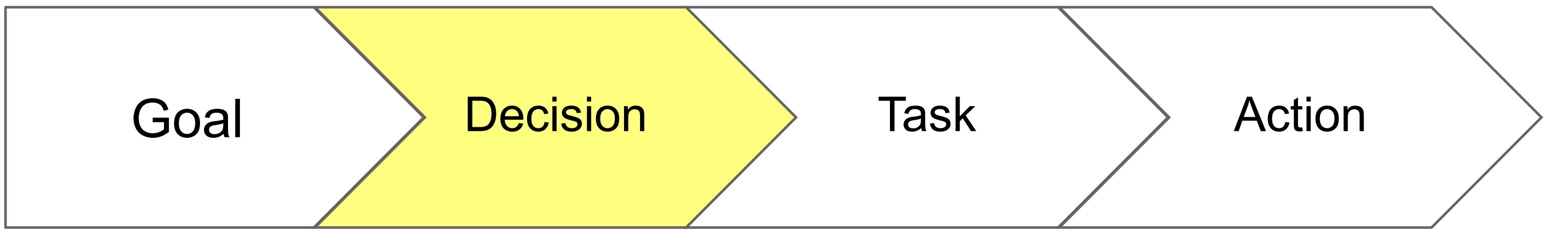
What should I pay attention to?

Goal-oriented task analysis



Endsley (2012)

Goal-oriented task analysis



Perception of elements in current situation → **Comprehension** of current situation → **Projection** of future states

Level 1 | **Level 2** | **Level 3**

Endsley (2012)

Link control operator goals

Allocate resources
Set up and ensure proper working order of equipment for support activities
Goal 1

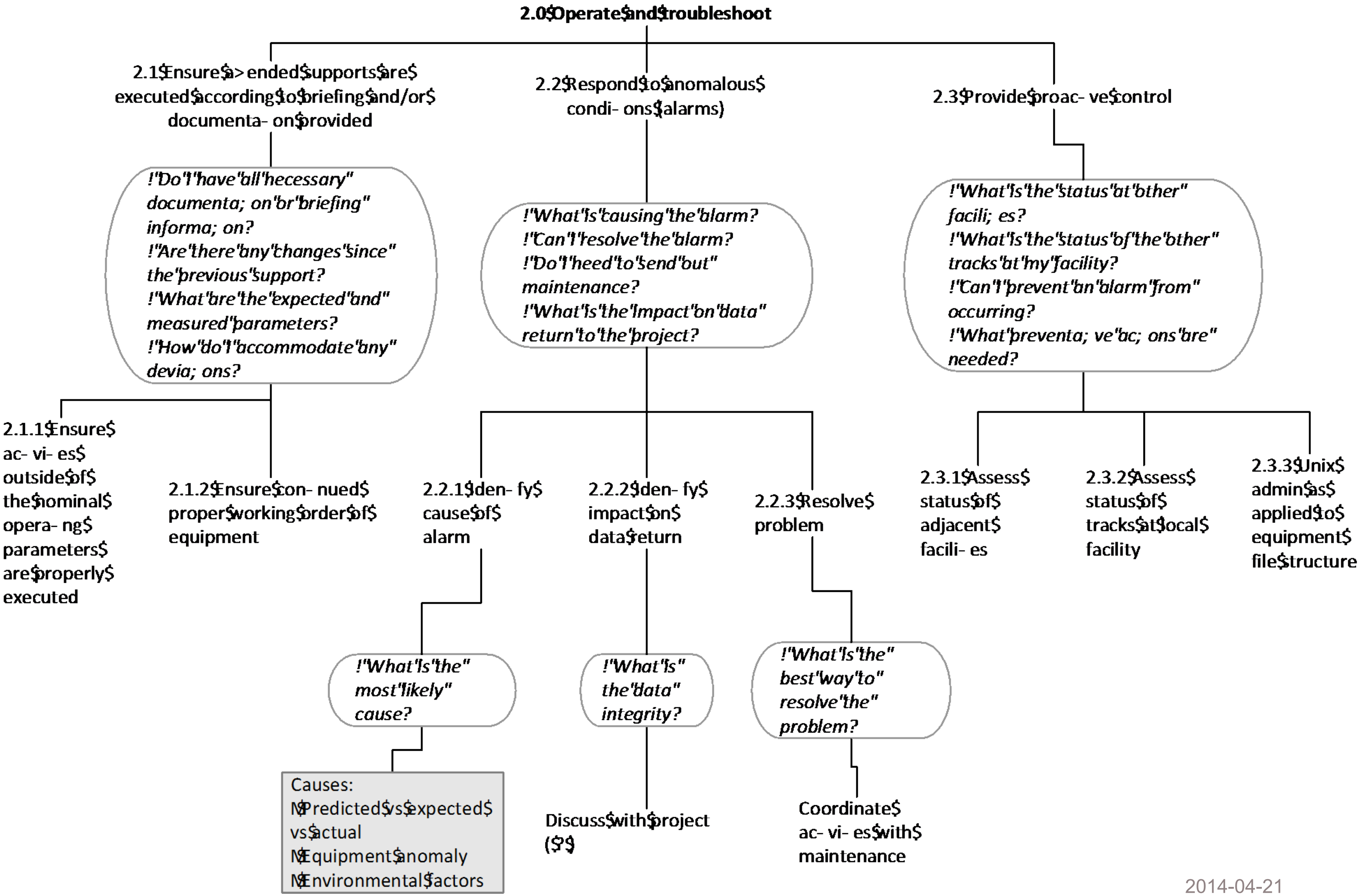
Operate and troubleshoot
Ensure supports are handled according to project instructions; prevent and respond to anomalies
Goal 2

Coordinate activities
Work with maintenance and test crews
Goal 3

Report and verify
Ensure and assist discrepancy reporting
Goal 4

Ensure safety
Be up to date on training and aware of surroundings
Goal 5

Holloway (2014)


2.0$Operate$and$troubleshoot
2.1$Ensure$a> ended$supports$are$ executed$according$to$briefing$and/or$ documenta- on$provided
!"Do"I"have"all"necessary" documenta; on"or"briefing" informa; on?
!"Are"there"any"changes"since" the"previous"support?
!"What"are"the"expected"and" measured"parameters?
!"How"do"I"accommodate"any" devia; ons?
2.1.1$Ensure$ ac- vi- es$ outsideof the$nominal$ opera- ng$ parameters$ are$properly$ executed
2.1.2$Ensure$con- nued$ proper$working$orderof equipment
2.2$Respond$to$anomalous$ condi- ons$(alarms)
!"What"is"causing"the"alarm?
!"Can"I"resolve"the"alarm?
!"Do"I"need"to"send"out" maintenance?
!"What"is"the"impact"on"data" return"to"the"project?
2.2.1$Iden- fy$ causeof alarm
!"What"is"the" most"likely" cause?
Causes:
N$Predicted$vs$expected$ vs$actual
N$Equipment$anomaly
N$Environmental$factors
2.2.2$Iden- fy$ impacton data$return
!"What"is" the"data" integrity?
Discuss$with$project ($?$)
2.2.3$Resolve$ problem
!"What"is"the" best"way"to" resolve"the" problem?
Coordinate$ ac- vi- es$with$ maintenance
2.3$Provide$proac- ve$control
!"What"is"the"status"at"other" facili; es?
!"What"is"the"status"of"the"other" tracks"at"my"facility?
!"Can"I"prevent"an"alarm"from" occurring?
!"What"preventa; ve"ac; ons"are" needed?
2.3.1$Assess$ statusof adjacent$ facili- es
2.3.2$Assess$ statusof tracksatlocal$ facility
2.3.3$Unix$ adminas appliedto equipment$ file$structure

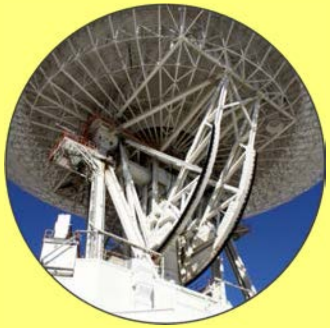
LINK CONTROL OPERATOR
OPERATE AND TROUBLESHOOT
FLOW ANALYSIS

Prepare
Verify necessary support documents and equipment

Step 1

Pre-cal
Configure, calibrate equipment

Step 2



In-Track
Provide necessary support

Step 3

Post-cal
Cool down and stow equipment

Step 4

Report
Document discrepancies

Step 5

Holloway (2013)

Process

User-centered design
Daily engagement of expert link control operators and other ops personnel

Data-driven prototyping
Realness of data contributes to realistic prototypes and richer conversations, even if the prototype is paper

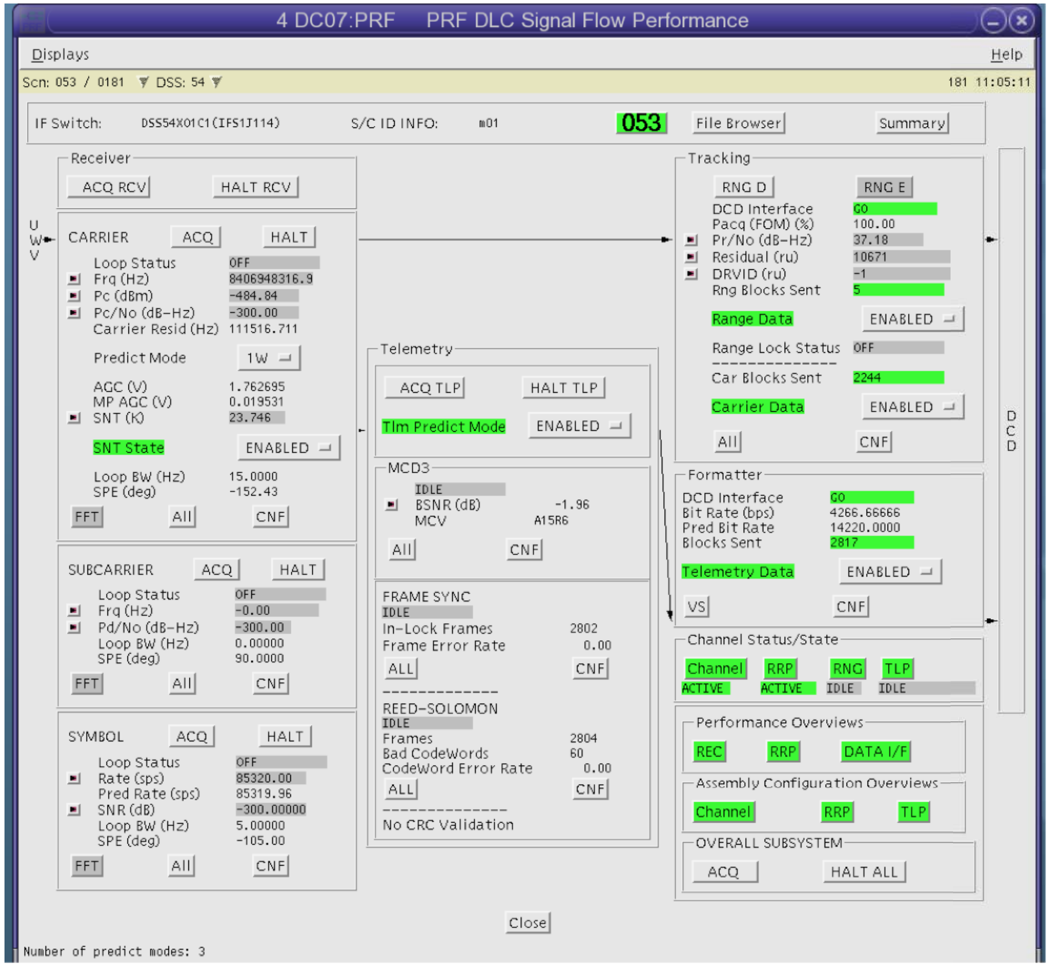
Vision statement
Complex sentence serves as a guiding principle or overarching goal

Hypothesis-led iteration
Each design iteration serves to address a specific hypothesis or open question

Frequent, short “sprints”
Two-week long sprints keep tasks focused; an overarching goal keeps sprints connected to vision

What’s been tried

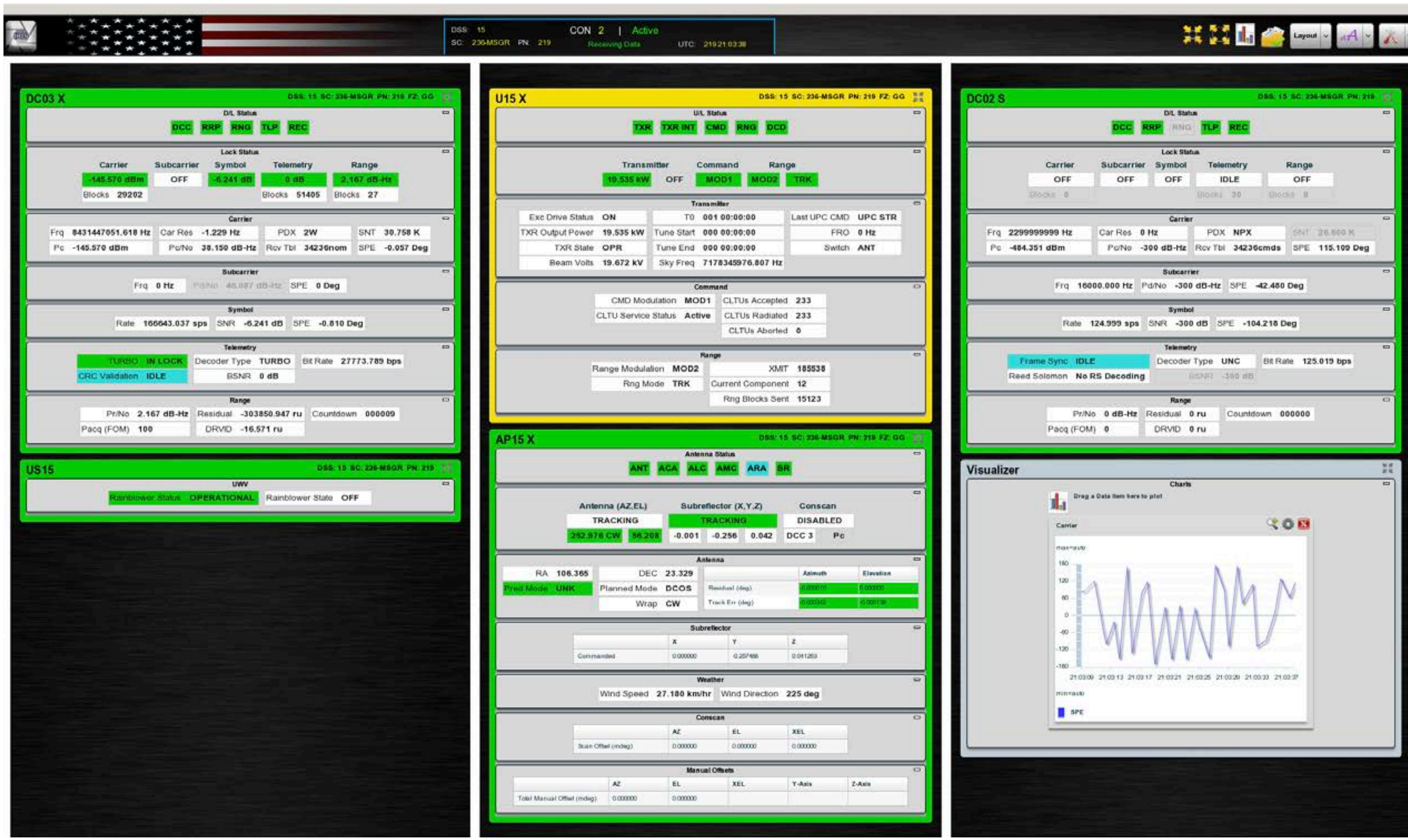
Original displays: One-to-one mapping with hardware



“There’s a billion displays.”

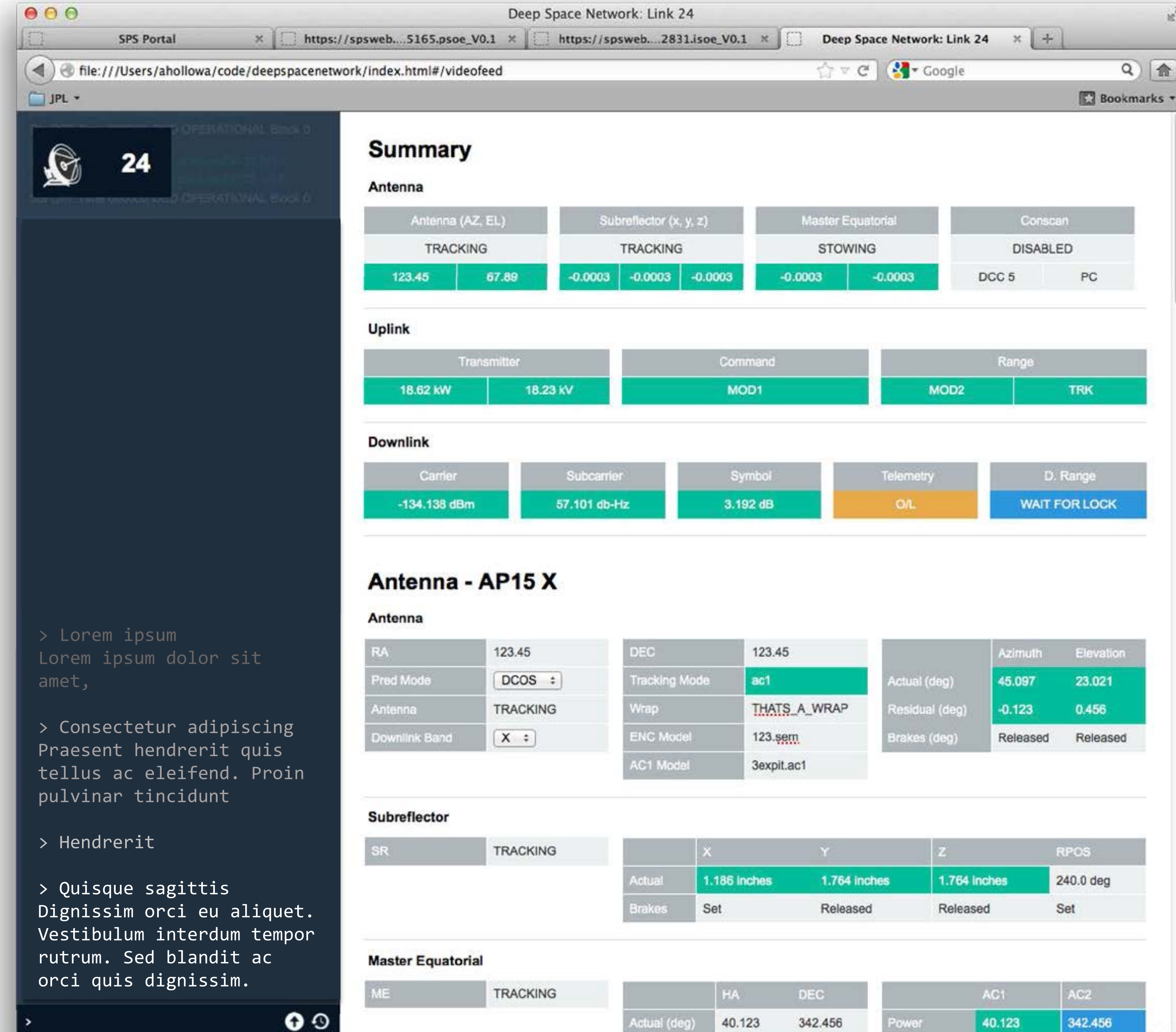
Davidoff (2013)

IRIS displays: too much hierarchy, latency



“What we need is speed.”

Ames (2013)


Deep Space Network: Link 24
SPS Portal
https://spsweb....5165.psoe_V0.1
https://spsweb....2831.isoe_V0.1
Deep Space Network: Link 24
file:///Users/ahollowa/code/deepspacenetwork/index.html#/videofeed
Google
JPL
Bookmarks
24
Summary
Antenna
Antenna (AZ, EL)
TRACKING
123.45
67.89
Subreflector (x, y, z)
TRACKING
-0.0003
-0.0003
-0.0003
Master Equatorial
STOWING
-0.0003
-0.0003
Conscan
DISABLED
DCC 5
PC
Uplink
Transmitter
18.62 kW
18.23 kV
Command
MOD1
Range
MOD2
TRK
Downlink
Carrier
-134.138 dBm
Subcarrier
57.101 db-Hz
Symbol
3.192 dB
Telemetry
O/L
D. Range
WAIT FOR LOCK
Antenna - AP15 X
Antenna
RA
123.45
Pred Mode
DCOS
Antenna
TRACKING
Downlink Band
X
DEC
123.45
Tracking Mode
ac1
Wrap
THATS_A_WRAP
ENC Model
123.sem
AC1 Model
3expit.ac1
Azimuth
Elevation
Actual (deg)
45.097
23.021
Residual (deg)
-0.123
0.456
Brakes (deg)
Released
Released
Subreflector
SR
TRACKING
X
Y
Z
RPOS
Actual
1.186 inches
1.764 inches
1.764 inches
240.0 deg
Brakes
Set
Released
Released
Set
Master Equatorial
ME
TRACKING
HA
DEC
Actual (deg)
40.123
342.456
AC1
AC2
Power
40.123
342.456
> Lorem ipsum
Lorem ipsum dolor sit amet,
> Consectetur adipiscing
Praesent hendrerit quis tellus ac eleifend. Proin pulvinar tincidunt
> Hendrerit
> Quisque sagittis
Dignissim orci eu aliquet. Vestibulum interdum tempor rutrum. Sed blandit ac orci quis dignissim.

In-track >

Operate, troubleshoot

Ensure supports are handled according to project instructions; prevent and respond to anomalies

Goal 2

Context : Monitor

-- Develop, retain awareness of the big picture to prevent and troubleshoot anomalous conditions

Control : Command

-- Perform functions necessary to provide support while preventing and troubleshooting anomalous conditions

-- Take over others' work as needed

In the world

At my site

In the room

With my stuff

An organized control system for
developing and maintaining
situation awareness,
supporting operator control,
and
facilitating fast decision-making
surrounding
automatic setup and maintenance of
Deep Space Network support activities

Research questions

Does *intervention* lead to better decisions than *control*?

Does *intervention* lead to **better decisions** than *control*?

Increased performance
Shorter time to task and lower error rate
Outcome variable 1

Decreased perceived workload
May be related to “display clutter”
Outcome variable 2

Increased situation awareness
As measured by subjective and objective measures
Outcome variable 3

Is everything okay?

Develop and maintain global situation awareness

Operationalized by postage stamp

Research Question 1

State of the future

Develop and maintain a model of the projected future

Operationalized by stamp ribbon

Research Question 2

Details and deltas

Support level-1 situation awareness with quick details; support level-2 situation awareness by calculating deltas

Operationalized by the “All” sub-display

Research Question 3

Make it visual

Use a strong data-ink ratio for large information transfer, rather than showing measurements and numbers alone

Operationalized by downlink carrier FFT display

Research Question 4

Strengthen the mental model

Arrange by spacecraft, antenna, subsystem, device, and by everything; Will filtering and search be helpful?

Operationalized by logging

Research Question 5

Making changes

Investigate appropriateness of everything-editable versus modal lock/edit states or special configuration displays

Operationalized by modals and config displays

Research Question 6

By my own rules

Investigate level-3 situation awareness with operator control for forming rulesets for realtime data processing

Operationalized by Complex Event Processing

Research Question 7

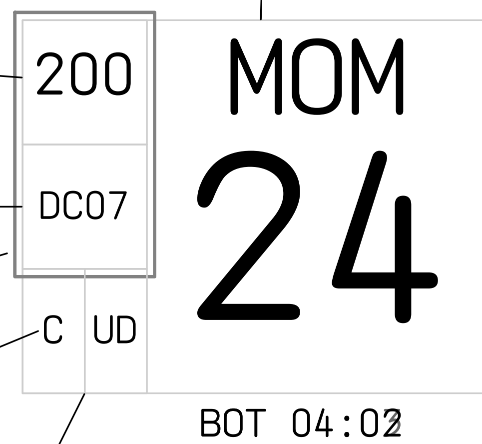
RQ1: Is everything okay?

Develop and maintain global situation awareness

What's in a

Postage Stamp?

Spacecraft name



Uplink:
(no data) = white, grey text
Appears in SOE = white, black text
ACQ U/L … = wheat (tan)
ACQ U/L WITH <#> = text populated with <#>

Downlink:
(no data) = white, grey text
Appears in SOE = white, black text
ACQ D/L … = white (tan)
ACQ D/L ON <#> = text populated with <#>

Support type:
(no data) = not shown
Appears in SOE as "2W" = grey
2W DL UL LOCK = green

Command mod:
(no data) = white, grey text
Appears in SOE = white, black text
CMD MOD ON = green
CMD MOD OFF = white

Ranging:
(no data) = white, grey text
Appears in SOE = white, black text
RNG MOD ON = green
RNG MOD OFF = white
ACQ RANGING = green

Time:
Before BOA: Until BOA
In track: Until EOT

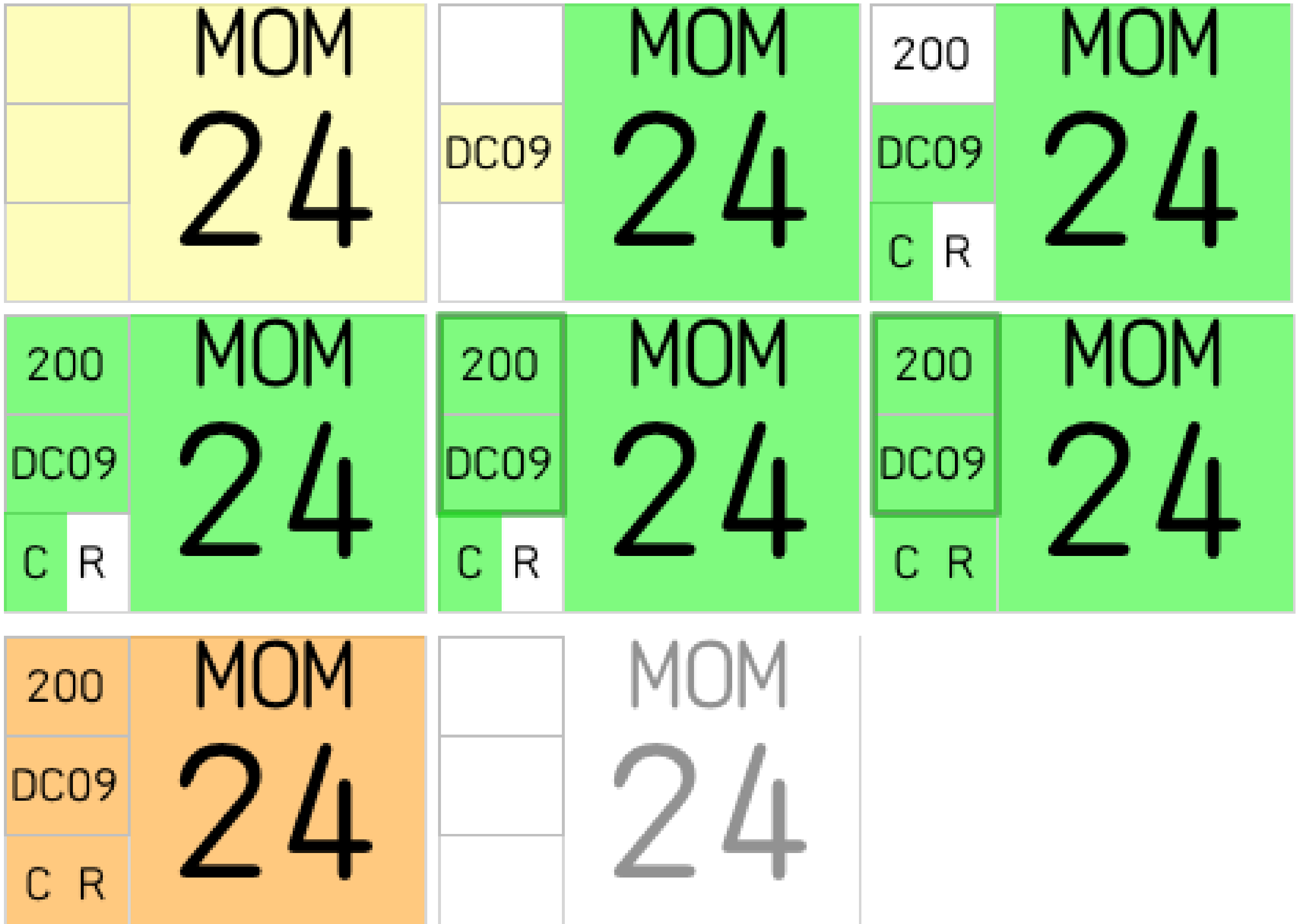
Track stage:
(no data) = white
BOA/BEGIN PRECAL = yellow
BOT = green
EOT/BEGIN POSTCAL = orange
END POSTCAL = white, text grey

Antenna number

Antenna state:
(no data) = white
ANT SLEWING = yellow
ANT ON POINT = green
ANT STOWING = orange
ANT STOWED = white
ANT STOPPED = pink
EOA/END POSTCAL/ANT RELEASED = white, text grey

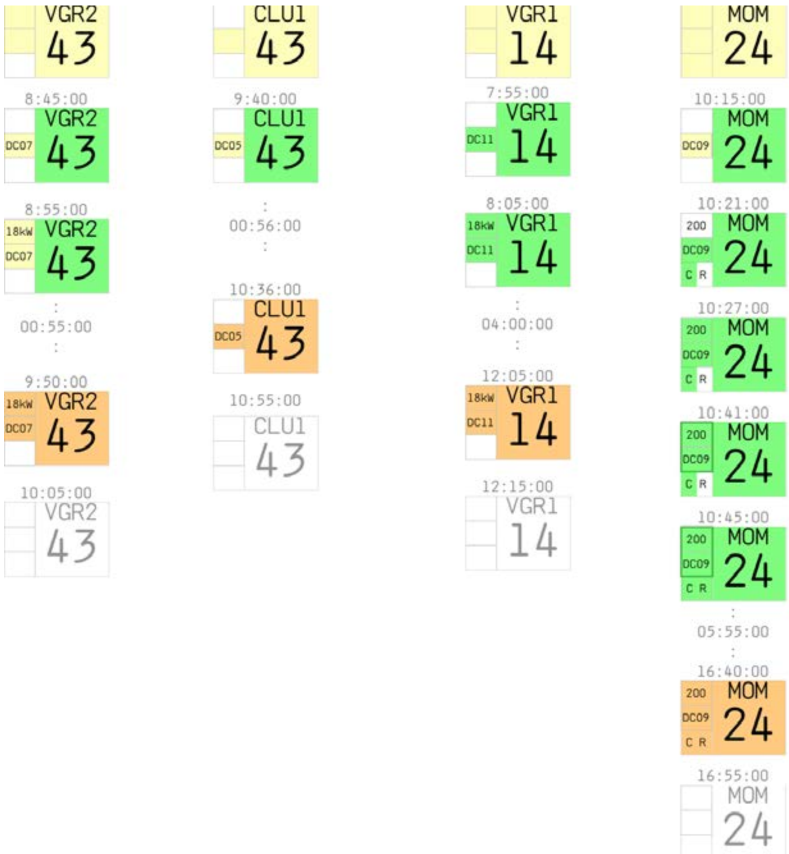
RQ1: Is everything okay?

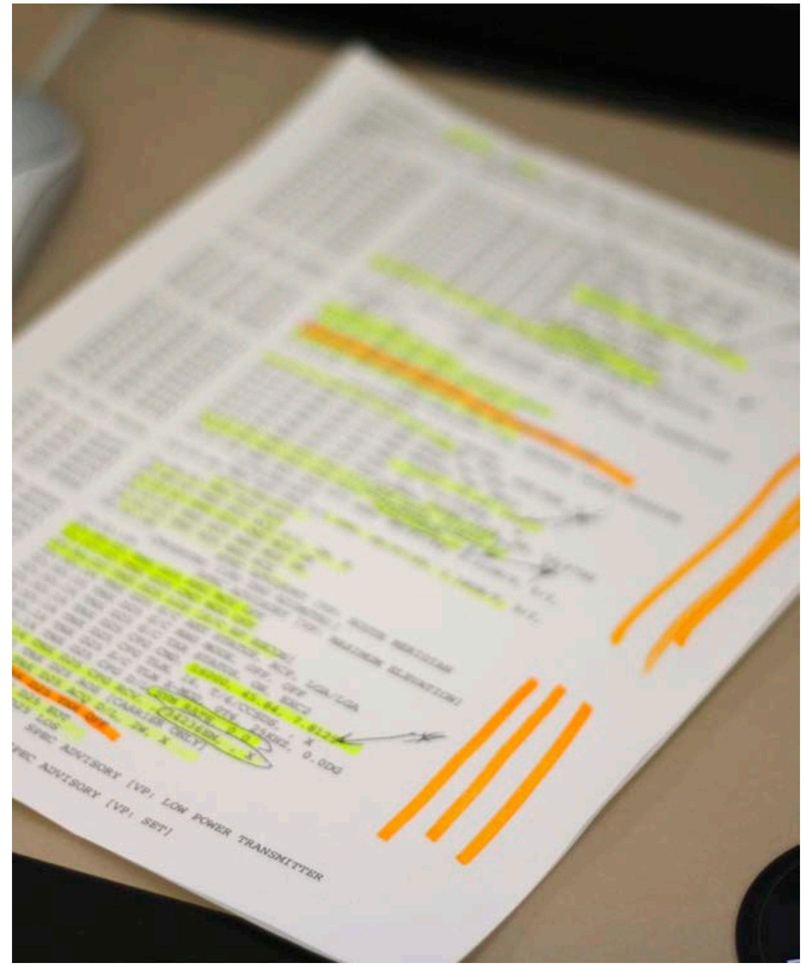
Develop and maintain global situation awareness



RQ2: State of the future

Develop and maintain a model of the projected future





RQ3: Details and deltas

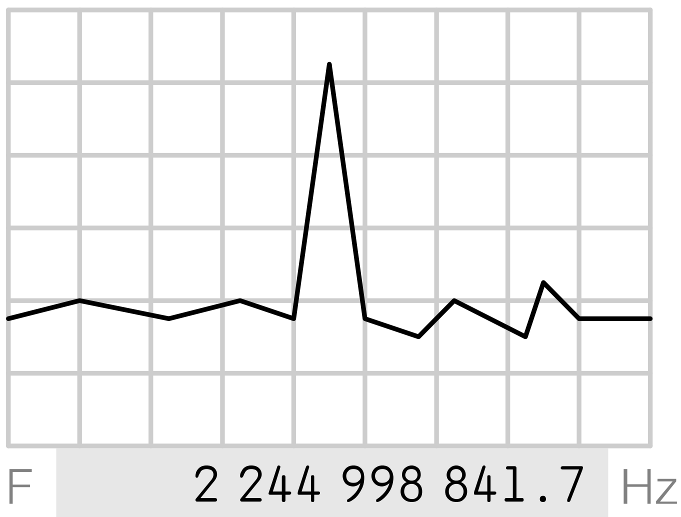
Support level-1 (perception) situation awareness with quick details; support level-2 (comprehension) situation awareness by calculating deltas

Acceleration	Predicted	0.000 002	Hz/s/s
	Measured	-115.599 998	Hz/s/s
	Delta	-115.599 996	Hz/s/s
Pt	Predicted	-115.599 998	dBm
	Measured	-477.458 405	dBm
	Delta	361.858 407	dBm
Pc	Predicted	-120.671 280	dBm
	Measured	-482.229 614	dBm
	Delta	361.558 334	dBm
Pc/No	Predicted	-120.671 280	dB-Hz
	Measured	-482.229 614	dB-Hz
	Delta	361.558 334	dB-Hz
	Best measured	-300.000 000	dB-Hz
	Residual	-362.488 037	dB-Hz
	Cumulative	-300.000 000	dB-Hz
Pt/No	Predicted	67.559 319	dB-Hz
	Measured	-295.228 790	dB-Hz
	Delta	-362.788 109	dB-Hz

	Measured	-0.072 689	Hz/s
Acceleration	Predicted	0.000 002	Hz/s/s
	Measured	-115.599 998	Hz/s/s
Pt	Predicted	-115.599 998	dBm
	Measured	-477.458 405	dBm
Pc	Predicted	-120.671 280	dBm
	Measured	-482.229 614	dBm
Pc/No	Predicted	-120.671 280	dB-Hz
	Measured	-482.229 614	dB-Hz
	Best measured	-300.000 000	dB-Hz
	Residual	-362.488 037	dB-Hz
	Cumulative	-300.000 000	dB-Hz
Pt/No	Predicted	67.559 319	dB-Hz
	Measured	-295.228 790	dB-Hz
Total power AGC	Measured	1.967 773	V
	MP measured	0.000 000	V
Loop SPE		-135.300 781	deg

RQ4: Make it visual

Use a strong data-ink ratio for large information transfer, rather than showing measurements and numbers alone



CARRIER	I N LOCK
Conscan	DC05
PC (dbm)	- 169. 613
Car residual	1 673. 061
Predicts	1W 2W 3W
SNT (k)	16. 414 1
SNT State	ENABLED
Car Band	X S Ka
AGC (V)	1. 704 1
Config Table	7031b160
IF	DSS14XO1C2
FC	FJ_A

RQ5: Strengthen the mental model

Arrange by spacecraft, antenna, subsystem, device, and by everything; Will filtering and search be helpful?

3505	10:05	PA	ant-43	stamp-VGR2	43	End postcal	VGR2
3506	10:05	PA	ant-43	stamp-VGR2	43	End of activity	VGR2
3507	7:10	AD	ant-14	stamp-VGR1	14	Beginning of activity	VGR1
3508	7:10	AD	ant-14	stamp-VGR1	14	Begin precal	VGR1
3509	7:20	PA	ant-14	stamp-VGR1	14	Antenna slewing	VGR1
3510	7:45	DR	ant-14	stamp-VGR1	14	Antenna on point	VGR1
3511	7:55	DR	ant-14	stamp-VGR1	14	Beginning of track	VGR1
3512	7:55	DR	ant-14	stamp-VGR1	14	Acquire downlink on DC11	VGR1
3513	8:05	DR	ant-14	stamp-VGR1	14	Acquire uplink with 18KW	VGR1
3514	9:00	DR	ant-14	stamp-VGR1	14	DROP downlink LOCK	VGR1
3515	9:03	DR	ant-14	stamp-VGR1	14	Acquire downlink on DC11	VGR1
3516	9:07	DR	ant-14	stamp-VGR1	14	One-way downlink LOCK	VGR1
3517	12:05	DR	ant-14	stamp-VGR1	14	End of track	VGR1
3518	12:05	DR	ant-14	stamp-VGR1	14	Begin postcal	VGR1
3519	12:05	PA	ant-14	stamp-VGR1	14	Antenna stowing	VGR1
3520	12:10	PA	ant-14	stamp-VGR1	14	Antenna stowed	VGR1
3521	12:15	PA	ant-14	stamp-VGR1	14	End postcal	VGR1
3522	12:15	PA	ant-14	stamp-VGR1	14	End of activity	VGR1
3523	9:45	PA	ant-24	stamp-MOM	24	Beginning of activity	MOM
3524	9:45	PA	ant-24	stamp-MOM	24	Begin precal	MOM
3525	9:50	DA	ant-24	stamp-MOM	24	Antenna slewing	MOM

RQ6: Making changes

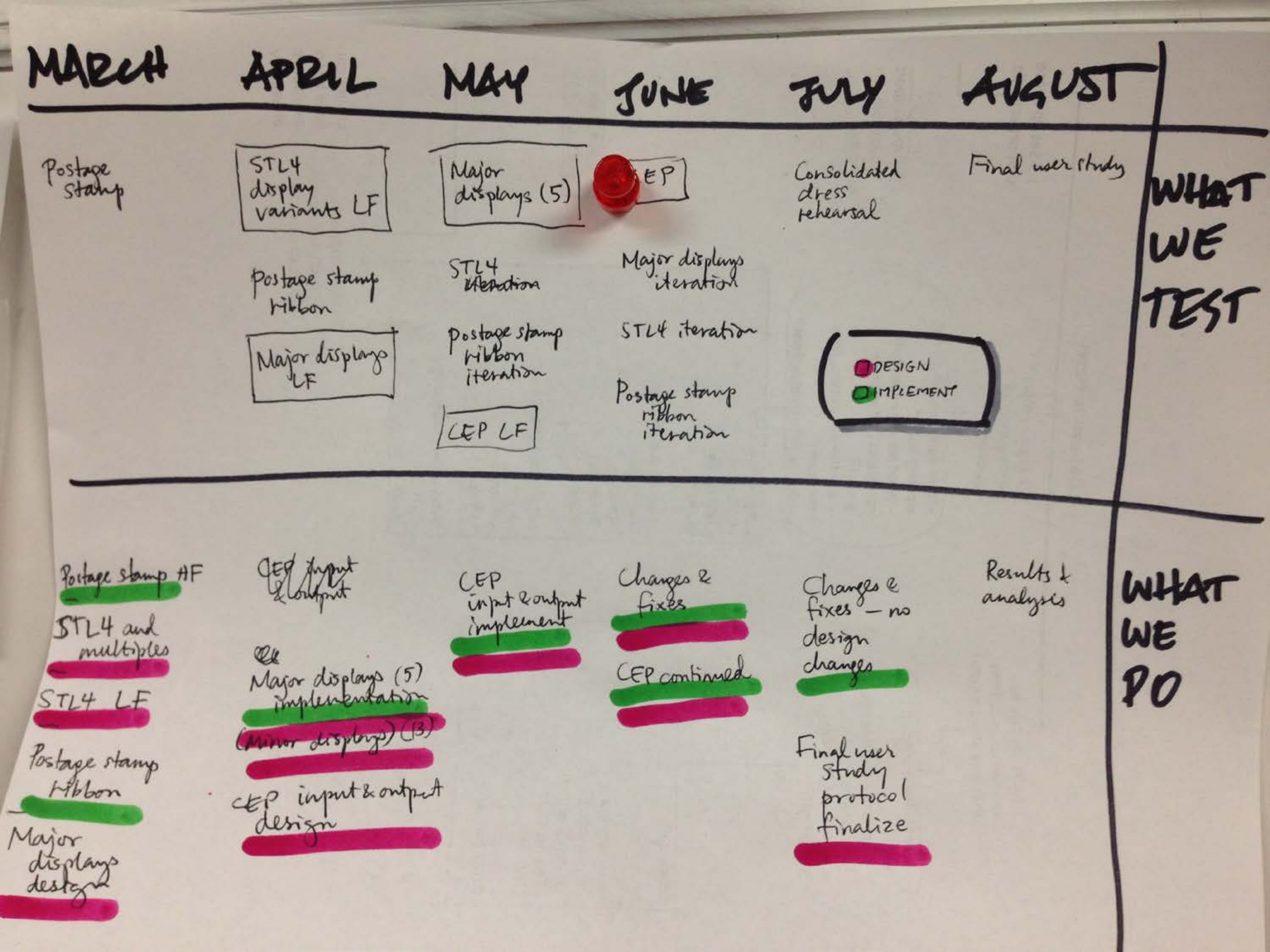
Investigate appropriateness of everything-editable versus modal lock/edit states or special

RQ7: By my own rules

Investigate level-3 (projection) situation awareness with operator control for forming rulesets for realtime data processing

Fin

Development and test plan


MARCH
APRIL
MAY
JUNE
JULY
AUGUST
WHAT WE TEST
Postage stamp
STL4 display variants LF
Postage stamp ribbon
Major displays LF
Major displays (5)
STL4 iteration
Postage stamp ribbon iteration
CEP LF
CEP
Major displays iteration
STL4 iteration
Postage stamp ribbon iteration
Consolidated dress rehearsal
Final user study
DESIGN
IMPLEMENT
WHAT WE DO
Postage stamp HF
STL4 and multiples
STL4 LF
Postage stamp ribbon
Major displays design
CEP input & output
Major displays (5) implementation
(Minor displays) (3)
CEP input & output design
CEP input & output implement
Changes & fixes
CEP continued
Changes & fixes — no design changes
Final user study protocol finalize
Results & analysis