16.422

Human Supervisory Control

Nuclear and Process Control Plants

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Process Control Plants

- Continuous or batch processing
- Examples: Electricity generation (nuclear power plants), refineries, steel production, paper mills, pasteurization of milk
- Characterized by:
  - Large scale, both physically and conceptually
  - Complex
  - High risk
  - High automation
- Remote vs. direct manipulation of plant equipment

Three Mile Island

- March 28th, 1979
- Main feedwater pump failure, caused reactor to shut down
- Relief valve opened to reduce pressure but became stuck in the open position
  - No indication to controllers
  - Valve failure led to a loss of reactant coolant water
- No instrument showed the coolant level in the reactor
- Operators thought relief valve closed & water level too high
  - High stress
  - Overrode emergency relief pump

Three Mile Island

- Automation worked correctly
- Confirmation bias: people seek out information to confirm a prior belief and discount information that does not support this belief
  - At TMI, operators selectively filtered out data from other gauges to support their hypothesis that coolant level was too high

Process Control Human Factors Challenges

- Control room design
- Increasing automation requires cognitive support as opposed to manual control support
- Human-machine interface design
- Team decision making
- Standardized procedures vs. innovation
- Trust & confidence

Supervisory Process Control Tasks

- Monitor process
- Detect disturbances, faults, & abnormalities
- Counter disturbances, faults, & abnormalities
- Operating procedures must be followed
- Communications
  - A log must be kept
  - Other team members (shift changes)
- Emergency procedures
- Training and retraining

Cognitive Demands When Monitoring Process Control Plants

- Vigilance
  - Continuous vs. time share
  - Active vs. passive monitoring
- Memory
- Selective attention
- Visual attention/perception
- System complexity
- System reliability
  - Critical vs. non-critical components

Cognitive Demands, cont.

- Display and control design
  - – Lack of referent values
  - – Lack of emergent features
  - – Lack of integrated information
- Alarm system design
  - – Nuisance alarms
  - – Cycling around limits
    - Desensitization
- Automation design
  - – Lack of appropriate feedback
  - – Direct vs. indirect cues

Coping Strategies

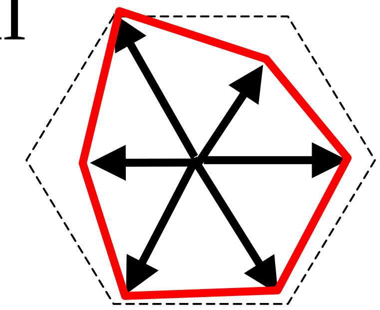
- Increase desired information salience and reduce background noise
  - Clearing and disabling alarms
  - Cross checking with other reactors
- Create new information
  - Operators manipulated set points for earlier alarms
- Offload cognitive processing onto external aids
  - Leaving doors open & sticky notes
- Deviations from “approved” procedures

Advanced Displays in Process Control

- Classical displays (bar graphs, meters, annunciators) are being replaced with computerized displays
  - Keyhole effect
  - Temporal considerations
  - Integration of information
- Flexible & adaptable displays
  - Local vs. global problems
- Configural & Ecological displays

Configural Displays

- Separable vs. integral vs. configural
- Gestalt principles in design
- Emergent features



A Process Control Design Case Study

- Model-Based Predictive Control (MPC) of a refinery plant
- Multi-input & multi-output automatic controllers
  - Optimize the process based on maximizing production and minimizing utility cost.
  - Higher levels of automation – human less in the loop
- Three variable types
  - CVs - Controlled Variables – process variables to be kept at setpoints or within constraints (20-30 variables).
  - MVs - Manipulated Variables – Variables (typically valves) that are adjusted to achieve CVs while optimizing (6-8 variables).
  - DVs - Disturbance Variables - Variables that can measured but not controlled, e.g., ambient air temp. (2-3 variables)
- Humans have difficulty monitoring, diagnosing, controlling these advanced systems

REGEN BED TEMP Detail Display

CV DETAIL

RX / REGEN CTL | ON OFF | WARM | OPTIMIZING

TAG	25ATCV01				
DESC	REGEN BED TEMP				
SOURCE	25ATCV01.PV			LINEAR OBJ COEF	-1.00
				QUAD OBJ COEF	0.00
PV VALUE	579.3	STATUS	GOOD	DESIRED CV VAL	0.00
PRED VAL	579.36			SCALING FACTOR	0.329
FUTURE	579.38	SP.LIM TRACKS PV	YES NO		
SS VALUE	581.36	UPDATE FREQUENCY	= <	CV LO ERROR WEIGHT	1.00
		CRITICAL CV	YES NO	CV HI ERROR WEIGHT	1.00
SETPOINT		CONTROL THIS CV	YES NO		
				PERFORMANCE RATIO	1.00
LO LIMIT	400.00	# OF BAD READS ALLOWED	5	CLS LOOP RESP INT	54.800
ACTIVE	400.00			FF TO FB PERF RATIO	0.50
		LO LIMIT RAMP RATE	10.000		
HI LIMIT	600.00	HI LIMIT RAMP RATE	10.000	SETPOINT GAP	0.00
ACTIVE	600.00	UNBIASED MODEL PV	379.35	NUMBER OF BLOCKS	10.0

APPLCN MENU | PROCESS DISPLY | CV DISPLY | MV DISPLY | DV DISPLY | STATUS MESG | MV TUNING | CV TUNING | GAIN/ DELAY | TREND DISPLY

Gain/Delay Matrix – The Goal State

ONLINE GAIN AND DELAY CHANGE

RX / REGEN CTL | ON OFF | WARM | OPTIMIZING

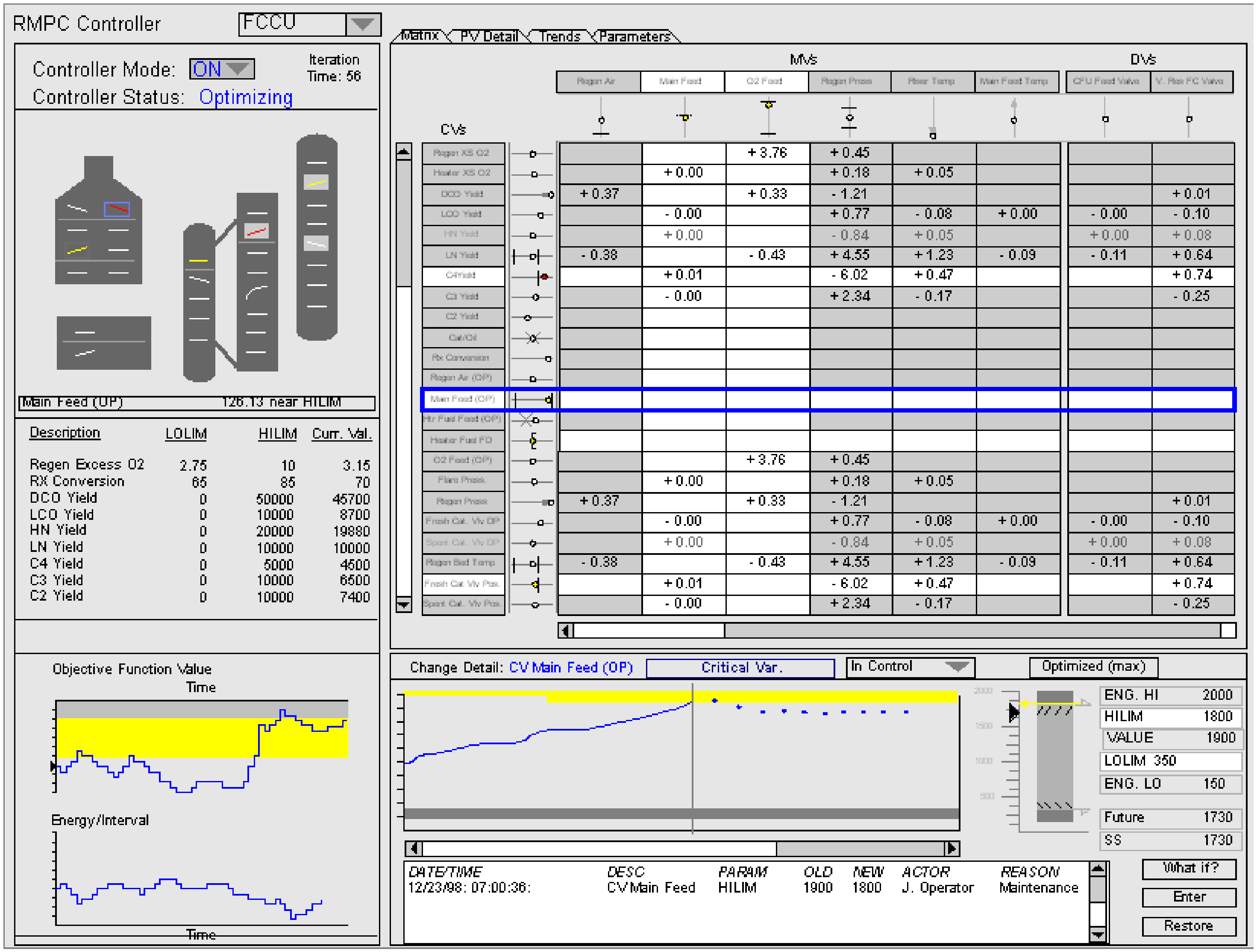
	CV DESCRIPTION	MV01	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV09	MV10	DV01
1	REACTOR BED TEMP	-1.0	2.0	-3.5	4.2		6.1	-0.5	0.25			
2	REGEN BED TEMP	4.0				5.9						
3	REGEN EXCESS O2	0.3		-1.0	2.0	-3.5	4.2		6.1	-0.5	0.25	
4	RX/REGEN DELTA P	.12	-1.0	2.0	-3.5	4.2		6.1	-0.5	0.25		
5	REGEN CAT SLV DP	10.0	-3.0	1.0	-2.5	4.2		6.1	-0.7	0.70		
6	SPENT CAT SLV DP	-0.4		7.2		9.0						
7	STRIPPER LEVEL	12.0					-8.0		-2.0		6.9	
8	BLOWER AMP's	-.60		3.0	5.2	-2.5	9.0			1.5		3.6
9	WET GAS RPM's	1.2						-3.5				
10	FEED HDR-PRESS	3.0			-5.5			.02	6.2		-8.3	2.1
11	FRAC BTMS TEMP	2.2		-7.3			4.5					
12	FRAC DELTA PRESS	.04										
13	BLOWER VLV OP	5.1		4.4		2.6			-9.0		-.06	5.5
14	WET GAS VLV OP	3.2	6.3		4.0			6.2		-.25		
15	RX PRED OCTANE	-0.4					4.3		7.0	-8.2		

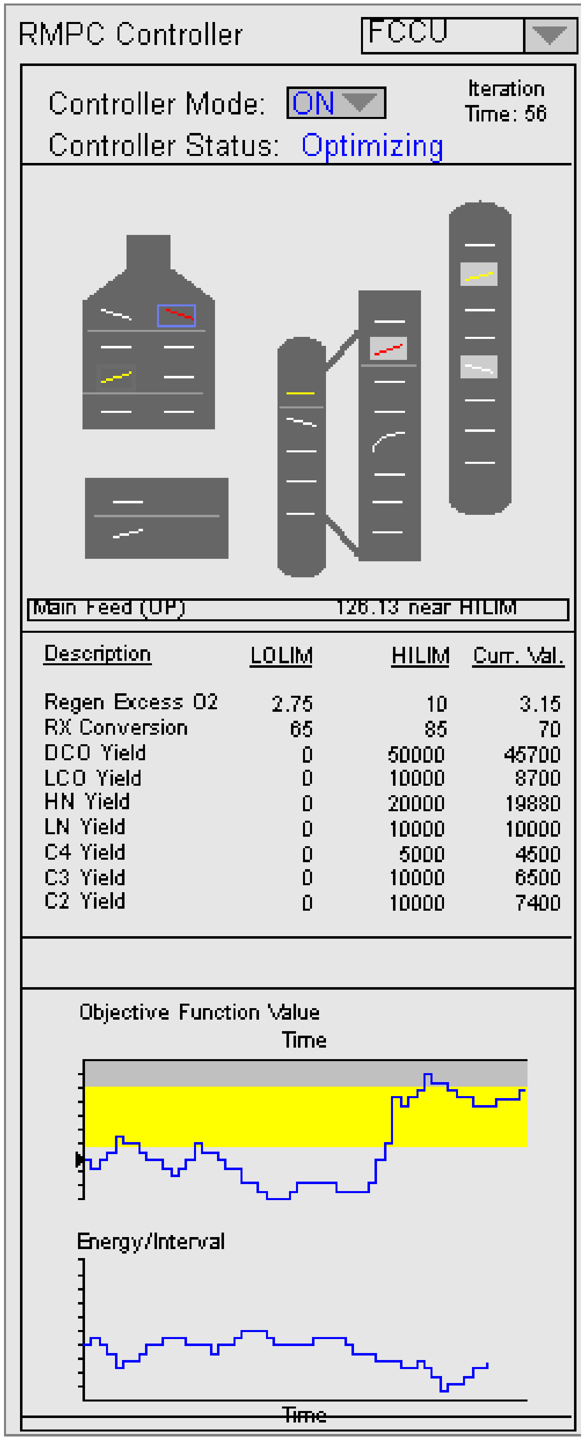
Gain Multiplier 1.000 Deadtime Bias 0.000

Gain 3.750 Deadtime 0.000 Max Deadtime 2.00

APPLCN MENU	PROCESS DISPLY	CV DISPLY	MV DISPLY	DV DISPLY	STATUS MESG	MV TUNING	CV TUNING	GAIN/ DELAY	TREND DISPLY

The Display Redesign

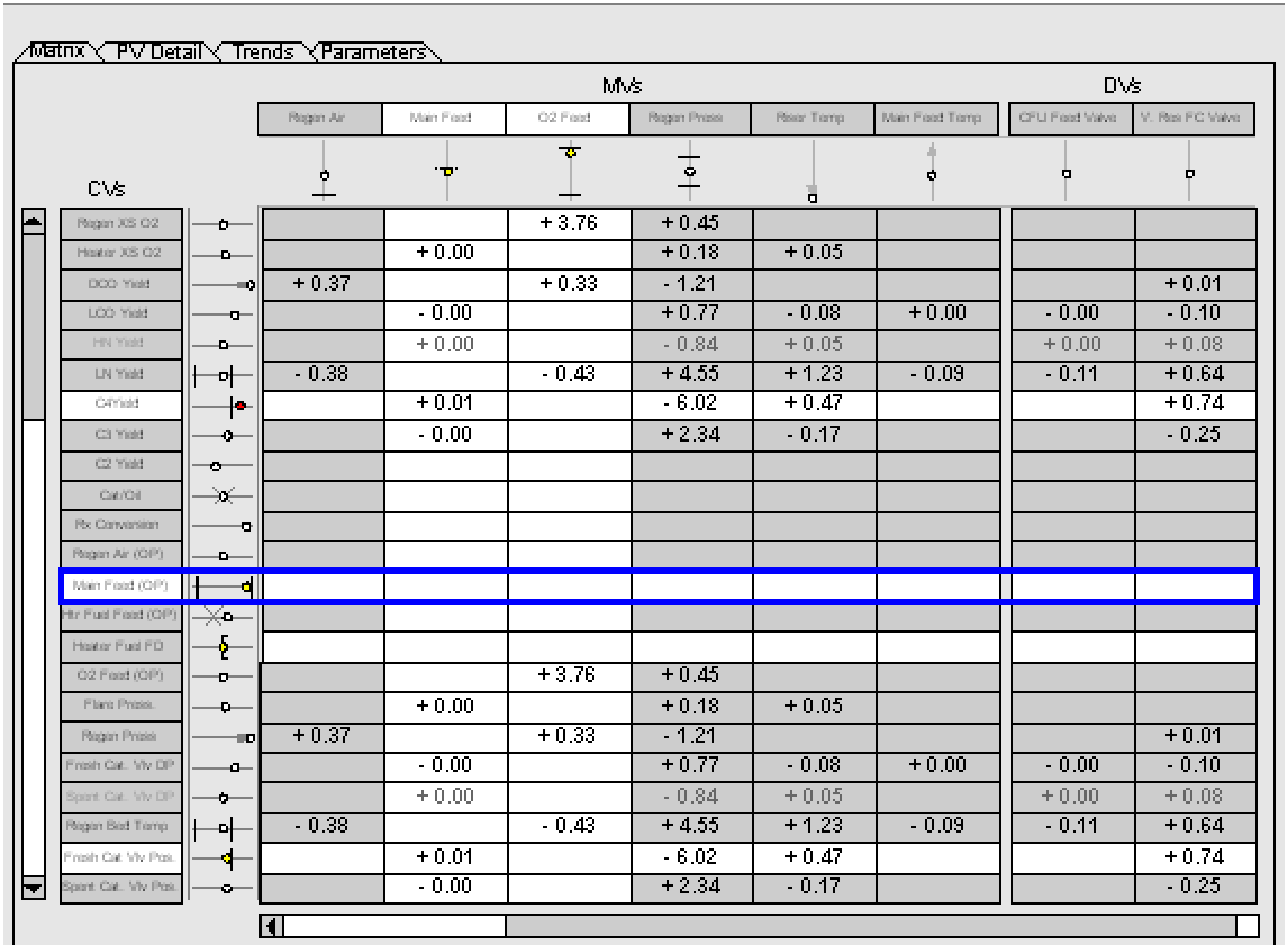




Supporting Monitoring

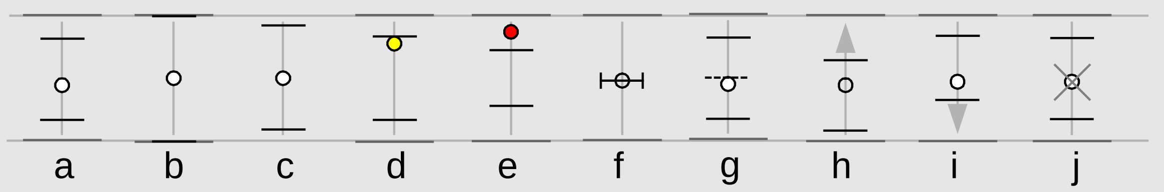
- Overview display
  - Alerts
- Easy recognition of problems
  - Summary
  - Direct manipulation
- Representation Aiding
  - Trend information depicted graphically
    - Variable state as well as optimization history
  - Color important

Supporting Diagnosing



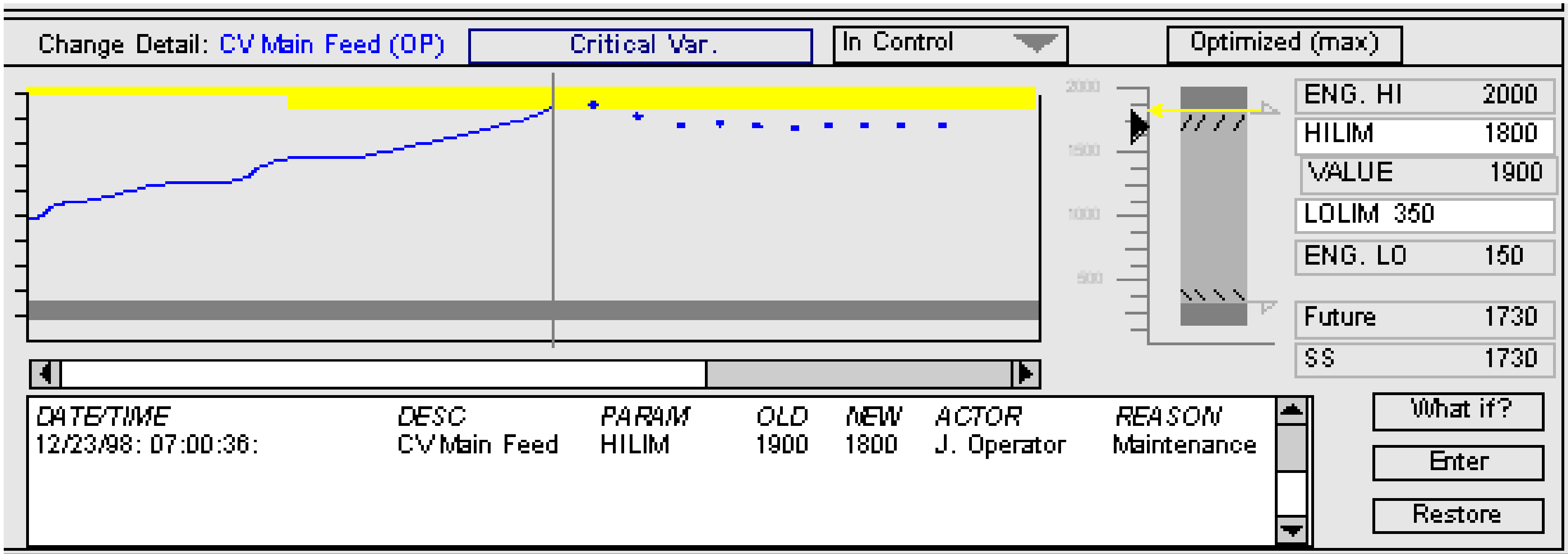
CVs	Regen Air	Main Feed	O2 Feed	Regen Press	Riser Temp	Main Feed Temp	CFU Feed Valve	V. Rec FC Valve
Regen XS O2			+ 3.76	+ 0.45				
Heater XS O2		+ 0.00		+ 0.18	+ 0.05			
DCO Yield	+ 0.37		+ 0.33	- 1.21				+ 0.01
LCO Yield		- 0.00		+ 0.77	- 0.08	+ 0.00	- 0.00	- 0.10
HN Yield		+ 0.00		- 0.84	+ 0.05		+ 0.00	+ 0.08
LN Yield	- 0.38		- 0.43	+ 4.55	+ 1.23	- 0.09	- 0.11	+ 0.64
C4 Yield		+ 0.01		- 6.02	+ 0.47			+ 0.74
C3 Yield		- 0.00		+ 2.34	- 0.17			- 0.25
C2 Yield								
Cat/Oil								
Rx Conversion								
Regen Air (OP)								
Main Feed (OP)								
Htr Fuel Feed (OP)								
Heater Fuel FD								
O2 Feed (OP)			+ 3.76	+ 0.45				
Flare Press.		+ 0.00		+ 0.18	+ 0.05			
Regen Press	+ 0.37		+ 0.33	- 1.21				+ 0.01
Fresh Cat. Vlv OP		- 0.00		+ 0.77	- 0.08	+ 0.00	- 0.00	- 0.10
Spent Cat. Vlv OP		+ 0.00		- 0.84	+ 0.05		+ 0.00	+ 0.08
Regen Bed Temp	- 0.38		- 0.43	+ 4.55	+ 1.23	- 0.09	- 0.11	+ 0.64
Fresh Cat Vlv Pos.		+ 0.01		- 6.02	+ 0.47			+ 0.74
Spent Cat. Vlv Pos.		- 0.00		+ 2.34	- 0.17			- 0.25

Representation Aiding in Diagnosis



a. Normal state, both operator and hard engineering limits shown
b. Normal state, operator limits = engineering limits
c. Normal, no engineering hard limits defined
d. Current state within 1% of operator limits
e. Current state exceeded operator limits
f. Normal state, variable constrained to setpoint.
g. Value “wound-up”, valve fully closed or open
h. Negative linear coefficient (maximize value)
i. Positive linear coefficient (minimize value)
j. Non-zero quadratic coefficient (resting value)

Supporting Interaction



- Performance over time
- Important to provide “logging” ability
- What-if

Decision Aid Design

- An assistant versus a coach
  - What-if's (a form of preview)
  - Narrowing a solution space
  - Recommendations
  - Critiquing
- Problems
  - Clumsy automation?
    - Will they work in all situations?
  - Codifying rules and updating them
    - Plant upgrades & system evolution
    - Especially tricky in intentional domains
  - Automation bias
- Interactivity in decision support

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